# Facility- and Service-based Competition and Investment in Fixed Broadband Networks: Lessons from a Decade of Access Regulations in the European Union Member States

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**Abstract**

This paper employs firm-level panel data of 57 incumbent and entrant firms for 23 European countries in the decade from 2003 to 2012. We examine the impact of service- and facility-based competition on firm level investment as well as the strategic effects underlying infrastructure investment decisions. At the same time we explicitly model the structural dynamics of broadband investment using dynamic panel estimation techniques. We find that facility-based competition exerts a positive and significant impact on both incumbents and entrants implying that incumbents' and entrants' investment decisions are strategic complements. Moreover, this strategic complementarity is much more pronounced with respect to the entrants. Finally, we show that service-based competition appears to have no significant impact on the investment decision of incumbents and entrants and that there is no supportive evidence for the so-called "ladder of investment" hypothesis. With respect to the later phase of market regulation, service-based competition exerts a negative impact on entrants' investment.

JEL classification: L43, L52, L96.

# 1. Introduction

Following the liberalization of electronic communications markets in 1997/1998, the European Commission (EC) issued several guidelines to introduce competition in those markets by means of mandated access obligations. Typically, these obligations were asymmetrically imposed on formerly state-owned “incumbent” operators who were deemed to have significant market power related to the possession of monopoly-like legacy infrastructure. In particular, the EC in its Directive 2887/2000 has foreseen mandated wholesale access to the local loop (European Parliament & Council, 2000) and thus enabled new market operators (“entrants”) to offer retail narrowband voice and broadband services directly to customers. Service-based competition that hinges directly upon a set of pre-defined access regulations and cost-oriented wholesale access charges, in particular, allows the entrant to offer competitive retail services without getting engaged in timely, costly, and risky roll-out of own access network infrastructure, if access obligations are effectively implemented by the national regulatory authorities (NRAs). In the early stages of market liberalization service-based competition massively increased price competition and thus had an immediate and positive welfare effect in terms of static efficiency.

The EC also emphasized in its Directive 2002/19/EC that mandated access should not reduce the incentives of entrants to invest in alternative infrastructure (European Parliament & Council, 2002). The latter, in turn, would be essential to foster competition in the long-run in terms of dynamic efficiency. Moreover, infrastructure- (or: facility-) based competition involves a much lower degree of industry micro-management and hence lower administrative costs. However, the EC has never explicitly mandated the entrant to start investing in its own network after a certain period of time, with a formal requirement to enter facility-based competition. Consequently, the decision to invest in own facilities is up to the entrant contingent, inter alia, on regulatory investment conditions. As a result, wireline communications markets are still characterized by two different types of entrants, those who remain service-based competitors, and those who gradually self-deploy network infrastructure and thus also enter facility-based competition becoming at least partly independent network operators.

The latter development adheres to the so-called “ladder of investment” (LoI) hypothesis (Cave & Vogelsang, 2003; Cave, 2006). According to this hypothesis, regulatory-induced service-based competition serves as a stepping stone for entrants to engage progressively in backward integration and ultimately to self-deploy access infrastructure.[1] The former, however, still represents by far the predominant group of entrants.

One of the most controversial questions is which mode of competition is preferable in order to lower prices and to achieve high investment at the same time. This issue becomes even more important in view of the deployment of fibre-based next (or second) generation communications infrastructure; in particular, it is hotly debated whether emerging communications infrastructure should be subjected to a similar set of sector-specific access regulations and whether service-based competition is essential, in a similar way as in the beginning of liberalization of first generation networks, or if it rather diminishes ex ante investment incentives.[2] Infrastructure-based operators argue that service-based competition via mandatory access regulations restricts their ability to generate sufficient revenues and would thus be detrimental to ex ante investment incentives and network innovations. Conversely, for NRAs and service-based entrants a potential threat of new and possibly more intense monopoly areas arises in the course of the deployment of fibre-based infrastructure, which entails the need to have again an appropriate access regulation in place.

Utilizing the experience of a decade of regulating first-generation broadband networks, our paper intends to draw lessons on the impact of both modes of competition on investment in fixed broadband markets. In answering this, we employ an unbalanced panel data set of 57 operators from 23 European Union (EU) member states for the years from 2003 to 2012. The period of analysis thus covers the beginning of service-based competition based on wholesale broadband access regulations and the early phase of transition to next generation infrastructure deployment that has been initiated

[1] Hence in the U.S. the LoI is known as the “stepping stone” hypothesis.
[2] The reader is referred to Telecommunications Policy special issue published in 2013 (Volume 37(10)) which collects controversial papers on the topic “Regulatory approaches and investment in new communications infrastructure”.

only recently in most EU member states.[3] We therefore exploit information over a whole decade of market liberalization and regulation involving both modes of competition in order to have a sound basis to truly inform the debate on the future regulatory policies to be imposed on new communications infrastructure.

Our empirical specification incorporates: i) generalized methods of moments (GMM) and bias-corrected fixed effects estimators to account for the endogeneity bias due to the dynamic specification of the investment equation, omitted variables and reverse causality patterns; as suggested by the related literature (Grajek & Röller, 2011), the latter appears to be of particular relevance for the relationship between regulation and competition on the one hand and investment activities on the other; ii) strategic firm-level effects regarding investment decisions, and finally, iii) the structural dynamics of adjustment costs in terms of a dynamic investment accelerator model.

The remainder of the paper is organized as follows: Section 2 reviews the related and recent empirical literature. Section 3 outlines our basic hypotheses. Section 4 describes the data set underlying our empirical investigation. Section 5 presents the empirical baseline specification and our identification strategy. Section 6 describes and interprets the main results of the empirical analysis. Section 7 summarizes and compiles important assessments for future regulatory policies.

## 2. Empirical evidence

In this section we review the most related and recent contributions from the empirical literature. In doing this, we build on the well-cited survey by Cambini and Jiang (2009) who review the older literature on investment and regulation. The authors conclude that the majority of the contributions find that service-based competition in terms of different forms of cost-based access regulations discouraged both incumbents and alternative competitors from investing in fixed networks. In the following we also consider empirical

[3] Note that we exclude wireless mobile broadband access technologies in our analysis. The latter have already been facilitated by previous mobile technologies such as GPRS, EDGE, UMTS und HSDPA but due to technological limitations did not represent a substitute access device to the majority of consumers as regards the overall analysis period. Of course, mobile broadband services have become increasingly popular in recent years and might become a stronger competitor even as regards second generation (wireline) broadband services in view of the latest wireless communications technologies (LTE).

studies that employ measures of broadband penetration which is output-related and hence might provide a better proxy for consumer welfare in efficiently functioning markets as explicitly argued by some authors (Crandall et al. 2013, p. 266).[4]

Bouckaert et al. (2010) examine the determinants of broadband penetration based on data for 20 OECD countries for the years from 2003 to 2008. The authors find that infrastructure-based competition has a positive impact on broadband penetration, whereas service-based competition is an impediment to penetration. The authors argue that their findings suggest that the LoI hypothesis does not provide sufficient justification for imposing comprehensive broadband access regulations. Grajek and Röller (2011) empirically estimate the relationship between regulation and investment as regards telecommunications investment of incumbent and entrant operators using data for EU member states for the years from 1997 to 2006. The authors are among the few who explicitly take into account the endogeneity problem of regulation and investment in terms of reverse causality, however, the authors ignore the bias that arises from their dynamic investment specification. Using a formal regulatory index the authors find that access regulation reduces both individual firm and total industry investment. Moreover, the authors find that incumbents invest more in response to investment increases of entrants indicating that investments are strategic complements, although the complementarity is not significant the other way around, i.e. from the incumbents to entrants. Bacache et al. (2013) examine the incentives embedded in the EU regulatory framework on migration from old to new fibre-based access infrastructures using data from 15 EU member states for 17 semesters over the period from July 2002 to July 2010. The authors relate the number of access lines based on new access technologies to the number of unbundling and bitstream lines in order to test the validity of the LoI hypothesis. Whereas the authors find some support for the LoI hypothesis for the migration from bitstream access to local loop unbundling at the lower rungs of the

[4] Of course, increases in investment do not necessarily imply welfare increases (Höffler, 2007) in general. However, regarding communications markets and broadband markets, in particular, one can first argue that the "Averch-Johnson" effect (too much capital employed) can be expected to be small because service-based as well as infrastructure-based competition has already transformed legacy monopoly-like market structures into more competitive market structures since the beginning of liberalization and sector-specific regulation. Second, as argued convincingly in the empirical literature (e.g., Czernich et al. (2011); Koutroumpis (2009); Röller and Waverman (2001); Thompson and Garbacz (2007)), one can expect substantial positive externalities related to broadband infrastructures that are not captured in the markets.

ladder with lower investment requirements, there is no empirical support for the hypothesis that mandatory local loop unbundling fosters entrants to invest in new and much more cost intense communications infrastructures. Nardotto et al. (2012) find similar results using broadband penetration quarterly data from December 2005 to December 2009 for the whole of the UK. The authors find support for a short ladder leading from resale to bitstream access and unbundling but not to self-deployed entrants' infrastructure. Crandall et al. (2013) is a recent OECD based study that utilizes country level data for the years from 2001 to 2010. The authors find that unbundling obligations have almost no significant impact on broadband penetration in the short run but a significantly negative impact on penetration in the long run. Finally, Briglauer et al. (2013) are the first to investigate the determinants of fibre-based infrastructure deployment using data for the years from 2005 to 2011. Their empirical specification incorporates investment data in physical units at the EU27 country-level. The authors find that the more effective wholesale broadband access regulation and hence service-based competition is, the more negative the impact on fibre deployment.

Summarizing, the recent empirical analysis on access regulations and investment seem to prove the results in Cambini and Jiang (2009), according to which service-based competition and related broadband access regulations tend to be either statistically unrelated or negatively related to investment incentives. Furthermore, there is evidence that infrastructure-based competition exerts a positive impact on investment at the aggregate level. To the best of the authors´ knowledge, there is no work that employs firm-level investment data, incorporates the structural dynamics of broadband investment and simultaneously takes into account both modes of competition as well as the relevant sources of endogeneity. This paper intends to fill this gap and identify the causal effects of service-based and facility-based competition on broadband investment.

## 3. Hypotheses

This section identifies the main determinants of broadband investments in Europe in the decade from 2003 to 2012 and sets out corresponding hypotheses, which are aligned to the main modes of competition in fixed-broadband markets: Service-based competition (Section 3.1) and facility-based competition (Section 3.2). Moreover, we explicitly outline the dynamics of broadband investment in terms of a flexible accelerator investment model (Section 3.3).

## 3.1. Service-based competition

At the beginning of market liberalization, EU member states introduced asymmetric (one-way) access regulations imposed on the incumbent operators, which enabled service-based competition at cost-oriented access charges set by NRAs. The EU regulatory framework basically provides three different kinds of wholesale access obligations, namely: i) “resale”, ii) “bitstream”, and iii) “unbundling”. Simple resale means that the entrant sells the services of the incumbent with no technical scope of product differentiation i.e., value is added only at the retail level, such as branding, advertising or customer care. In this case the entrant is hardly confronted with fixed and sunk costs. In the case of bitstream, the entrant has to build its own backbone networks, which enables him to differentiate the quality characteristics of its retail services to some extent. In the case of unbundling, the entrant operates much more independently, since it gets physical access to the incumbent’s local loop copper lines.

In view of multi-level access remedies, the LoI hypothesis has been considered as a guiding principle in the EU regulatory framework tool to promote both price competition and broadband investment (ERG, 2005). An entrant that gradually invests moving from rung to rung (from simple resale to bitstream and then to unbundling and self-deployed infrastructure) shows incentives to add value to its services and operate more and more independently; in the first step service-based entrants will acquire more information and establish a customer base, and therefore in the second step they will be able to invest in their own infrastructure, which ultimately results in facility-based competition representing the top of the ladder (Briglauer & Gugler, 2013). The latter, i.e., the last rung of the ladder, also represents by far the highest investment requirements for alternative operators. As a consequence of facility-based and service-based competition, retail prices decrease and product variety increases, which may lead to an increase in total demand for broadband services. This demand increasing effect might also increase investment incentives by incumbents (Foros, 2004; Kotakorpi, 2006). Moreover, in the case of excessive capacities, when more downstream competition decreases retail prices, which in turn may be associated with an increase in total demand, it could be the case that the regulated incumbent is almost one-to-one compensated for foregone monopoly profits. From this point of view, rather than being substitutes, service- and facility-based competition would complement each other and there would be no inter-temporal trade-off between static and dynamic efficiency. Therefore, access regulations would ideally resolve this trade-off, inducing retail competition and fostering investment of entrant and incumbent operators according to the LoI hypothesis.

However, several opposing effects predict that stricter access regulations deteriorate investment incentives of incumbent and/or entrant operators: first, the incumbent will only be able to make monopoly profits until asymmetric access regulation is introduced which enables the entrant to enter the market at cost-oriented access charges. However, rents earned from wholesale access at cost-oriented prices are simply lower than monopoly rents from selling infrastructure directly to retail customers. This effect gets reinforced in case risks are shifted from entrants to incumbents, which is typically the case under standard cost-based access regimes (Pindyck 2007; Valletti 2003). Guthrie (2006) and Bourreau and Dogan (2006) emphasize that the ex ante regulated incumbent is exposed to a considerable risk, while the entrant has second-mover advantage due to the investment flexibility available in terms of exploiting new technologies. Innovations, such as xDSL technologies, enable the entrant to offer new products or higher quality services without facing the risk due to demand-side uncertainties. Thus, having the second mover advantage enables the entrant to avoid investment in unsuccessful technologies after getting sufficient information from the market. Guthrie (2006) criticizes that regulatory models do not incorporate the option value of “wait and see strategies” that the entrant obtains by investing second. Overall, favourable access regulations constitute substantial opportunity costs for entrants’ investment and may thus postpone or hinder their infrastructure investment.

Summarizing, service-based competition and related access regulations exert a positive impact on entrants' investment incentives only if the LoI hypothesis holds true and dominates entrants' opportunity costs (representing the benefit from cheap access). However, the LoI hypothesis appears reasonable only with respect to moves along the lower rungs of the ladder which come along with comparatively low investment requirements, especially for moves from resale to bitstream access. With respect to the investment incentives of the incumbent the net effect is indeterminate to the extent that service-based competition simultaneously captures negative investment incentives related to the strictness of (standard cost-based) access regulations, as well as the demand expanding effect according to which total revenues increase with the level of service-based competition.

## 3.2. Facility-based competition

In this case, we add another dimension of competition stemming from alternative broadband operators, namely the entrant's own self-deployed access lines, which represent facility-based competition that does not depend on any kind of asymmetric access regulations. The entrant by investing in facility-based access infrastructure enjoys additional benefits referring to entrepreneurial independency or better quality of services. Ideally, and as stipulated by the LoI, the entrant first establishes its market position and increases its customer base via service-based competition which then enables the entrant to ultimately connect its service-based customers to its own facilities. In reality, however, besides incumbents only operators with access to infrastructure elements prior to market liberalization substantially invested in deploying access networks. Most notably, these networks refer to coax-cable broadband infrastructure with prior cable TV networks or municipal utilities with prior duct infrastructure. In fact, the LoI did not induce any substantial self-deployed access infrastructure on the side of pure service-based entrants which can be interpreted as the "natural outcome of the economics of fixed broadband access" (Vogelsang 2013, p. 212). Bender and Goetz (2011) provide a theoretical explanation why entrants do not climb the rungs according to the LoI hypothesis. The authors model competition between the incumbent and an entrant who faces a make-or-buy decision as regards the upstream level. The authors argue that the service-based entrant has, in principle, an incentive to invest in view of possible cost savings but is also confronted with a strategic effect: lower costs enable lower retail prices, however, these might imply aggressive pricing and investment reactions from the incumbent in order to limit consumer migration to the entrants' retail services.

Wireline facility-based competition stemming from entrant operators hereinafter only refers to access networks of cable operators complemented by some municipal investment activities which is distinctively different from activities of service-based entrants acting at the lower rungs of the ladder. Regarding the relationship between facility-based competition and investment, there is no clear prediction at the micro-level as shown in Schmutzler (2010) in general. Rather, the relationship depends on the definition of competitive intensity and the oligopoly framework and consequently investments can be increasing or decreasing functions of competition. However, it is well-known from the pre-emption literature that a potential infrastructure provider has an incentive to pre-empt another infrastructure provider by being the first and thus reducing the rivals' profitability and incentives to invest. As a consequence, infrastructure providers might get engaged in a race to invest first and earn the rents. Such a pre-emption race is of particular relevance for investment upgrades in telecommunications (Gans, 2001; Grajek & Röller, 2011; Guthrie, 2006) where infrastructure duplication is only possible in areas with high population density whereas – due to the economics of fixed broadband access – infrastructure investment is only profitable, if it all, for one operator in all other areas. This opens up the potential for a long-lasting first-mover advantage which thus fosters ex ante investment incentives.

Summarizing, incumbents' and entrants' infrastructure investment decisions reinforce each other, i.e. investment decisions are strategic complements, if the operators engage in pre-emption strategies and “race” for the first-mover advantage in terms of aggressive price competition at the retail level and infrastructure investment.

## 3.3. Investment dynamics: a flexible accelerator model

Below we present a flexible accelerator investment model using a neoclassical production function with constant returns to scale and no substitution between input factors. Thus, it only takes into account quantity variables, while price variables are not included into the model (Chirinko, 1993). The first derivative and cross partials of the production function are positive and the second derivates are negative. This implies that the marginal products are positive at decreasing rates and are positively related to other input factors employed. Thus, increasing the output level would require an increase in inputs, following the objective of cost minimization and depending on the adjustment cost (Eisner, 1978).

The main and most important assumption of this model is about the firm's desired level of capital expressed in terms of a fixed capital to output ratio. We denote the desired level of capital of the firm $i$ at time $t$ by $K_{i,t}^*$, the output level by $Y_{i,t}$ and the capital to output ratio by $\alpha$. Based on the notion of optimal capital accumulation, the optimal level of capital is proportionally related to the level of output:

(1) $$K_{i,t-1}^* = \alpha Y_{i,t-1}$$

where $K_{i,t-1}^*$ and $Y_{i,t-1}$ represent the desired level of capital and the output level of the firm $i$ in the previous period of time $t-1$, respectively. Consequently, a high capital to output ratio is associated with high investment expenditures, and vice versa. In the simple accelerator investment model $\alpha$ is constant. If the adjustment is immediate and ignoring depreciation, investment would be simply the difference in the desired capital stocks in period $t$ and $t$-1:

(2) $$I_{i,t} = (K_{i,t}^* - K_{i,t-1}^*) = \alpha(Y_{i,t} - Y_{i,t-1}) \equiv \alpha \Delta Y_{i,t}$$

where $I_{i,t}$ represents current investment in period $t$ for firm $i$. However, the older literature (Eisner, 1978; Koyck, 1954) as well as recent and telecommunications related evidence (Briglauer et al., 2013; Grajek & Röller, 2011) suggest that it is unlikely that firms fully adjust their capital stock due to a change in the output level in the current period of time (in our case, within one year). Accelerator investment models where changes in the level of capital require longer time to move toward a new equilibrium implied by a change in the level of output are referred to as flexible accelerator investment models. Furthermore, it is assumed that changes in the capital stock from year $t-1$ to year $t$ follow an adjustment process by a proportion $1-\lambda$ of the difference between the actual and desired level of capital:

(3) $$K_{i,t} - K_{i,t-1} = (1-\lambda)(K^{*}_{i,t} - K_{i,t-1})$$

Next, we introduce replacement investment, i.e. the rate of the capital depreciation, in the flexible accelerator mechanism. As a result, the capital stock is expressed as the sum of the previous capital stock and the level of current investment minus the depreciation of the previous level of the capital stock (Jorgenson & Siebert, 1968):

(4) $$K_{i,t} = K_{i,t-1} + I_{i,t} - \delta K_{i,t-1}$$

Where $\delta$ represents the constant rate of depreciation. From equation (4) we solve for $I_{i,t}$ and obtain:

(5) $$I_{i,t} = K_{i,t} - (1-\delta)K_{i,t-1}$$

From the flexible accelerator mechanism in equation (3) we now solve for $K_{i,t}$ and obtain:

(6) $$K_{i,t} = (1-\lambda)K^{*}_{i,t} + \lambda K_{i,t-1}$$

To complete the flexible accelerator investment model we insert equation (6) into equation (5) and obtain:

(7) $$I_{i,t} = (1-\lambda)K^{*}_{i,t} - (1-\delta)K_{i,t-1} + \lambda K_{i,t-1}$$

Finally, we integrate the capital to output ratio and the investment dynamics as captured by the lagged dependent variable to obtain the dynamic flexible accelerator investment model:[5]

$$I_{i,t} = \lambda I_{i,t-1} + \alpha(1-\lambda)Y_{i,t} - \alpha(1-\delta)(1-\lambda)Y_{i,t-1} \quad (8)$$

Summarizing, if broadband investment is subject to a partial adjustment process, we expect that the coefficient estimate of the lagged dependent variable, λ, lies in the interval [0;1] where the lower limit indicates that adjustment takes place instantaneously and the upper limit indicates persistency, i.e. there is no convergence towards an optimal desired long-run broadband infrastructure stock. Furthermore, with $\alpha > 0$ and $0 < \delta < 1$ we expect that the coefficient estimate of the (lagged) output variable is positive (negative).

## 4. Data and variables

Our dataset covers 23 EU member states and 57 firms, including 21 incumbents and 36 entrants for the years from 2003 to 2012. Our panel data set is unbalanced, since data availability regarding the start and end of the time period varies by firms and countries. We use the following main data sources: EU progress reports provide country level data on total broadband lines, i.e. regulated wholesale lines, entrants' own lines and incumbent's own lines; Worldscope provides firm level data regarding capital expenditures, tangible fixed assets, sales and cash flow. Our sample comprises 57 different firms,[6] which vary widely in their size.[7] Hence, we divide capital expenditures, sales and cash flows by the one period-lagged tangible fixed assets. The lagged

[5] The reader is referred to the Appendix for a detailed derivation of the dynamic flexible accelerator model.

[6] The Orbis database enables the identification of firms that operate in wireline telecommunications markets, which correspond to NACE code number 611010. For the resulting list of operators we verified which firms are registered on the Stock Exchange Markets based on the International Securities Identification Number (ISIN) which enabled us to get the firm-level data from the Worldscope database.

[7] There is a big difference not only between the incumbents and entrants, but also within incumbents and entrants. For example the mean of capital expenditures of the Austrian incumbent, A1 Telecom Austria, is €689 million, while the mean of capital expenditures of the Malta incumbent, GO PLC, is €18 million. On the other hand, the mean of capital expenditures of the entrant German Freenet AG is €80 million, while the mean of capital expenditures of the Polish entrant Telestrada SA is €47 thousand.

tangible fixed assets are used in order to eliminate the possibility of endogeneity between capital expenditures and the tangible fixed assets, since increasing capital expenditures may increase tangible fixed assets of the current period. In addition, we use several other data sources for our control variables: the World Bank (The World Development Indicators) and the International Telecommunications Union (World Telecommunication/ICT Indicators Database) provide us with the GDP per capita and the number of personal computers in use per capita, respectively. Finally, the European Central Bank and "MarketLine" enable us to introduce two additional control variables, namely, long term interest rate and population density, respectively.

## 4.1. Dependent variable

Our dependent variable, *capex_as*, represents firm level capital expenditures divided by the lagged tangible fixed assets in the telecommunications industry in terms of property, plant and equipment. This contains, most notably, investment in backbone and access networks. Note that whereas most of the incumbents are active in both fixed and mobile broadband markets, the entrants included in our sample are mainly offering fixed broadband services only.

## 4.2. Independent variables

Based on our hypotheses we divide our explanatory variables into the following three groups: i) access regulation in terms of the strictness of service-based competition ii) facility-based competition, and iii) control variables. The latter category contains variables related to our dynamic investment accelerator model as well as demand and cost controls.

First, **service-based competition,** *strictness*, is measured by dividing the number of regulated lines (including unbundling, bitstream and simple resale lines) by the sum of the regulated lines and incumbent's retail lines, thus showing the share of incumbent's lines made available through the regulated wholesale market. Hence, this variable captures the strictness of service-based competition and is directly conducive to the regulatory "treatment" in terms of relevant wholesale broadband access regulations. The variable *strictness* incorporates both the wholesale and retail market, since incumbent's retail lines represent the lines which the incumbent uses internally to deliver its services to the customers in the retail market.

**Facility-based competition**, *fbc*, is directly related to infrastructure investment of both the incumbent and entrants. Therefore, we employ two different variables, which enables the estimation of strategic effects regarding the incumbent's and entrants' investment decisions. First, facility-based competition is obtained as the share of the entrants' own lines related to total number of retail broadband lines, *fbc_ent*. Entrants' own lines show the number of broadband lines that are directly connected to entrants' self-deployed infrastructure by using other technologies than DSL. Most notably, entrants' own lines represent real investments of cable operators and a corresponding increase puts pressure on the incumbent in terms of a higher level of facility-based competition stemming from alternative infrastructure operators. In turn, the other facility-based competition variable, *fbc_inc*, is obtained as the share of the incumbent's retail lines related to total number of retail broadband lines.

Regarding the group of **control variables**, we first refer to the variables related to our dynamic investment accelerator model. With respect to the desired level of capital stock ($K^*$), there are different theories that assume that the desired level of capital stock is proportional to different indicators of business activity. According to the capacity utilization theory, the level of capital expenditures is positively related to the capital to output ratio (Jorgenson & Siebert 1968). According to Eisner (1978), applying sales as a main observable (proxy) variable of output ($Y$), the capital stock is expected to change with changes in sales and, thus, capital expenditures are taken as a distributed lag function of current and past sales. Accordingly, we include the sales to tangible fixed assets ratio, *sales_as*, and the one period lagged sales to tangible fixed assets ratio. Moreover, we introduce an additional firm level variable, namely, cash flow to tangible fixed assets ratio, *cflow_as*. Fazzari et al. (1988) examine the effects of asymmetric information on access to external funds and thus on the firms' investment level. The authors conclude that firms that are financially constrained are more sensitive to the availability of internal funds, such as cash flow. There is a large literature that investigates the relationship between cash flow and investment, that takes into account different factors that might explain this relationship, including: creditworthiness, size and ownership structure (Bond et al., 2003; Gugler, 2003; Kaplan & Zingales, 1997; Vermeulen, 2002). So, different coefficient estimates for the variable *cflow_as* in the incumbents' and entrants' equations point to different levels of cash constraints due to creditworthiness, size and ownership structure.

Finally, we employ additional control variables to capture demand and cost side investment determinants: i) GDP per capita, *gdp_pc*, captures the income effects at the country level; ii) the number of personal computers in use per capita, *comp_pc*, reflects the importance of the information technologies for the population (ssuming that each computer has an internet connection, the variable *comp_pc* also stands proxy for the overall broadband market size); iii) the long-term interest rate, *lt_ir*, is expected to capture the cost of capital for long-term telecommunications investment and finally; iv) population density, *pop_dens*, shows different cost structures due to varying population densities across countries.

All the variable definitions, expected signs and sources as well as summary statistics are listed below in Table 1 and Table 2, respectively.

**Table 1: Variable description and sources**

| Variable (expected sign) | Description | Source |
|---|---|---|
| | **Dependent variable** | |
| *capex_as* | Firm capital expenditures divided by lagged tangible fixed assets (property, plant and equipment) – capital expenditures to tangible fixed assets ratio. | Worldscope |
| | **Main explanatory variables** | |
| *strictness (+/- incumbent; +/- entrant)* | Regulated lines (including unbundling, bitstream and simple resale lines) divided by the sum of regulated lines and incumbent's retail lines. | EU Digital Agenda Scoreboard |
| *fbc_ent (+)* | The share of the entrants' own lines related to total number of retail broadband lines. | EU Digital Agenda Scoreboard |
| *fbc_inc (+)* | The share of the incumbent's retail lines related to total number of retail broadband lines. | EU Digital Agenda Scoreboard |
| *sales_as (+)* <br> *$sales\_as_{t-1}$(-)* | Firm sales divided by lagged tangible fixed assets (property, plant and equipment) - sales to tangible fixed assets ratio. | Worldscope |
| | **Control variables** | |
| *cflow_as (+)* | Firm cash flow divided by lagged tangible fixed assets (property, plant and equipment) – cash flow to tangible fixed assets ratio. | Worldscope |
| *gdp_pc (+)* | Gross domestic product per capita in Euro. | The World Bank - The World Development Indicators |
| *comp_pc (+)* | The number of personal computers in use normalized to population. | World Telecommunication/ ICT Indicators Database |
| *lt_ir (-)* | Harmonized long-term interest rates among the EU Member States. The rates were accessed as secondary market yields of government bonds with a remaining maturity of ten years. | EU Digital Agenda Scoreboard |
| *pop_dens (+)* | A country's population density in persons per square kilometre. | MarketLine |

**Table 2: Descriptive statistics**

| Variable | #Observations | Mean | Std. deviation | Min | Max |
|---|---|---|---|---|---|
| | | **Firm level (Incumbents)** | | | |
| *capex_as* | 198 | .1820146 | .0675826 | .0360704 | .3243908 |
| *sales_as* | 198 | 1.361392 | .5035869 | .419731 | 2.709114 |
| *cflow_as* | 198 | .3918595 | .1371634 | .1165235 | .7541049 |
| | | **Firm level (Entrants)** | | | |
| *capex_as* | 244 | .413567 | 1.694773 | .0007115 | 26.3725 |
| *sales_as* | 302 | 12.28357 | 17.26536 | 0.0729615 | 105.4997 |
| *cflow_as* | 300 | .5876553 | 3.428136 | -26.81395 | 10.07056 |
| | | **Country level** | | | |
| *strictness* | 216 | .2565829 | .1750965 | .000249 | .695199 |
| *fbc_inc* | 218 | .4930646 | .1313302 | 0 | .9438086 |
| *fbc_ent* | 215 | .310205 | .1836551 | .002915 | .761344 |
| *gdp_pc* | 230 | 21787 | 11385 | 2349 | 43831 |
| *comp_pc* | 230 | .4729649 | .2743952 | .055061 | 1.232903 |
| *lt_ir* | 230 | 4.652 | 2.221106 | .57 | 22.5 |
| *pop_dens* | 230 | 182.397 | 254.5591 | 17.1369 | 1280.74 |

# 5. Econometric modelling

First, we describe our empirical baseline specification in Section 5.1 and then our estimation and identification strategy in Section 5.2.

## 5.1. Econometric specification

Our baseline specification refers to a dynamic reduced-form model in which investment expressed in monetary terms is specified for the operator *i* in EU member state *j* and year *t* as follows:

$$
\begin{aligned}
(9) \qquad capex\_as_{i,t} = {} & \gamma + \beta_0 capex\_as_{i,t-1} + \beta_1 sales\_as_{i,t} + \beta_2 sales\_as_{i,t-1} + \\
& + \beta_3 strictness_{j,t-1} + \beta_4 fbc_{j,t} + \beta_5 cflow\_as_{i,t} + \beta_6 gdp\_pc_{j,t} + \\
& + \beta_7 comp\_pc_{j,t} + \beta_8 lt\_ir_{j,t} + \beta_7 pop\_dens_{j,t} + \eta_t + \varphi_i + \psi_{it}
\end{aligned}
$$

where $\beta_0 = \lambda$, $\beta_1 = \alpha(1-\lambda)$ and $\beta_2 = -\alpha(1-\delta)(1-\lambda)$ according to the dynamic accelerator model (equation (8)). $\beta_0$ represents the coefficient of the lagged dependent variable. $\beta_1$ measures the investment-output sensitivity which depends on the adjustment process. The difference between $\beta_1$ and $\beta_2$ is that $\beta_2$ also captures the rate of replacement investment.

Our baseline specification includes the regulatory-induced service-based competition variable, $strictness_{j,t-1}$, and the facility-based competition variable, $fbc_{j,t}$, as the main competition variables of interest. The latter variable measures the contemporaneous stock of infrastructure of the incumbents ($fbc\_inc_{j,t}$) and the entrants ($fbc\_ent_{j,t}$). In order to identify different causal effects and strategic interactions, we estimate equation (9) separately for incumbents and entrants. Based on our dynamic investment accelerator model, we include $sales\_as_{i,t}$ and $sales\_as_{i,t-1}$. In addition, we include $cflow\_as_{i,t}$ to control for firm-specific financial constraints, while other country level variables, such as, $gdp\_pc_{j,t}$, $comp\_pc_{j,t}$, $lt\_ir_{j,t}$ and $pop\_dens_{j,t}$ represent our demand and cost controls. Finally, $\gamma$ represents the intercept, $\varphi_i$ firm-specific fixed effects, $\eta_t$ time-specific effects, and $\psi_{i,t}$ represents the error term.

## 5.2. Estimation and identification strategy

The desire to measure causation and to avoid endogeneity in spite of the reliance on non-experimental data is the key concern in empirical economics (Cameron & Trivedi, 2005, p. 715; Wooldridge, 2002, p. 421). In estimating the baseline specification in equation (9), we are confronted with several sources of endogeneity: first, there might be potential endogeneity in terms of reverse causality underlying our regulation and competition variables, which are partly driven by the level of investment. However, the causal link between an increase of the level of investment and the number of (regulated) broadband lines within a period of time will be mitigated, since switching the broadband operator is subject to inertia due to long-term contracts with consumers (typically up to two years). Notwithstanding this, we include the lagged variable relating to service-based competition, $strictness_{j,t-1}$, which further mitigates potential endogeneity in case if there is no serial correlation in the original error term. However, we have to take into account endogeneity due to unobserved heterogeneity and the presence of the lagged dependent variable as a right-hand side variable (Nickell, 1981).

Dynamic GMM panel data estimation techniques represent the most prominent candidate estimator that allows us to simultaneously consider all the aforementioned sources of endogeneity underlying our main explanatory variables related to competition in broadband markets as well as sales and cash flow at the firm level. Arellano and Bover (1995) and Blundell and Bond (1998) show by Monte Carlo analysis that their general method of moments system estimator (GMM-SYS) has a smaller bias than the general method of moments difference estimator (GMM-DIFF) initially developed by Arellano and Bond (1991) for finite samples. In addition, Bruno (2005a, 2005b) developed a bias-corrected LSDV estimator (LSDVC) for unbalanced and dynamic panel data, which however requires that all other right-hand side variables are strictly exogenous. Therefore, we consider additional LSDVC estimations to test the robustness of our GMM-SYS estimation results.

## 6. Discussion of the main results

Table 3 and Table 4 below show the main estimation results based on the specification in equation (9) for the incumbents and entrants, respectively. All standard errors reported are robust to arbitrary forms of heteroscedasticity and autocorrelation in the $\psi_{i,t}$'s for GMM and bootstrapped for LSDVC models.[8] The key identifying assumption underlying the GMM estimator is that the error terms in the original specification, $\psi_{i,t}$'s, are serially uncorrelated. For all GMM models reported in Table 3 and Table 4 the Arellano-Bond AR(2) tests for zero autocorrelation in the first-differenced errors do not reject at order two at conventional levels. This implies, most importantly, that there is no evidence for serial correlation in the original error. Also, the Hansen-Sargan tests do not reject the over-identifying restrictions at the conventional levels in all GMM models. In addition, all explanatory variables, except cost and demand controls, are considered as endogenous in all GMM specifications. In order to avoid an overfitting bias in case of too many instruments employed in GMM models, we restrict the maximum number of lagged instruments to keep the total number of instruments close to the number of groups. Finally, Table 3 and Table 4 show regression results for alternative estimators (GMM-SYS vs. LSDVC) and for alternative selections of control variables. All the main variables of interest appear to be robust with respect to these alternative model specifications.[9,10]

First, as regards the coefficient of the lagged dependent variable, $capex\_as_{t-1}$, Table 3 and Table 4 show highly significant and substantial estimates in all regressions indicating that the dynamic baseline specification is adequate. As expected, the coefficient is between 0 and 1. However, the coefficient estimates for the incumbent equation lie in the interval of [0.463; 0.790] which is substantially above the range of the corresponding estimates for the entrant equation [0.329; 0.543]. This indicates that there are adjustment costs underlying NGA deployment which are apparently much

[8] Stata 13.1 is used to estimate the regressions.
[9] This also applies when we reduce the number of instruments by using the “collapse" option of STATA´s “xtabond2" command (results are available upon request from the authors).
[10] Due to the variation in the entrants’ firm size we checked for potential outliers by excluding 1% of the largest observations. Estimation results remain robust and are available upon request from the authors.

more pronounced for the incumbent. A possible explanation for this is that investment data for the incumbent also contain investment in mobile network infrastructure, which involves comparatively high investment requirements and complex technical network planning as well as institutional rigidities due to limited spectrum licences. Another explanation would be that incumbents are simply larger and more diversified (active in all lines of businesses in the telecommunications sector), giving rise to smoother investment profiles than for entrants.

Second, the coefficient of the variable $sales\_as_{i,t}$ is significantly positive, whereas the coefficient estimate of the lagged sales variable, $sales\_as_{i,t-1}$, is significantly negative in all model specifications in Table 3 and Table 4. This represents strong supportive evidence for our dynamic flexible investment accelerator model as outlined in Section 3.3. Additionally, we can distinguish between the short- and long-run effects.[11] An increase in *sales_as* by 10%, increases the incumbents' *capex_as* by up to 4% in the short-run and by 18% in the long-run. An increase in *sales_as* by 10% increases the entrants' *capex_as* by up to 1% in the short-run and by 2% in the long-run. While the constant rate of replacement investment ($\delta$) is almost equal for both incumbents ($\delta$ ~ 0.12) and entrants ($\delta$ = 0.11) in the full GMM specifications, the low level of the coefficient estimate of the variables $sales\_as_{i,t}$ and $sales\_as_{i,t-1}$ for the entrants is attributed to their low capital to output ratio ($\alpha$ ~ 0.0063). The cash flow variable, $cflow\_as_{i,t}$, shows positive sign as expected, but it is only significant for the entrants' equation in both GMM and LSDVC regressions. This in turn indicates that entrants might face difficulties to borrow money externally on the financial markets due to their smaller size, ownership, and creditworthiness. The positive and significant coefficient estimate shows that imperfect capital markets lead entrants to increase their investment level when internal funds get higher. An increase in $cflow\_as_{i,t}$ by 10% increases the entrants' *capex_as* by up to 0.3% in the short-run and by 0.4% in the long-run.

Third, as regards facility-based competition in terms of the contemporaneous infrastructure stock, $fbc_{j,t}$, the corresponding variables of the incumbent and entrant

[11] Short-run coefficient $(\beta_1 + \beta_2)$ for $sales\_as$, analogous for the other coefficients and variables; long-run coefficient $\frac{\beta_1 + \beta_2}{1 - \beta_0}$ for $sales\_as$, analogous for the other coefficients and variables.

operators (*fbc_inc*$_{j,t}$ and *fbc_ent*$_{j,t}$) exhibit significant and positive coefficient estimates throughout all regressions. This indicates that firms' investment decisions are strategic complements and investment decisions reinforce each other as hypothesized in Section 3.2. However, this effect is much more pronounced with respect to the entrants. Hence, if regulatory policies – broadly understood encompassing any sector-specific regulations – exert a strong direct impact on investment of the incumbent operators, there is also a substantial indirect impact on the investment activities of entrants. In addition, an increase in *fbc_ent* by 10% would lead to an increase in incumbents' *capex_as* by up to 1.5% in the short-run and by 5.7% in the long-run. On the other hand, an increase in *fbc_inc* by 10% would lead to an increase in entrants' *capex_as* by up to 3.3 % in the short-run and by 5.9% in the long-run.

Finally, the effectiveness of service-based competition as measured by the variable *strictness*$_{j,t-1}$, which hinges on relevant wholesale broadband access regulations, appears to have no significant impact on the investment decisions of incumbents and entrants on average, i.e. during the overall period of analysis. Insignificant coefficient estimates might be the outcome of the opposing effects identified in Section 3.1, but, they also indicate that there is no supportive evidence for the policy goal of promoting investment via service-based competition and the LoI hypothesis. Furthermore, the impact of service-based competition might depend on the different phases of liberalization and regulation. Most notably, it can be assumed that service-based competition promoted investment in the early phase of liberalization when infrastructure-based competition has been hardly established. In turn, with increasing levels of infrastructure-based competition and an effectively implemented and broadly established set of wholesale access obligations, the investment promoting role of service-based competition might have decreased. In particular, entrants who enjoy favourable access conditions will not further climb the LoI or even self-deploy infrastructure.

Table 5 reports GMM regression estimates for incumbents (regressions (1)-(2)) and entrants (regressions (3)-(4)) where we additionally included the interaction term, *i_strictness*$_{j,t-1}$*_dummy03_07*, which captures the differential impact of service-based competition in the first phase of liberalization, i.e. for the years from 2003 to 2007.[12] The dummy variable takes on the value 1 for the years from 2003 to 2007, or else and the value 0. Indeed, we now find a neutral effect of service-based competition as regards entrants' investment in the early phase and a significantly negative impact for the late phase of liberalization, i.e. for the years from 2008 to 2012. In turn, the impact of service-based competition appears to be insignificant for the entire period of analysis for incumbents.

[12] In defining the interaction term we equally split our period of observation. Estimation results, however, are robust towards different specifications of liberalization phases (results are available from the authors upon request).

**Table 3: Regression results for incumbents' equation**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **Dependent variable:** *capex_as*$_{i,t}$ | **GMM SYS** | **GMM SYS** | **GMM SYS** | **LSDVC** |
| *capex_as*$_{i,t-1}$ | 0.771*** | 0.790*** | 0.712*** | 0.463*** |
| | (0.0003) | (0.0001) | (0.0008) | (0.0000) |
| *strictness*$_{j,t-1}$ | 0.189 | 0.0280 | 0.0230 | -0.00274 |
| | (0.3892) | (0.6443) | (0.7095) | (0.9505) |
| *fbc_inc*$_{j,t}$ | 0.130* | 0.0813** | 0.101** | 0.119* |
| | (0.0976) | (0.0494) | (0.0289) | (0.0525) |
| *sales_as*$_{i,t}$ | 0.221*** | 0.220*** | 0.233*** | 0.128*** |
| | (0.0076) | (0.0043) | (0.0038) | (0.0000) |
| *sales_as*$_{i,t-1}$ | -0.197*** | -0.172** | -0.170* | -0.0532** |
| | (0.0026) | (0.0224) | (0.0641) | (0.0309) |
| *cflow_as*$_{i,t}$ | -0.0144 | -0.121 | -0.128 | 0.0965* |
| | (0.9145) | (0.2565) | (0.1794) | (0.0763) |
| *gdp_pc*$_{j,t}$ | 2.89e-11 | -3.85e-11 | | 1.11e-11 |
| | (0.8645) | (0.8080) | | (0.9406) |
| *lt_ir*$_{j,t}$ | -0.00393 | -0.00240 | | -0.000283 |
| | (0.2288) | (0.4312) | | (0.8416) |
| *pop_dens*$_{j,t}$ | -0.00000180 | | | 0.000949 |
| | (0.9516) | | | (0.8416) |
| *comp_pc*$_{j,t}$ | -0.000000116 | | | -4.44e-08 |
| | (0.5303) | | | (0.9567) |
| *Constant* | -0.0445 | -0.000804 | -0.0198 | |
| | (0.4579) | (0.9886) | (0.7117) | |
| AR(1) test *p*-value | 0.010 | 0.009 | 0.014 | |
| AR(2) test *p*-value | 0.489 | 0.640 | 0.514 | |
| Hansen-Sargan-test *p*-value | 0.836 | 0.896 | 0.905 | |
| R-sq.: within | | | | 0.6608 |
| #Instruments | 21 | 21 | 21 | |
| #Observations | 170 | 170 | 170 | 170 |

Regressions (1)-(3) employ the two-step GMM system estimator. Regression (1) represents the full specification, while in regressions (2) and (3) we gradually reduce the number of control variables. In regression (4) we estimate the full specification using the LSDVC estimator. Since year dummies were jointly insignificant, we did not include them. Regressions (1)-(4) do include firm fixed effects which we do not report for the sake of brevity. *p*-values for the AR(1) and AR(2) tests and the Hansen-Sargan test of over identifying restrictions are reported. *p*-values for estimated coefficients are reported in parentheses and are robust to heteroscedasticity in GMM estimates. In regressions (1)-(3) the lagged dependent variable, *capex_as*$_{t-1}$, and the main explanatory variables, *fbc_ent*$_{j,t}$, *sales_as*$_{i,t}$, *cflow_as*$_{i,t}$ and *strictness*$_{j,t-1}$ are instrumented by maximum number of *t* - 4 lags. LSDVC standard errors are bootstrapped based on 100 iterations with bias correction for estimates up to order O(1/T). * $p<0.1$; ** $p<0.05$; *** $p<0.01$

**Table 4: Regression results for entrants' equation**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **Dependent variable:** *$capex\_as_{i,t}$* | **GMM SYS** | **GMM SYS** | **GMM SYS** | **LSDVC** |
| *$capex\_as_{i,t-1}$* | 0.329*** | 0.311*** | 0.537*** | 0.543*** |
| | (0.0005) | (0.0006) | (0.0000) | (0.0000) |
| *$strictness_{i,t-1}$* | -0.0490 | 0.0140 | -0.0698 | 0.0921 |
| | (0.6394) | (0.8591) | (0.903) | (0.479) |
| *$fbc\_inc_{i,t}$* | 0.270** | 0.287** | 0.387*** | 0.212** |
| | (0.0229) | (0.0238) | (0.0000) | (0.0382) |
| *$sales\_as_{i,t}$* | 0.00421** | 0.00398** | 0.00597*** | 0.00462*** |
| | (0.0201) | (0.00193) | (0.0000) | (0.0076) |
| *$sales\_as_{i,t-1}$* | -0.00369* | -0.00343* | -0.00599*** | -0.00461*** |
| | (0.0717) | (0.0768) | (0.001) | (0.0000) |
| *$cflow\_as_{i,t}$* | 0.0240* | 0.0258* | 0.0175** | 0.0336*** |
| | (0.0746) | (0.0500) | (0.0150) | (0.0004) |
| *$gdp\_pc_{i,t}$* | 7.84e-09 | 6.44e-09 | | -5.27e-08 |
| | (0.5650) | (0.5439) | | (0.5889) |
| *$lt\_ir_{i,t}$* | 0.00522 | 0.00257 | | -0.000702 |
| | (0.3691) | (0.6121) | | (0.9310) |
| *$pop\_dens_{i,t}$* | -0.000291 | | | -0.00136 |
| | (0.2878) | | | (0.6364) |
| *$comp\_pc_{i,t}$* | 0.00000124 | | | -0.00000233 |
| | (0.3008) | | | (0.3178) |
| *Constant* | -0.0239 | -0.0520 | -0.10295** | |
| | (0.7937) | (0.5141) | (0.0264) | |
| AR(1) test *p*-value | 0.462 | 0.486 | 0.029 | |
| AR(2) test *p*-value | 0.138 | 0.143 | 0.123 | |
| Hansen-Sargan test *p*-value | 0.946 | 0.930 | 0.958 | |
| R-sq.: within | | | | 0.5684 |
| #Instruments | 46 | 46 | 48 | |
| #Observations | 177 | 177 | 177 | 177 |

Regressions (1)-(3) employ the two-step GMM system estimator. Regression (1) represents the full specification, while in regressions (2) and (3) we gradually reduce the number of control variables. In regression (4) we estimate the full specification using the LSDVC estimator. Since year dummies were jointly insignificant, we did not include them. Regressions (1)-(4) do include firm fixed effects which we do not report for the sake of brevity. *p*-values for the AR(1) and AR(2) tests and the Hansen-Sargan test of over identifying restrictions are reported. *p*-values for estimated coefficients are reported in parentheses and are robust to heteroscedasticity in GMM estimates. In regressions (1)-(3) the lagged dependent variable, *$capex\_as_{t-1}$*, and the main explanatory variables *$fbc\_ent_{j,t}$*, *$sales\_as_{i,t}$*, *$cflow\_as_{i,t}$* and *$strictness_{i,t-1}$* are instrumented by a maximum number of *t*-4 lags. LSDVC standard errors are bootstrapped based on 100 iterations with bias correction for estimates up to order O(1/T).
* *p*<0.1; ** *p*<0.05; *** *p*<0.01.

**Table 5: Regression results for different phases of liberalization**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| **Dependent variable:** | **Incumbent** | | **Entrants** | |
| *capex_as*$_{i,t}$ | **GMM SYS** | **GMM SYS** | **GMM SYS** | **GMM SYS** |
| *capex_as*$_{i,t-1}$ | 0.7253179*** | 0.7389698*** | 0.3645235*** | 0.3724944*** |
| | 0.000 | 0.000 | 0.000 | 0.000 |
| *strictness*$_{j,t-1}$ | 0.0785026 | 0 .0727734 | -0.1919019** | -0.1344174*** |
| | 0.579 | 0.228 | 0.045 | 0.005 |
| *i_ strictness*$_{j,t-1}$*_dummy03_07* | 0.0025872 | -0.0157678 | 0.2046678** | 0.1562788* |
| | 0.939 | 0.626 | 0.013 | 0.072 |
| *fbc_ent*$_{j,t}$ | 0.1319121** | 0.1000161* | | |
| | 0.040 | 0.092 | | |
| *fbc_inc*$_{j,t}$ | | | .22495* | 0.2226577* |
| | | | 0.083 | 0.100 |
| *sales_as*$_{i,t}$ | 0.1811017*** | 0.1604974*** | 0.0063623** | 0.004727** |
| | 0.004 | 0.002 | 0.049 | 0.010 |
| *sales_as*$_{i,t-1}$ | -0.1347561*** | -0.1292153*** | -0.0067916** | -0.0055017*** |
| | 0.009 | 0.004 | 0.019 | 0.008 |
| *cflow_as*$_{i,t}$ | -0.0887085 | -0.0582102 | 0.0234413* | 0.0263242*** |
| | 0.523 | 0.533 | 0.052 | 0.008 |
| *gdp_pc*$_{j,t}$ | 1.45e-10 | | 6.32e-10 | |
| | 0.395 | | 0.879 | |
| *lt_ir*$_{j,t}$ | -0.0011165 | | 0.0092048 | |
| | 0.753 | | 0.315 | |
| *pop_dens*$_{j,t}$ | -9.38e-06 | | -0.000228 | |
| | 0.796 | | 0.592 | |
| *comp_pc*$_{j,t}$ | 3.77e-07 | | 1.38e-06 | |
| | 0.745 | | 0.321 | |
| *Constant* | -0.0402278 | -0.0171992 | 0.003761 | 0.0471036 |
| | 0.463 | 0.574 | 0.972 | 0.543 |
| AR(1) test *p*-value | 0.021 | 0.010 | 0.179 | 0.177 |
| AR(2) test *p*-value | 0.668 | 0.594 | 0.093 | 0.057 |
| AR(3) test *p*-value | | | 0.238 | 0.205 |
| Hansen-Sargan test *p*-value | 0.994 | 0.974 | 0.903 | 0.818 |
| #Instruments | 29 | 29 | 41 | 43 |
| #Observations | 170 | 170 | 177 | 177 |

Regressions (1)-(4) employ the two-step GMM system estimator. Regressions (1) and (3) represent the full specification, while in regressions (2) and (4) we reduce the number of control variables. Since year dummies were jointly insignificant, we did not include them. Regressions (1)-(4) do include firm fixed effects which we do not report for the sake of brevity. *p*-values for the AR(1), AR(2) and AR(3) tests and the Hansen-Sargan test of over identifying restrictions are reported. *p*-values for estimated coefficients are reported in parentheses and are robust to heteroscedasticity in GMM estimates. In regressions (1)-(4) the lagged dependent variable, $capex\_as_{i,t-1}$, and the main explanatory variables, $fbc\_ent_{j,t}$, $sales\_as_{i,t}$, $cflow\_as_{i,t}$ and $strictness_{j,t}$ are instrumented by maximum number of $t$ - 4 lags. In regressions (3) and (4) the lagged dependent variable, $capex\_as_{t-1}$, and the main explanatory variables, $fbc\_ent_{j,t}$, $sales\_as_{i,t}$, $cflow\_as_{i,t}$ and $strictness_{j,t-1}$ are instrumented by maximum number of $t$ - 5 lags, starting from $t$ - 3 due to a significant value of the AR(2) test, therefore we also report the AR(3) test p-value for regressions (3)-(4).

* $p$<0.1; ** $p$<0.05; *** $p$<0.01.

# 7. Conclusions

This paper intends to assess the impact of the two main modes of broadband competition on investment in broadband markets utilizing firm level data for European incumbent and entrant operators in the decade from 2003 to 2012.

We find that facility-based competition exerted a positive and substantial impact on investment for both types of operators and clearly outperforms service-based competition which had no significant impact for the average incumbent and entrant operator during the period of analysis. As regards the late phase of liberalization, service-based competition even exerted a significantly negative impact on entrants´ investment activities. Hence, data from a decade of broadband access regulation are at odds with one of the main guiding regulatory principles of the EU regulatory framework as envisaged in the LoI hypothesis. This casts doubt on future regulatory access policies which continue to foresee the LoI as a guiding principle also for regulating emerging fibre-based access networks (European Commission, 2010, recital 3). In turn, the role of facility-based competition appears to be even stronger as regards migration towards fibre-based infrastructure which will basically constitute more symmetric market structures with new and additional market players (Bourreau et al., 2010, p. 693). Therefore, and in line with the vast majority of the related previous literature, our findings suggest deregulatory approaches towards new access infrastructure with facility-based competition being one of the main drivers of investment in new communications access infrastructure. Regulatory policies should be directed from the asymmetric (legacy-based) regulatory paradigm to a more symmetric one focusing on an industry coordinating role and enabling cooperation models in the actual building and sharing of infrastructure (Gomez-Barroso & Feijoo, 2010; Briglauer & Gugler, 2013).

In view of the empirical evidence, NRAs claiming that mandatory broadband access regulations remain necessary in the future shall bear the burden of proving convincingly that asymmetric market interventionism can be expected to be welfare enhancing. Moreover, NRAs have to consider that investment related policy decisions will exert a direct and indirect impact since firms' investment decisions are strategic complements which reinforce the impact of an erroneous decision.

# Appendix

***The dynamic flexible accelerator model***

By lagging equation (5) we obtain:

$$I_{i,t-1} = K_{i,t-1} - (1-\delta)K_{i,t-2} \tag{A.11}$$

Solving for $K_{i,t-2}$ we obtain:

$$K_{i,t-2} = \frac{K_{i,t-1} - I_{i,t-1}}{1-\delta} \tag{A.12}$$

By lagging equation (6) we obtain:

$$K_{i,t-1} = (1-\lambda)K^{*}_{i,t-1} + \lambda K_{i,t-2} \tag{A.13}$$

Next we insert equation (1) in equation (7) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - (1-\delta)K_{i,t-1} + \lambda K_{i,t-1} \tag{A.14}$$

In the equation (A.14) we insert equation (A.13) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - (1-\delta)\left[(1-\lambda)K^{*}_{i,t-1} + \lambda K_{i,t-2}\right] + \lambda\left[(1-\lambda)K^{*}_{i,t-1} + \lambda K_{i,t-2}\right] \tag{A.15}$$

Next we reformulate equation (A.15) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - (1-\delta)(1-\lambda)K^{*}_{i,t-1} - \lambda(1-\delta)K_{i,t-2} + \lambda(1-\lambda)K^{*}_{i,t-1} + \lambda^2 K_{i,t-2} \tag{A.16}$$

Now we combine equation (1) and (A.16) and insert the resulting expression in equation (A.12) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - \alpha(1-\delta)(1-\lambda)Y_{i,t-1} - \lambda(1-\delta)\frac{K_{i,t-1} - I_{i,t-1}}{1-\delta} + \lambda(1-\lambda)K^{*}_{i,t-1} + \lambda^2 K_{i,t-2} \tag{A.17}$$

Next we reformulate equation (A.17) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - \alpha(1-\delta)(1-\lambda)Y_{i,t-1} + \lambda I_{i,t-1} - \lambda K_{i,t-1} + \lambda(1-\lambda)K^{*}_{i,t-1} + \lambda^2 K_{i,t-2} \tag{A.18}$$

Again we insert equation (A.13) in the equation (A.18) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - \alpha(1-\delta)(1-\lambda)Y_{i,t-1} + \lambda I_{i,t-1} - \lambda\left[(1-\lambda)K^{*}_{i,t-1} + \lambda K_{i,t-2}\right] + \lambda(1-\lambda)K^{*}_{i,t-1} + \lambda^{2}K_{i,t-2} \quad \text{(A.19)}$$

Next we reformulate equation (A.19) and obtain:

$$I_{i,t} = \alpha(1-\lambda)Y_{i,t} - \alpha(1-\delta)(1-\lambda)Y_{i,t-1} + \lambda I_{i,t-1} - \lambda(1-\lambda)K^{*}_{i,t-1} + \lambda^{2}K_{i,t-2} + \lambda(1-\lambda)K^{*}_{i,t-1} + \lambda^{2}K_{i,t-2} \quad \text{(A.20)}$$

Finally, we reformulate equation (A.20) and obtain our dynamic flexible accelerator investment model:

$$I_{i,t} = \lambda I_{i,t-1} + \alpha(1-\lambda)Y_{i,t} - \alpha(1-\delta)(1-\lambda)Y_{i,t-1} \quad \text{(A.21)}$$

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