Race to the top: Does competition in the DSL market matter for fibre penetration?

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JEL: L96 (telecommunications), O33 (technological change), L5 (regulation and industrial policy)

Abstract

High speed broadband creates potential productivity gains and has a positive impact on economic growth. Achieving Europe's broadband access objectives will require large scale investment in next generation broadband networks, and it is imperative that an appropriate investment climate is created to encourage fibre network rollout. This study considers whether and how competition in the DSL market affects the incentives of operators to invest in the deployment of high-end fibre optic networks. Most earlier research on the drivers of investment in broadband technology has focused on the effect of mandatory access policies, such as local loop unbundling, or competing infrastructures. We posit that competition in the DSL sector may also influence fibre penetration, possibly to a considerable extent. We find that the relationship between service-based competition and fibre penetration is non-linear: a lack of or severe DSL competition is correlated with a negative effect on fibre penetration, but if a moderate degree of competition is already present in the market, more service-based competition may positively influence fibre penetration. The scale of these effects however varies with the openness of the DSL market: operators' incentives to invest in fibre appear to be more sensitive to changes in DSL competition if there is extensive local loop unbundling.

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1. Introduction

The Digital Agenda for Europe has as one of its objectives to "ensure that by 2020, (i) all Europeans have access to much higher internet speeds of above 30Mbps and (ii) 50 percent or more of European households subscribe to internet connections above 100Mbps" (European Commission, 2010). Creating the right investment environment and conditions for penetration of high-end networks to meet these goals is a matter of debate, and so far, empirical evidence suggests that existing market conditions have been insufficient to ensure the desired outcomes (Briglauer, 2015; Briglauer, Cambini and Grajek, 2015).

The broadband investment environment and the level of penetration are, inter alia, a function of competition in the telecommunications market and the regulatory policies that are in place. While the effect of regulation on investment in broadband has been the focus of much research (see for example Bauer, 2010; Boukaert, van Dijk and Verboven, 2010; Kongaut and Bohlin, 2014; Briglauer, 2015; Briglauer, Ecker and Gugler, 2013), the relationship between market concentration and investment is not equally well understood. Existing empirical research (discussed more elaborately in a later section of this paper) reveals that the relationship between competition and investment has many facets and that assessing the impact of competition poses many challenges. Our paper aims at contributing to the understanding of this impact.

A better understanding of the competitive characteristics that determine network operators' incentives to invest, which in turn provide preconditions for fibre penetration, should inform competition authorities' merger evaluations and help regulatory authorities design effective policies. From this perspective, we examine the relationship between market concentration in the Digital Subscriber Lines (DSL) market and fibre penetration. To the extent that penetration may serve as a proxy for investment in high speed, next generation networks (NGNs), such an analysis also sheds light on the relationship between concentration and investments. Bouckaert et al. (2009) also consider penetration, and motivate their paper in terms of the relationship between regulation and investment (specifically, investment incentives and the ladder of investment hypothesis). Similar for Kongaut and Bohlin (2014), who discuss their findings based on penetration data in relation to investment in infrastructure and investment incentives. Penetration has the advantage of being an output-related variable and therefore more closely related to consumer welfare (Briglauer et al., 2016). For fiber rollout, in particular, one may expect that there is a relationship between penetration and rollout. The reason is that fiber projects often get initiated after having the commitment to subscribe from a significant fraction of households in the investment area (for FTTH), or on actual contracts with corporate customers (for FTTO). It should be noted though that penetration may depend on country-specific variables, such as population density and income distribution (see Bouckaert et al., 2009). In our empirical specification, we address this problem by controlling for urban population density, which presumably affects network coverage.

The aim of this paper is to address the question of whether and how competition in the DSL market affects penetration of high-end fibre optic networks[1], i.e. fibre-to-the-home/ business (FTTH/B), which (indirectly) reflects the incentives of operators to invest in the deployment of such fibre networks. Most earlier research on the drivers of investment in broadband technology has focused on the effect of mandatory access policies or competing infrastructures. We posit that competition in the DSL sector may also influence fibre penetration, possibly to a considerable extent. We illustrate that it is not sufficient to evaluate the effect of service-based competition by solely looking at the take-up of LLU. Instead, it is necessary to look more directly at competition between operators, to understand their incentives to escape competition by investing in the fibre network.

We draw from a sample of 27 European countries from 2004 to 2015, to illustrate this relationship. We posit that the relationship follows an inverted U-curve, where countries with a moderate degree of competition in their DSL markets have higher fibre penetration than countries where DSL competition is absent, or fierce. A correct understanding of the impact that competition in the DSL market has on investment in fibre deployment and on fibre penetration is pivotal to formulating the appropriate regulatory or competition policy response to achieve the objectives set out in the Commission's Digital Agenda for Europe.

The next section considers the relationship between the intensity of competition and the incentive to invest from a theoretical perspective, and Section 3 provides background on the nature of competition in telecommunications markets. Section 4 relates our research hypothesis to the relevant literature. Section 5 presents the results of the empirical analysis, which are summarized in the conclusion in section 6.

2. The theoretical relationship between competition and investment

Investment in fibre can be seen as a form of innovation, whereby operators improve their product offerings. For the purpose of this paper, we use the terms 'innovation' and 'investment'

[1] FTTH/B includes fibre-to-the-home and fibre-to-the-apartment (with LAN distribution), but excludes FTTB/VDSL, which is classified as DSL. It also includes FFLAN (fibre-fed LAN), FTTH-POP and FTTH-PTP (Analysys Mason, 2016).

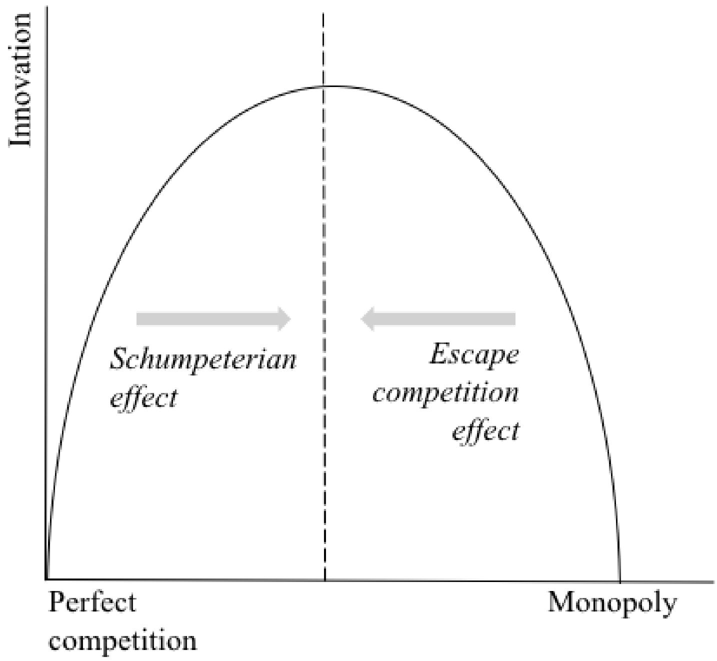
interchangeably to refer to the process whereby more fibre is added to the broadband network of a country. Economic theory suggests that the relationship between competition and innovation is typically not linear or uniform. Innovation can be influenced by two opposing forces: an 'escape competition' effect and a 'Schumpeterian' effect (Aghion et al., 2005).

In markets where competition increases, firms may have an incentive to innovate to 'escape competition' by outcompeting their rivals. This supports the claim that strong product market competition can promote innovation (Tang, 2006). EU Commissioner Margrethe Vestager affirmed this by saying that "in business, innovation is the answer to the need to compete. You innovate because if you don't, your rival certainly will. And then no one would want your tired old products anymore" (Vestager, 2016).

In contrast, innovation may also increase if competition decreases, as monopolists are faced with less market uncertainty and are better able to appropriate monopoly rents from investment in innovation. The 'Schumpeterian' effect – due to Joseph Schumpeter (1942) – creates an incentive for monopolists to innovate by using profit-maximising opportunities resulting from their market power (Romer, 1990). Firms that have "deep pockets" as a result of monopoly rents may have better access to finance than firms in more competitive environments where margins are small (Tang, 2006). The incentive to innovate may also be encouraged by the desire to maintain market power: Schumpeter (1942, p. 102) aptly states that "a monopoly position is in general no cushion to sleep on. As it can be gained, so it can be retained only by alertness and energy".

The 'Schumpeterian effect' can be consolidated with the 'escape competition effect' into a non-linear, inverted U-shaped relationship between product market competition and innovation. Aghion et al. (2005) provide theoretical and empirical evidence in support of this relationship. The authors conclude that competition may increase the additional profit from innovating (the "escape-competition effect"), but when competition becomes sufficiently intense it may also reduce the innovation incentives of laggards (the "Schumpeterian effect").

Figure 1: The inverted U-curve relationship between competition and innovation



Caution should however be taken when drawing conclusions about the *causal* relationship between market structure and innovation. While the theories presented above suggest that market concentration affects innovation, the causal relationship may also run in the opposite direction: opportunities for innovation in a given market may affect the market structure, which then becomes the result of rather than the trigger for innovation (Katz and Shelanski, 2007). The relationship between competition and investment is therefore not isolated from other market dynamics, and may be affected by factors that determine the associated payoffs, such as technological progress or the regulatory environment. This is especially important in the DSL market, where mandatory access regulations have been put in place to increase competition, but where these policies may have come at the cost of reduced incentives to invest (Boukaert et al., 2010). Consequently, they may have an impact on the transition from service-based competition to facility-based competition (discussed in section 3, and in the literature review in section 4).

It should be noted that the economic literature also reports findings that do not confirm the shape of an inverted U-curve. Sacco and Schmutzler (2011) derive, in a natural set-up, a non-inverted U-relationship between competition and investment, which are confirmed in laboratory experiments that they carried out. Their set-up features a stage in which firms invest in cost reductions, followed by a stage of differentiated Cournot competition. While it is beyond the scope of this paper to discuss this strand of the literature in more detail, we do note that one cannot assume that a market will always exhibit an inverted U. Our purpose is to explore this issue further in a specific market situation, that is, in the broadband telecommunications market.

The ambiguous relationship between market structure and innovation creates potential difficulties for policy makers in assessing the impact of mergers on consumer welfare. Merger control traditionally focusses on maximising consumer welfare under the presumption that competitive market structures improve allocative efficiency. However, as a central tenet of economic growth, innovation forms an important component of consumer welfare and in the long run could arguably affect consumer welfare even more than variations in price (Audretsch et al., 2001). European merger control prioritises the protection of competition, but leaves room for the impact of productive efficiency and dynamic efficiency enhancements to be considered. With specific relevance to dynamic efficiency, Article 2(1) of the European Merger Regulation prescribes that, in appraising a concentration, the Commission shall, inter alia, “take the development of technical and economic progress [into account], provided that it is to consumers’ advantage and does not form an obstacle to competition”.

Innovation through the rollout of fibre networks can be classified as a form of dynamic efficiency enhancement. If the inverted U-curve holds for the relationship between market concentration in the DSL sector (a measure of competition) and investment in fibre deployment, too much or too little competition may inhibit the Commission from achieving its NGN broadband access objectives, and should be considered in their assessment of horizontal mergers in the DSL sector.

3. Competition in broadband

To understand the nature of competition within the broadband market, a distinction can be made between competition at the connectivity layer of the market, and competition at the level of service providers (Peitz and Valletti, 2015). The former is known as facility-based competition (also infrastructure-based or inter-platform competition), and the latter as service-based (or intra-platform) competition. Facility-based competition refers to competition between networks, e.g. between network operators of fibre, cable and DSL broadband. In contrast, service-based competition reflects competition between operators who share a specific broadband infrastructure (e.g. DSL). In the EU, mandatory access policies have been put in place in the DSL market to increase competition at the service level by encouraging entry at this level of the broadband market.

Facility-based competition is determined by the physical location of access networks and the technological alternatives that are available. An important characteristic of the broadband market is that consumers select broadband connections based on the nature and quality of service (e.g. bandwidth, telecommunications services, media content) rather than the underlying infrastructure. This creates a degree of demand substitutability between different types of current network infrastructure, with fibre allowing for a substantial jump in speed.

Depending on historical aspects in specific countries, broadband services have traditionally been provided over DSL or cable modem networks. These “legacy” broadband networks are still the most prevalent broadband infrastructure. Figure 2 plots the total number of broadband connections across a selection of European countries[2] (see section 5 for a description of the data set), and shows that while DSL connections remain by far the most common, its growth has started to flatten.

[2] The countries included in this study are Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the UK.

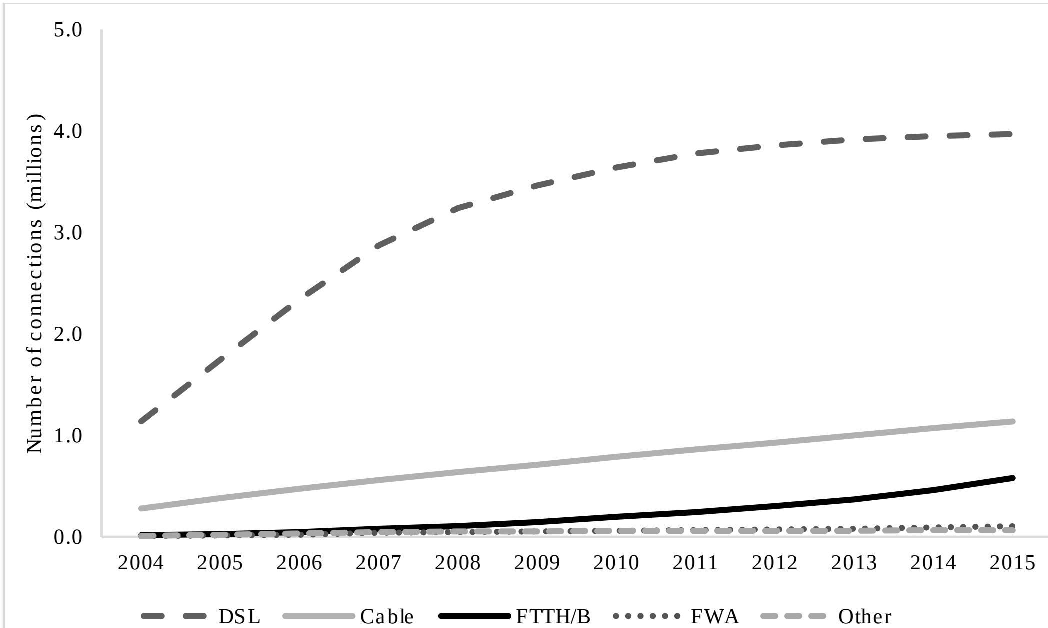


Figure 2: Number of broadband connections per type of technology[3]

Fibre optic broadband networks have more recently entered the market, offering higher transmission speeds than legacy DSL and cable networks. Fibre broadband can be used for the transmission of video, data, voice and interactive video-telephone services and can reach download and upload speeds of up to 1 Gbps (FTTH Council, 2016), making it preferable to any other form of broadband technology. FWA broadband makes use of radio links between base stations that form part of the mobile telecommunications network, and is especially useful in rural areas where fixed line infrastructure is not yet available or too costly to exploit.

Figure 3 shows fibre penetration for a selection of European countries and shows the divergent trends in fibre penetration between countries.

[3] DSL includes all the family of DSL technologies, including ADSL and its variants, SDSL and its variants and VDSL, irrespective of downstream speed, fibre to the cabinet (FTTC) with VDSL tails and FTTB-VDSL. Cable includes total cable modem connections, irrespective of downstream speed. FWA (Broadband fixed wireless access) includes any wireless transmission technology that delivers from a fixed hub to distributed fixed points where limited in-cell mobility is possible, but not seamless cell handover. Excludes broadband mobile technologies and 'last-inch' technologies such as Wi-Fi or WLAN, but includes mobile WIMAX protocols. 'Other' includes all other 'fixed' type broadband connections, including non-FTTB LANs, powerline technologies and WLAN connections, but does not include leased lines (based on information pertaining to the data set provided by Analysys Mason; see section 5).

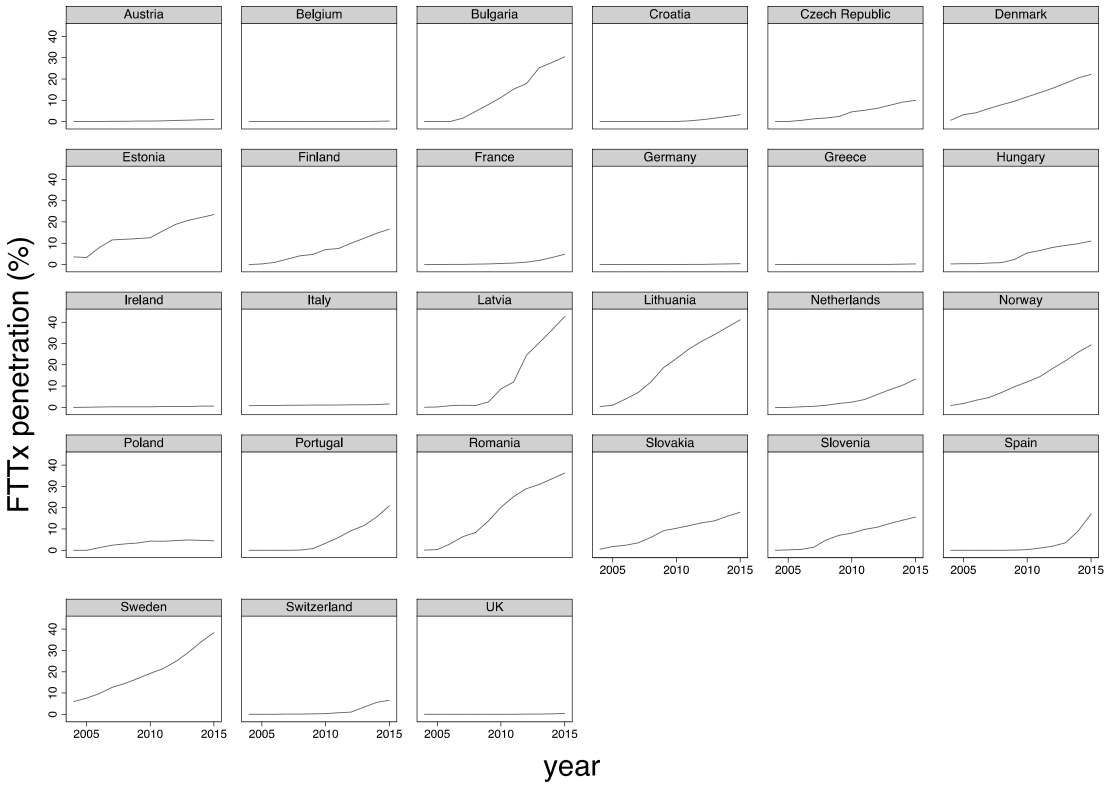


Figure 3: FTTH/B penetration by country, 2004-2015

We posit that the fast growth in fibre penetration that some countries have experienced, may bear a relation to competition in their DSL sectors. Soon after liberalization of the European telecommunications sector in the early 1990s, mandatory access became an important policy tool to encourage competition in the provision DSL broadband (de Bijl and Peitz, 2005). Local loop unbundling (LLU) was legislated by the European Parliament and Council in 2000[4] to address the absence of competition in the local loop, requiring "incumbents to offer access to their competitors on the last segment of telephone wire [i.e. the local loop] linking the network with the subscriber" (Buigues, 2001). Different forms of unbundling were implemented, and a high-level distinction can be made between full unbundling and line sharing (shared / bitstream access), offering entrants varying degrees of technological differentiation.[5]

The rationale behind LLU is that by allowing third parties to gain access to a competitor's infrastructure on wholesale terms, these entrants will invest in their own infrastructure once they have established a customer base. This has become known as the "Ladder of Investment" (LoI) hypothesis, but has been proven to only hold for lower rungs of the investment ladder (Briglauer

[4] Regulation (EC) No 2887/2000

[5] Full unbundling allows entrants sufficient control over the copper wire to allow them to offer voice telephone as well as broadband services to their customers. Alternatively, line sharing allows incumbents to retain control over the copper network while entrants lease the high-speed, non-voice portion of the copper spectrum. Through bitstream access, incumbents can give entrants access to their networks by offering DSL products configured by the incumbent with limited scope for technological differentiation.

et al., 2015). The cost of obtaining wholesale access to an incumbent's DSL network is often lower than the investment costs and risks of deploying a new network, limiting entrants' incentives to invest in new network infrastructure at 'higher rungs' of the investment ladder. Incumbents further have little incentive to invest in their DSL network if LLU allows competing operators to derive the benefit thereof (these arguments draw from studies discussed in Section 4). LLU might therefore effectively stimulate service-based competition to increase DSL access, but does not necessarily lead to further investment in DSL broadband networks.

While LLU might not create explicit incentives for investment in DSL broadband, the service-based competition which it encourages may nevertheless create incentives for investment in fibre, as operators look for a way to escape this competition. Cave (2006, p. 224) expects LLU to have a positive impact on NGN rollout and argues that "achieving extensive competition of this kind has the inestimable advantage of making the next generation of technology contestable—in effect creating a race among the competitors to implement it." In what follows we consider other studies that have analysed the relationship between competition and investment in the broadband market.

4. Research hypothesis and related literature

This section provides a review of recent, mainly empirical, literature to contextualise our research hypothesis. The impact of service-based and facility-based competition on investment and/or broadband penetration has been the subject of much research. Cambini and Jiang (2009) contain a survey of earlier literature on the relationship between access regulation and investment. The inconclusive nature of the findings that they discuss suggest that at the time of their study, insufficient time had passed to understand the dynamic process of new technology diffusion.

Garrone and Zaccagnino (2015) use data on incumbent operators in 27 OECD countries from 1993-2008, to understand whether pro-entry regulations (in the form of having mandatory unbundling or sharing of access networks) and competition in the fixed line communications market are correlated with incumbents' overall investment. Competition is represented by the market share of entrants. The authors, incorporating interactions between competition and the unbundling regime, find that if the unbundling regime fosters competition, "the incumbent's incentives to invest are revitalized" as a means of retaining market power (Garrone and Zaccagnino, 2015, p. 399).

In another firm-level study, Briglauer et al. (2016) look at a panel of incumbent and entrant operators in 23 European countries from 2003 to 2012, to analyse the effects of service-based and facility-based competition on capital expenditure (i.e. investments in property, plants and equipment for backbones and access networks). For incumbents, these investments may pertain to fixed and mobile telecoms, while the entrants in the data set are mainly active in fixed broadband services. Service-based competition is represented by the fraction of the number of regulated retail connections available in the wholesale market and the total number of retail lines. Facilities-based competition is represented by the number of entrants' own lines divided by the total number of retail lines. The authors find that facility-based competition has a positive and significant impact on the incentives of operators to invest, and that service-based competition has no significant average effect on investments but that it may have a negative impact on entrants' investment activities during the late phase of market liberalisation.

A distinction can be drawn between studies that evaluate investment incentives in general (which includes investment in broadband infrastructure), or those that focus on broadband penetration or the rollout of NGNs. Boukaert et al. (2010) examine how different forms of regulated competition (driven by different unbundling regimes) affect general broadband penetration in a sample of 20 OECD countries, using data from 2003 to 2008. To measure competition, the authors consider three types of concentration indices, namely for inter-platform competition (between DSL and non-DSL technologies), facilities-based intra-platform competition (between *wholesale* DSL offered by the incumbent and alternative DSL providers using LLU and bitstream access), and service-based intra-platform competition (between *retail* DSL offered by the incumbent and alternative DSL providers using resale and bitstream access). The access types that correspond to these types of competition involve different levels of investment required by entrants, and provide different incentives to invest in their own infrastructure. It relates to entrants' make-or-buy decisions. The unbundling regimes are therefore implicitly incorporated in the analysis by distinguishing between different competition modes. The study finds that access regulations that promote service-based competition bear a negative relationship with broadband penetration, while broadband penetration is encouraged by facility-based competition.

Kongaut and Bohlin (2014) also consider the impact of unbundling policy and infrastructure competition on broadband penetration, using data from 2002 to 2008 in 30 OECD countries. More precisely, they assess the impact of infrastructure competition on broadband penetration, while taking unbundling into account through a dummy variable. Infrastructure competition is represented by a concentration index that captures broadband provided by different technologies (infrastructures); it is defined as the fraction of the sum of squared values of broadband subscriptions for different technologies and the square of the total number of broadband subscriptions. The authors find that, in general, LLU regulation went together with higher broadband penetration (especially if there are few infrastructure options available), and that more competition between infrastructures increased penetration. They interpret their results by suggesting that, initially, unbundling policy has a larger impact than infrastructure competition, or that DSL is a dominant technology in certain countries. At a later stage, infrastructure competition becomes more important as a driver of penetration.

While these studies have looked at the effects of service and facility-based competition on legacy (or replacement) DSL and cable networks, the dynamics may differ for investment in (new) NGNs due to the differentiated broadband service being provided. Briglauer et al. (2013) evaluate the determinants of investment in NGNs based on FTTx technologies using a panel of 27 EU member states for 2005 to 2011, to establish whether an inverted U-shaped relationship holds for NGN deployment. The dependent variable, a penetration index, is the fraction of connections deployed ("homes passed" instead of connected) in per capita terms. The explanatory variables include service-based competition (measured by the percentage of all wholesale broadband lines relative to the number of retail lines) and facilities-based competition (measuring, also by looking at the number of connections, the competitive pressure from cable as well as mobile). The authors specifically consider the impact of a "previous" access regime (applied to incumbents' current networks) on the emergence new infrastructure (fibre), and there is thus no problem of reverse causality. The authors expect that an upgrade to a NGN helps traditional fixed operators to escape broadband competition from cable and mobile networks, while intense infrastructure competition makes NGN investments riskier (p. 145-146). Facility-based competition may therefore encourage investment up to a certain point of competition, after which investment declines. This may be due to a replacement effect whereby, at low levels of competition, fibre networks “cannibalise” rents from legacy broadband. When competition increases, the pay-off from escaping competition by investing in NGNs becomes larger. At some point, though, operators are not able to generate the necessary profits for investments, leading to lower fibre deployment. The data confirms the presence of such an inverted U-shaped relationship for infrastructure competition. This is different for service-based competition: here, more competition simply reduces investments in NGNs by incumbents and entrants.[6]

Whereas the previous paper aimed at identifying he determinants of NGA deployment and penetration, Briglauer and Gugler (2013) examine the impact of alternative NGA policies. They explore the relationship between patterns in NGA deployment and penetration and national sector-specific and governmental policies in the EU. To do so, they compare EU27 member states with the US and other non-EU27 countries. Furthermore, the authors identify European and non-European clusters of countries with different competitive conditions, regulatory policies and state aid rules (thus the paper follows a distinct econometric approach, consisting of a cross-sectional comparison to identify country clusters, followed by regressions to analyze diffusion processes within countries and clusters). They find that the European regulatory framework of cost-based access pricing is likely to reduce NGA infrastructure investment in terms of coverage and penetration. Also, competition alone may not be sufficient to induce NGA rollout, due to the high investment levels that are needed. In such cases, public subsidies are typically required. Their international cross-sectional comparison indicates that European incumbent operators are reluctant to invest in fibre networks. Depending on country characteristics, besides state aid a solution may lie in infrastructure competition.

The majority of studies conclude that while facility-based competition encourages broadband penetration, service-based competition as approximated by mandatory access regulations discourages overall investment in broadband networks (Boukaert et al., 2010; Brieglauer et al., 2015; Kongaut and Bohlin, 2014), as well as specifically in NGNs (Briglauer, 2015; Briglauer et al., 2013). However, these studies measure service-based competition in terms of broadband access regulations, the share of unbundled local loops, or the share of DSL services provided by entrants. They do not consider the concentration of operators in the DSL sector per se.[7] We argue that additional insights may be obtained from taking market concentration in the DSL sector into account, to evaluate the impact of service-based competition on fibre penetration.

To conclude this survey, we briefly discuss a theoretical paper, namely Bourreau et al. (2012), who analyze the incentives of an incumbent and an entrant to migrate to a “new” technology, as a function of access regulation. They find that the switch to a new technology depends non-monotonically on the current technology’s access price. A high access price for the legacy network incites the entrant firm to invest, while the incumbent’s response to a high access price depend on the relative size of the effect on wholesale revenues versus retail-level migration. This type of result relates to our paper because the access price determines the intensity of competition in the retail market. In what follows, we look directly at the impact of competition on fibre penetration.

[6] In a more recent study, based on a wider time range for the data set (containing earlier as well as more recent data, also for EU27 countries), Briglauer (2015, p. 212) comes to a similar conclusion, based on evidence that "previous" access regulation reduces aggregate NGN investments.

[7] The firm-level study by Garrone and Zaccagnino (2015), discussed earlier, is the only study found to take the role of market concentration in service-based competition into account.

Country differences in the independent variable of competition may lie in the national details of access regulation.

5. Empirical implementation

Competition in the DSL sector, encouraged through mandatory access policies, may create different incentives for investment in NGNs[8], in addition to what is explored in the literature. Fibre penetration in most countries is still limited, causing the competitive advantage that can be gained by investing in a fibre network to be potentially large. In addition, access regulations of NGNs vary widely between countries (Briglauer et al., 2015) and, where still limited, may increase the relative payoffs of investing in fibre as opposed to investing in DSL. In assessing fibre penetration (and indirectly, investment incentives for fibre), it is therefore useful to look beyond DSL access regulations, to also consider the effect of competition in the DSL market.

Accordingly, this paper considers the impact of unbundling as well as competition in the DSL market on fibre penetration. DSL competition is captured by the common Herfindahl Hirschman Index. Unbundling is represented by its impact or effectiveness, that is, by the number of unbundled connections as a fraction of all copper loops. In this manner, we hope to shed light on the incentives to escape competition based on legacy networks by investing in fibre infrastructure. This set-up, while adopting elements from the papers discussed above that consider investment in "current/ legacy" technology networks, addresses a similar question as Briglauer et al. (2013), namely the effect on new generation technology. An important difference is that, whereas Briglauer et al. (2013) measures service-based competition by considering ratios reflecting different types of connections (see above), we use a concentration index based on DSL market shares. This variable may contain different information about the intensity of competition, as it directly reflects the level of market concentration.[9] Like Briglauer et al. (2013) we also look at the effect of facility-based competition, but adopt a different proxy for this, as explained below. Note also that Briglauer et al. (2013) consider actual investments (corresponding to "homes or offices passed"), whereas we will use penetration data (corresponding to "homes or offices connected").

We posit that the relationship between market concentration in the DSL sector and fibre penetration follows an inverted U-curve. The rationale is that too little competition causes DSL providers to become comfortable in earning monopoly profits, whereas severe competition puts too much pressure on margins to allow operators room to invest. An inverted U-curve relationship has been established for the effect of *facility-based* competition on NGN broadband investment (Briglauer et al., 2013; Briglauer, 2015), but not for *service-based* competition such as DSL competition.

[8] For example, service-based competition may allow an entrant to progressively acquire experience (Bourreau and Drouard, 2014). Possible illustrations of this type of entry, based on a development from using unbundled access towards an independent position in FttH, are Iliad in France and Optimus/Sonaecom in Portugal (WIK-Consult, 2015).
[9] The number of firms does not always provide a good indication of market power (Bishop and Walker, 2010). Price competition between only two firms can be vigorous (e.g. in a Bertrand oligopoly), and in a contestable market with low barriers to entry even a monopolist can have little market power. While mandatory access policies lower barriers to entry in the DSL market – especially so for bitstream or resale access, which requires minimal infrastructure investment on the part of entrants – one may assume that in most telecommunications markets some costs are sunk (Cave, 2006, p. 226). We therefore use market concentration as an indicator of competition.

5.1.Data and variables

Data from the Analysys Mason Telecommunications Matrix (AMTM) are recorded for 27 European countries, on an annual basis from 2004 to 2015. The AMTM provides a large selection of telecommunications metrics for fixed and mobile networks and, in many instances, presents data at the operator level.

We argue that fibre penetration, indicated by the number of connections as a percentage of the total population is influenced by various demand and supply side factors. In reduced aggregate form, the relationship can be expressed as in equation 1 (the model specification is shown below in equation 3):

Q=f(DSL HHI, LLU, ICI, alternative broadband infrastructure, socio-economic indicators) (1)

In this equation, we estimate a Herfindahl Hirschman Index (HHI), defined as the sum of squared market shares of all firms in a national market, to examine DSL market concentration in different countries over time. The underlying market shares are estimated based on the retail revenues of operators.

The second explanatory variable – openness of access through unbundling of local access networks (LLU) – is approximated by calculating the total number of unbundled local loops (for DSL or PSTN/ISDN) as a share of total copper loops. LLU provides a measure of the potential for competition to take place through opening the market for fixed line telecommunications (de Bijl and Peitz, 2005). Countries with a higher proportion of unbundled local loops can be expected to have more competition within the DSL sector: mandatory access policies typically make it easier for new operators to enter the market as they do not need to make huge investments in new network infrastructure.

LLU take-up can be influenced by factors such as the availability of alternative sources of network infrastructure (e.g. cable modem, which is typically unregulated regarding access), differences in the availability of wholesale supply (e.g. wholesale line rental or bitstream access) (de Bijl and Peitz, 2005), or differences in the price at which wholesale access is offered. We do not include these factors as explanatory variables, as they are implicitly captured in the number/take-up of unbundled local loops within a country.

The availability of alternative broadband networks is captured by including DSL penetration and cable penetration in the analyses, as well as an infrastructure competition index (ICI) to control for broadband facility-based competition. The availability of and competition between alternative broadband networks may affect operators' incentives to invest in fibre. Studies that have analysed the impact of facility-based competition on fibre penetration have used different metrics to quantify this effect. Following Kongaut and Bohlin (2014), we develop an ICI – as shown in (2) – to approximate facility-based competition between DSL, cable, FWA and other fixed broadband infrastructure, excluding fibre. An ICI index value of 1 indicates that only a single type of broadband infrastructure is present in the market.

$$ICI = \sum_{k=1}^{n} {(Connectionspertechnology_k)^2}/{Totalbroadbandconnections^2} \qquad (2)$$

Briglauer and Gugler (2013) suggest that European countries can be classified into three groupings according to their broadband strategies: In cluster 1 (‘European forerunners’) broadband state aid and financing of fibre networks by public utilities and municipalities have been an important driver of fibre penetration, as has been seen in many Nordic countries. Countries in cluster 2 (identified as ‘Laggards’) have experienced some success in deepening fibre penetration, possibly in part due to a degree of facility-based competition (e.g. the Netherlands, where DSL and cable networks compete). Countries in cluster 3 (‘European Starters’), typically have well-established DSL legacy networks, leading to a high replacement effect and hence low fibre subscription rates. This suggests that the relationship between facility-based competition and fibre penetration is likely to be non-linear: countries with low facility-based competition may either have *high* fibre penetration due to government support, or *low* fibre penetration due to a strong replacement effect. We come back to this hypothesis in the empirical analysis.

High-speed mobile network (4G/LTE) penetration is also included, as mobile data transmission may form a substitute for fixed broadband services. Fixed-mobile substitution (FMS) may especially be likely for high-speed mobile access through 4G/LTE networks and may affect the rate at which consumers adopt fixed line broadband services.

The rate at which fibre networks are deployed may also be influenced by a variety of socio-economic factors, beyond service-based and facility-based competition. Demographic variables[10] such as GDP per capita or the proportion of the population living in urban areas may play a role: GDP per capita is indicative of the purchasing power of consumers, while the density of a country’s urban population may also influence fibre investment by improving the business case through economies of scale. These country-specific characteristics are controlled for in the empirical analysis.

Table 1 provides detailed descriptive statistics of the variables included in the dataset, highlighting the between and within variation of the panel. The ‘fibre’ variable exhibits large variation between and within countries, suggesting that while some countries have made fast progress in fibre deployment, others have not. Market concentration (HHI) in the DSL sector shows larger variation between countries than the rate at which DSL market concentration within countries have changed. This may indicate that some incumbents have largely managed to maintain their market shares. There also appear to be larger differences in the proportion of unbundled local loops between countries, than LLU changes within countries over time. The ICI variable shows that while the level of infrastructure competition varied between countries, the composition of broadband infrastructure within countries remained relatively stable, and suggests that the composition of legacy infrastructures evolves slowly.

[10] Data from the World Bank Development Indicators.

Variable		Mean	Std. Dev	Min	Max
Fibre (%)	overall	6.33	9.16	0.00	42.65
	between		6.36	0.06	19.80
	within		6.70	-13.06	35.65
HHI	overall	6 177	2 406	2 552	10 000
	between		2 306	2 976	10 000
	within		809	4 045	10 263
LLU (%)	overall	8.30	11.09	0.00	54.65
	between		9.33	0.00	33.79
	within		6.24	-20.73	29.16
ICI	overall	5 827	1 835	3 076	10 000
	between		1 801	3 553	9 972
	within		482	4 213	7 640
DSL (%)	overall	32.70	17.95	0.05	79.77
	between		14.73	7.94	62.54
	within		10.60	-9.78	66.39
Cable (%)	overall	12.10	9.81	0.00	45.06
	between		8.78	0.00	33.49
	within		4.68	-4.05	26.51
4G/LTE (%)	overall	3.85	9.87	0.00	64.82
	between		3.10	0.63	13.16
	within		9.39	-9.31	55.51
GDP pc. (US$)	overall	33 341	12 006	11 624	65 781
	between		12 093	14 926	63 804
	within		1 699	27 884	38 105
Urban (%)	overall	71.46	11.32	49.62	97.85
	between		11.47	50.08	97.60
	within		0.98	66.53	75.73

Table 1: Descriptive statistics of variables included in the dataset

5.2.Model specification

We test the relationship between DSL competition and fibre penetration using a fixed effects (FE) estimation.[11] A Hausman specification test revealed that the null hypothesis that the unique errors are not correlated with the regressors can be rejected, suggesting that a random effects estimation would not have been consistent. This indicates the presence of fixed effects, as one would expect on a priori grounds due to country-specific deployment costs or country-specific demand differences that influence adoption. While the model does not solve issues of endogeneity, it still allows us to make inferences about the shape of the relationship. The model specification in its broadest form is shown in Eq. 3, for country *i* at time *t*. We test different variations hereof, as shown in Table 3.

$$Fibre_{it} = \beta_0 + \beta_1 HHI_{it} + \beta_2 {HHI_{it}}^2 + \beta_3 LLU_{it} + \beta_4 HHI_{it} LLU_{it} + \beta_5 HHI_{it}^2 LLU_{it} + \beta_6 ICI_{it} + \beta_7 {ICI_{it}}^2 + \beta_8 {ICI_{it}}^3 + \beta_\alpha x_{it} + \beta_9 year_t + \alpha_i + \epsilon_{it} \qquad \text{(eq. 3)}$$

Based on the hypothesis that fibre penetration can be deterred by too much or too little competition in the DSL market, we fit a polynomial regression model to test the effect of DSL market concentration (HHI) on fibre. An inverted U-shaped relationship would be reflected in a positive coefficient for HHI and a negative coefficient for HHI-squared. Competition in the DSL sector is however influenced by open access policies, and the effect of market concentration on fibre penetration may depend on the extent to which local loops have been unbundled. We therefore interact LLU with HHI to accommodate the effect of market concentration on fibre under different LLU scenarios. Interacting these terms changes the way in which the coefficients are interpreted, with β_1, the coefficient for HHI (see equation 3), showing the effect of market concentration on fibre for given values of LLU.

To determine the relationship between facility-based competition and fibre penetration, we test the effect of a quadratic and polynomial relationship between ICI and fibre. This hypothesis is based on the discussion above that facility-based competition is also likely to bear a non-linear relationship with fibre penetration.

Various control variables are included in x_{it}: alternative broadband networks (4G/LTE and cable) are included to test for substitution effects. We do not test the effect of competition between operators within these networks, as competitive pressure would likely not encourage them to invest in fibre but instead in upgrading their cable networks and mobile infrastructures.

We also control for socio-economic variables through GDP per capita and urban population density, and for underlying technological change by adding period effects to capture common shocks, such as the overarching EU regulatory framework or equipment prices set in a global market. ϵ_{it} indicates the residual error term and α_i reflects country fixed effects.

[11] We tested the robustness of the results by also running a pooled OLS estimation. The results confirmed the inverted U-curve.

5.3. Results and discussion

Figure 4 plots fibre penetration against DSL market concentration over time, with each dot representing one of the countries in the analysis. It shows the large variation in market concentration across countries throughout the period, and that fibre networks were still in their infancy in the mid-2000s. The figure suggests that, over time, fibre penetration has increased most prominently in countries with an intermediate degree of competition in the DSL market. At some point in time, an inverted U-shaped relationship may be materializing, although the figures in themselves are not sufficiently unambiguous to draw such a conclusion. One can however observe that countries that have severe competition (reflected in a low HHI) or very little competition (reflected in a high HHI) in the DSL sector have a low degree of fibre penetration. Countries that have an intermediate degree of competition in the DSL sector appear to have relatively higher levels of fibre penetration.

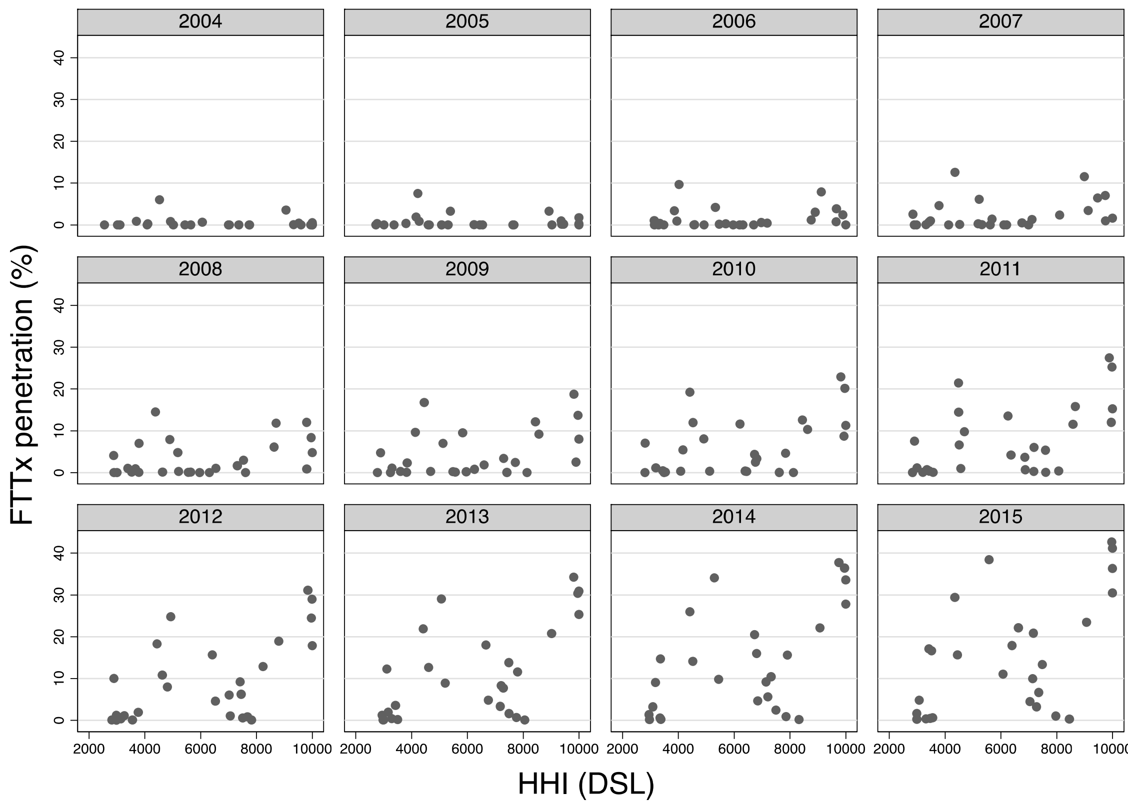


Figure 4: Relationship between fibre penetration and DSL concentration, 2004-2015

The figure also suggests that there are exceptions to the inverted U-shaped trend, with some countries having achieved high fibre penetration despite having monopolistic DSL markets. Figure 5 zooms in on the last of the twelve annual panels shown above. In some countries – Latvia (Lattelecom), Romania (Telekom), Lithuania (TEO LT) and Bulgaria (Vivacom) – the DSL market largely remains a monopoly, dominated by an incumbent.

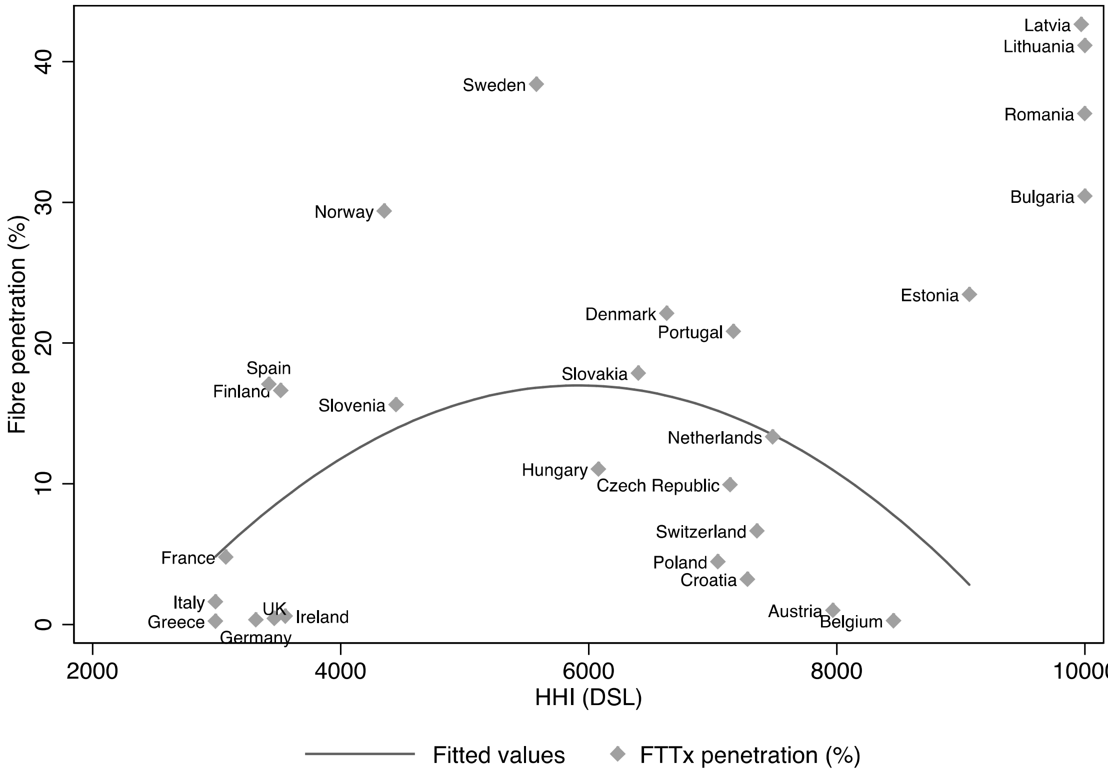


Figure 5: Relationship between fibre penetration and DSL market concentration, 2015

Before estimating the models, we test the data for sources of multicollinearity (Table 3) and consider 0.70 as a benchmark for high correlation (Kongaut and Bohlin, 2014). The results show that the only source of multicollinearity is between DSL and LLU. We address this by testing a model specification that excludes DSL.

	HHI	LLU	ICI	DSL	Cable	ln4G	Urban	GDP
HHI	1							
LLU	-0.630***	1						
ICI	-0.623***	0.581***	1					
DSL	-0.644***	0.797***	-0.552***	1				
Cable	-0.059	-0.013	-0.346***	0.282***	1			
ln4G	-0.078	0.098*	0.009	0.158***	0.224***	1		
Urban	-0.363***	0.323***	0.142**	0.444***	0.426***	0.127**	1	
GDP	-0.563***	0.329***	0.241***	0.584***	0.481***	0.164***	0.532***	1

**p<0.1, **p<0.05 and ***p<0.01*

Table 2: Pearson correlation coefficients, 2004-2015

Table 3 presents the outcomes of the different model specifications. Model 1 estimates the model in its most simple form, taking only variables directly related to competition into account. The negative coefficient for LLU is consistent with prior literature, that has found unbundling to negatively impact investment in fibre. However, the LLU and HHI interaction terms confirm that this relationship is non-linear, and that the effect of unbundling on fibre penetration is affected by the degree of concentration present in the DSL market.

Model 2 shows that the effect of facility-based competition (ICI) on fibre only becomes statistically significant if we control for the different clusters of fibre penetration. In countries with low penetration (the control group), more facility-based competition (i.e. a decrease in ICI) leads to lower fibre penetration. This is contrary to what most other researchers have found (see section 4), but may be explained by the low degree of 'within' variation of facility-based competition in these countries, in most instances characterized by extensive legacy broadband networks which have muted investment in fibre. In countries where a high level of fibre penetration has been achieved (Cluster 3), more facility-based competition leads to increased fibre penetration, consistent with prior research.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
HHI	-0.000306	-0.000377	-0.00183	-0.00308**	-0.00202	-0.00153
	(-0.0037)	(-0.0039)	(-0.0014)	(-0.00134)	(-0.0027)	(-0.00133)
HHI^2	7.83E-08	8.18E-08	1.78E-07	2.37e-07*	2.10E-07	1.55E-07
	(-2.69E-07)	(-2.84E-07)	(-1.25E-07)	(-1.17E-07)	(-2.11E-07)	(-1.12E-07)
LLU	-1.606**	-1.456*	-0.868	-1.138*	-1.407*	-1.111*
	(-0.721)	(-0.721)	(-0.543)	(-0.584)	(-0.72)	(-0.614)
HHI*LLU	0.000648*	0.000590*	0.000417	0.000505*	0.00053	0.000520*
	(-0.0003)	(-0.0003)	(-0.0002)	(-0.000268)	(-0.0003)	(-0.0003)
HHI^2*LLU	-8.57e-08**	-7.95e-08**	-5.38e-08**	-6.22e-08**	-6.71e-08**	-6.50e-08**
	(-3.41E-08)	(-3.43E-08)	(-2.43E-08)	(-2.76E-08)	(-3.18E-08)	(-2.82E-08)
ICI	-0.00349	0.0143	0.0263**	-0.00167	0.0304*	-0.00277
	(-0.0043)	(-0.0204)	(-0.0123)	(-0.00143)	(-0.0150)	(-0.0031)
ICI^2	4.28E-07	-2.59E-06	-4.67e-06**		-5.68e-06**	3.04E-07
	(-2.93E-07)	(-3.29E-06)	(-2.08E-06)		(-2.60E-06)	(-2.35E-07)
ICI^3		1.58E-10	2.61e-10**		3.24e-10**	
		(-1.65E-10)	(-1.07E-10)		(-1.35E-10)	
DSL			-0.383***	-0.342***		-0.405***
			(-0.0709)	(-0.0822)		(-0.0846)
Cable			-0.862***	-0.753***	-0.867***	-0.811***
			(-0.111)	(-0.119)	(-0.152)	(-0.124)
ln(4G)			-0.570**	-0.444**	-0.428*	-0.425*
			(-0.222)	(-0.209)	(-0.237)	(-0.221)
GDP			0.000833**	0.000976***	0.000951***	0.000730*
			(-0.0003)	(-0.000325)	(-0.0003)	(-0.0004)
Urban			1.460***	1.432***	1.607***	1.413***
			(-0.461)	(-0.446)	(-0.468)	(-0.458)
ICI*Cluster 2				0.00263*		
				(-0.00153)		
ICI*Cluster 3				0.00528***		
				(-0.00179)		
Constant	3.706	-28.71	-163.3***	-123.1***	-184.2***	-104.9**
	(-20.19)	(-40.86)	(-45.58)	(-39.49)	(-43.23)	(-41.03)
Observations	324	324	324	324	324	324
R-squared	0.658	0.664	0.841	0.842	0.782	0.827
Period Effects	YES	YES	YES	YES	YES	YES
Turning point	*3781*	*3711*	*3875*	*4059*	*3949*	*4000*

*Standard errors reported in parenthesis are robust to heteroscedasticity; *p<0.1, **p<0.05 and ***p<0.01; Cluster 1 is control group for Cluster dummy.*

Table 3: Fixed effects estimation, dependent variable: fibre penetration (%), 2004-2015

The interpretation of the coefficients of HHI and LLU is best presented visually. Figure 6 illustrates the predictive effects of HHI on fibre for Model 3 (which includes the full set of competition and control variables). If one looks at the different curves (for different values of LLU), it confirms the findings of prior literature, that service-based competition typically has a negative effect on broadband penetration. Yet, our results suggest certain nuances to the argument which, to our knowledge, have not been identified in prior research. We find that the relationship between service-based competition and fibre penetration is non-linear: in highly concentrated markets or in markets where competition is severe, the predicted effect of an increase in competition on fibre in clearly negative, but if an intermediate degree of competition is present, more service-based competition will have a modest impact on fibre. Since fibre rollout requires a certain level of economies of scale, a very fragmented market may offer less scope for such investments, which will then be observed in lower fibre penetration. Importantly, the scale of these effects on fibre varies with the openness of the DSL market: the greater the prevalence of local loop unbundling, the larger is the effect of a change in market concentration on fibre penetration. Put differently, if a country has extensive local loop unbundling, operators' incentives to invest may be more sensitive to changes in DSL competition than if there is limited unbundling. This observation has important implications for the assessment of mergers in the DSL market.

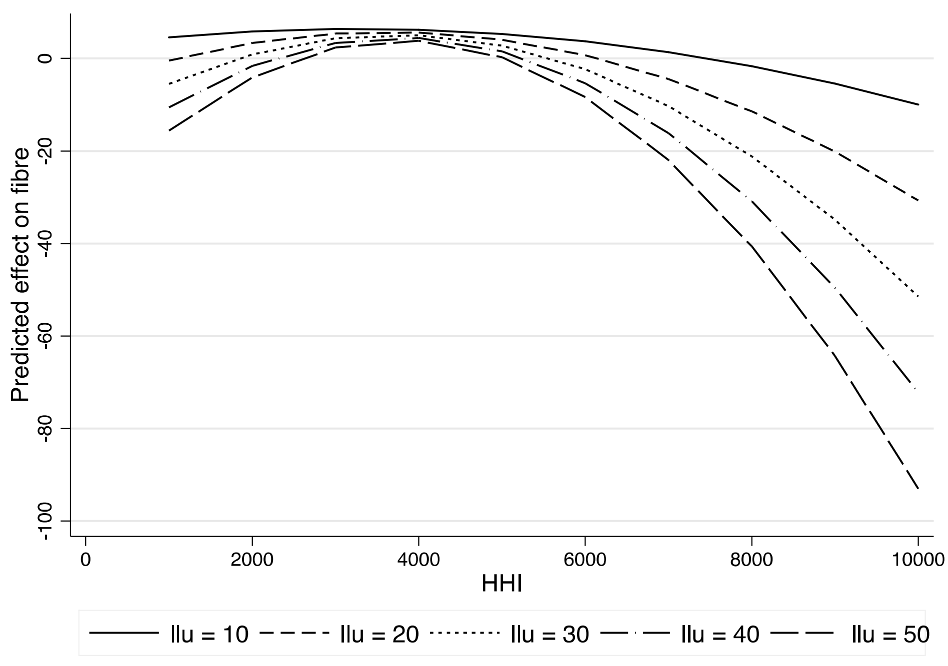


Figure 6: Predictive effects of HHI on fibre penetration for given values of LLU (Model 3)

This interpretation is illustrated differently in Figure 7: for lower values of HHI – i.e. if there is already a degree of competition present in the market - a change in the proportion of unbundled local loops holds less of a risk for fibre penetration. However, in more concentrated or monopolistic markets, an increase in local loop unbundling may lead to a decline in fibre penetration due to the disincentives for investment it may create. This suggests that operators may not see investment in fibre as a means of securing their competitive advantage in the presence of mandated open access in DSL. It confirms the findings of prior literature (discussed in section 4) that unbundling may have a negative impact on network investments. Yet, our results illustrate that while this is true in highly concentrated markets, the effect is muted if the degree of competition is already high to start with.

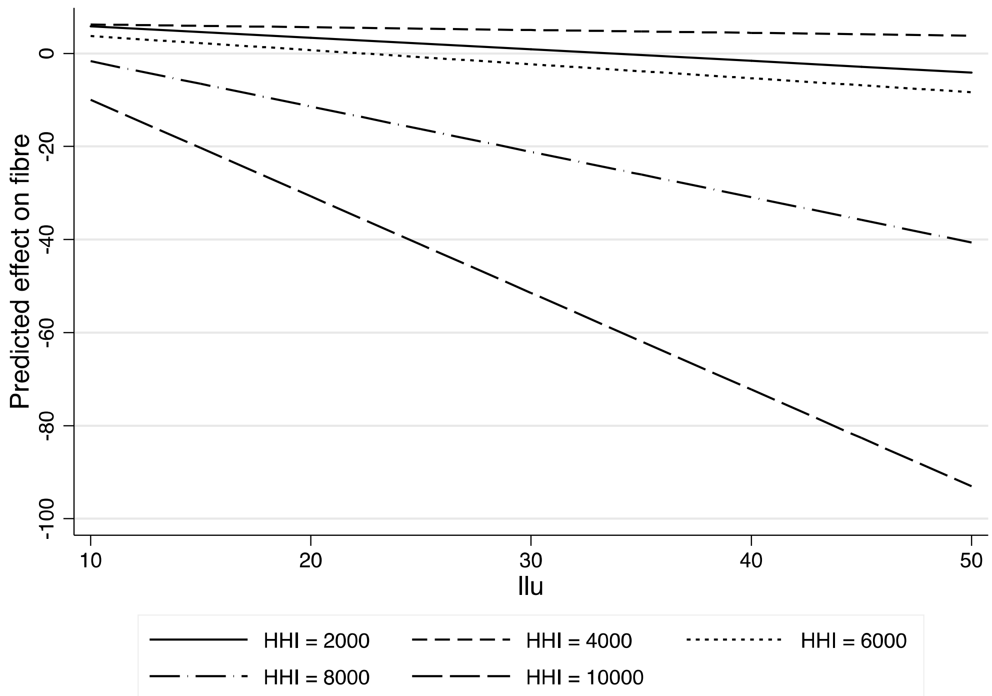


Figure 7: Predictive effects of LLU on fibre for given values of HHI (Model 3)

Based on our data, ICI bears a non-linear polynomial relationship with fibre penetration, as illustrated in the figure below. It confirms the findings of prior literature that facility-based competition generally has a positive impact on fibre penetration. The large effect on fibre in markets where there is very little ICI competition can likely be explained by state support for fibre, and appears to outweigh a replacement effect whereby monopolists do not want to invest in fibre. Facility-based competition that intensifies leftwards along the curve encourages fibre penetration, perhaps as investing in fibre may become the "only way out" for DSL operators threatened by extensive cable networks. However, this trend only lasts up to a certain point, hereafter facility-based competition becomes too severe to allow investment in fibre.

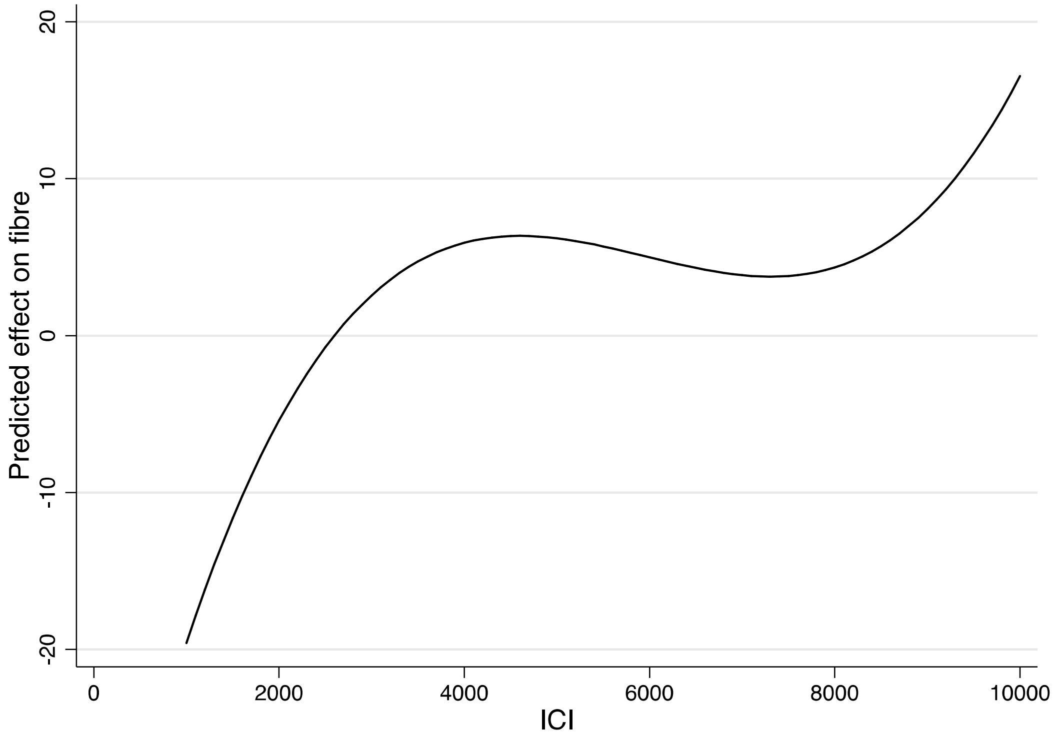


Figure 8: Predictive effect of ICI on fibre penetration (Model 3)

We also tested the effect of countries' different broadband strategies by creating a categorical variable to cluster countries according to their degree of fibre penetration.[12] The results are presented in Model 4. Assuming three clusters of countries, as identified by Briglauer and Gugler (2013) and described in 5.1 above, we interact this variable with ICI to understand the varying effects that facility-based competition can have on fibre penetration. The results confirm the non-linear trend, showing that for countries in cluster 1 (countries with high fibre penetration), more competition between cable and DSL broadband is unlikely to lead to a further increase in fibre. However, for countries with lower fibre penetration (cluster 1 and 2), more competition between cable and DSL could have a positive impact on fibre. The effect is largest for countries in cluster 3, who are only still 'Starters' in terms of fibre rollout.

The coefficients of the control variables largely conform to our expectations. The availability of cable and DSL broadband networks consistently show statistically significant and negative relationships with fibre, suggesting that fibre penetration may be more limited in countries where traditional broadband networks are expansive. The statistical significant of the coefficient for 4G/LTE is not robust to different model specifications, suggesting that mobile broadband is not (yet) a compliment or a substitute for fibre. This echoes Briglauer (2015), who finds no strong statistical evidence in support of fixed-mobile substitution (the FMS hypothesis). With 4G/LTE technology only recently having become an important player in the telecommunications market, it is at this stage still too early to draw clear inferences about the relationship between the two types

[12] K-means clustering was applied to partition the 27 countries into three groups.

of technology. As is to be expected, countries with a higher GDP per capita as well as countries where a larger share of the population lives in urban areas, have higher fibre penetration.

Models 5 and 6 present sensitivity tests. Due to the high correlation between DSL penetration and LLU, we exclude DSL in Model 5, and all coefficients appear to be robust to this change. Following Briglauer et al. (2013) and Briglauer (2015), we test whether facility-based competition bears a hyperbolic relationship with fibre deployment, but do not find statistically significant results.

6. Conclusion

High speed broadband access creates potential productivity gains and has a positive impact on economic growth (Briglauer et al., 2015). Achieving Europe's broadband access objectives will require large scale investment in NGNs, and it is therefore imperative that the right investment climate is created to encourage fibre network rollout. As a market characterised by strong network effects, much of the focus on increasing broadband access has been on implementing appropriate regulations to encourage investment and uptake. While open access regulations have managed to increase service-based competition and the uptake of broadband services, it has not had the desired effect on infrastructure investments (Briglauer et al., 2015). The ladder of investment hypothesis is therefore largely considered to have failed to encourage operators to invest in network infrastructure and increase fibre penetration.

This paper took a step back and asked, given that mandatory access regulations seem to have been unsuccessful in encouraging investments, whether the degree of competition in the DSL market bears any relationship with fibre penetration. The findings suggest that the relationship follows an inverted U-shaped curve, which corresponds to the intuition behind the similar shape of the relationship between competition and investments or innovation. It also shows that the effect of open access policies on fibre penetration may vary depending on the degree of competition in the market.

Our findings suggest certain nuances to the argument that service-based competition typically has a negative impact on investment in fibre. We show that the relationship between service-based competition and fibre penetration is non-linear: in highly concentrated markets, the predicted effect of an increase in competition on fibre in negative, but if a moderate degree of competition is present, more service-based competition may have a positive impact on penetration. This finding should inform competition authorities' assessment of mergers in the DSL broadband sector. It illustrates that, while it is important to evaluate the effect that broadband mergers may have on the price and quality of DSL services (through improving allocative efficiency), it is equally important to consider the dynamic efficiency effects that such mergers may bring about.

In addition, our results suggest that the effect of a change in DSL market concentration on fibre penetration varies with the degree of unbundling that is present: if a country has extensive local loop unbundling, operators' incentives to invest appear to be more sensitive to changes in DSL competition than if there is limited unbundling. Policy makers need to be aware of this potential medium-term trade-off between mandatory access and encouraging fibre penetration.

Our findings show that achieving the right level of competition and regulation may help encourage investment in fibre, and thereby contribute to achieving the objectives regarding fibre penetration of Europe's Digital Agenda.

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Appendix

Cluster 1 (High)	Cluster 2 (Moderate)	Cluster 3 (Low)
Bulgaria Denmark Estonia Latvia Lithuania Norway Romania Sweden	Czech Republic Finland Hungary Netherlands Portugal Slovakia Slovenia Spain	Austria Belgium Croatia France Germany Greece Ireland Italy Poland Switzerland UK

Table A1: Country clusters by mean fibre penetration (2004-2015)

Zero to 2% of local loops	More than 2% but less than a quarter of local loops	More than a quarter of local loops
Poland Czech Republic Estonia Belgium Hungary Lithuania Bulgaria Croatia Latvia Romania Slovakia	Spain Norway Netherlands Austria Slovenia Portugal Denmark Finland Sweden Ireland Switzerland	France UK Greece Italy Germany

Table A2: LLU penetration, 2015 (% of unbundled local loops)