UNIVERSITY OF PIRAEUS
SCHOOL OF ECONOMICS, BUSINESS AND INTERNATIONAL STUDIES
DEPARTMENT OF ECONOMICS

Essays on the Determinants of Fixed and Mobile Broadband Diffusion and the role of Access Regulation on Fixed Broadband Proliferation

Ph.D. Thesis

Athanasios Pachis

A DISSERTATION SUBMITTED
TO THE DEPARTMENT OF ECONOMICS OF UNIVERSITY OF PIRAEUS
IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Piraeus, 2018

UNIVERSITY OF PIRAEUS
SCHOOL OF ECONOMICS, BUSINESS AND INTERNATIONAL STUDIES
DEPARTMENT OF ECONOMICS

Δοκίμια στους Προσδιοριστικούς Παράγοντες της Σταθερής και Κινητής Ευρυζωνικής Διάχυσης και ο ρόλος των Ρυθμιστικών Πολιτικών Πρόσβασης στην Διάδοση της Σταθερής Ευρυζωνικότητας

Διδακτορική Διατριβή

ΑΘανάσιος Παχής

Η ΔΙΑΤΡΙΒΗ ΥΠΟΒΑΛΛΕΤΑΙ ΣΤΟ ΤΜΗΜΑ ΟΙΚΟΝΟΜΙΚΗΣ ΕΠΙΣΤΗΜΗΣ ΤΟΥ ΠΑΝΕΠΙΣΤΗΜΙΟΥ ΠΕΙΡΑΙΩΣ ΣΕ ΜΕΡΙΚΗ ΕΚΠΛΗΡΩΣΗ ΤΩΝ ΥΠΟΧΡΕΩΣΕΩΝ ΓΙΑ ΤΗΝ ΑΠΟΚΤΗΣΗ ΔΙΔΑΚΤΟΡΙΚΟΥ ΔΙΠΛΩΜΑΤΟΣ

Πειραιάς, 2018

UNIVERSITY OF PIRAEUS
SCHOOL OF ECONOMICS, BUSINESS AND INTERNATIONAL STUDIES
DEPARTMENT OF ECONOMICS

Essays on the Determinants of Fixed and Mobile Broadband Diffusion and the role of Access Regulation on Fixed Broadband Proliferation

Ph.D. Thesis

Athanasios Pachis

Supervisor: Professor Demetrius Yannelis

Piraeus, 2018

UNIVERSITY OF PIRAEUS
SCHOOL OF ECONOMICS, BUSINESS AND INTERNATIONAL STUDIES
DEPARTMENT OF ECONOMICS

Essays on the Determinants of Fixed and Mobile Broadband Diffusion and the role of Access Regulation on Fixed Broadband Proliferation

Ph.D. Thesis

Athanasios Pachis

Defense Committee

Professor Demetrius Yannelis
Professor Evangelos Sambracos
Professor Pantelis Pantelidis
Professor Michael Sfakianakis
Associate Professor Sotirios Karkalakos
Assistant Professor Dimitris Varoutas
Assistant Professor Michael Polemis

Piraeus, 2018

Acknowledgements

First and foremost, I want to thank my supervisor Professor Demetrius Yannelis. I wouldn't be able to complete this endeavor without his guidance and support that he gladly offered me all these years. His help both on academic as well as practical matters was invaluable to me. Above all I want to thank him for being there for me, offering me his support with generosity even at difficult times during the writing of the current Ph.d Thesis.

I would also like take this opportunity to thank my co-supervisor committee members Professor Evangelos Sambracos and Assistant Professor Michael Polemis. For the econometric analysis I am especially grateful to Assistant Professor Michael Polemis, who provided me with vital help during my research. He always responded to my inquires with genuine enthusiasm, insightful ideas and critical comments that embettered this dissertation. I would also like to wholeheartedly thank Marcos Tselekounis for offering his valuable time to review my work and make perceptive comments about my research.

Furthermore, I would also like to thanks my friends, whose encouragement was not only one of the reasons I started this endeavor but also kept me motivated during all stages of this venture.

Above all, I would like to thank my parents for their unconditional love and support they gave me in all stages of my life and endeavors. You are the primary reason if I have accomplished anything in my life.

Athanasios Pachis

Abstract

The development of Information Access Technologies (ICT) has resulted in our world entering a new digital age that has transformed the way we live. Broadband has a prominent role in this transformation as it increases productivity and economic growth, has altered the way we socially interact, has allowed for the introduction of new services, and has accelerated dissemination of information and knowledge.

This dissertation aims to identify the determinants of both fixed and mobile broadband. It attempts to identify both how certain regulatory policies has impacted the diffusion of fixed broadband as well as how, among other factors, various socioeconomic factors have influenced fixed and mobile broadband adoption.

Chapter 1 examines the impact of access regulation on fixed broadband and alternative access technologies diffusion for the 28 EU member states. Our main conclusion is that while access regulation of the local loop unbundling facilitates overall fixed broadband penetration at the same time hinders the diffusion of broadband lines that are accessed through alternative technologies. This contrasting effect is due to a facilitating effect of unbundling on broadband lines within the technology that is was historically applied, which is broadband lines accessed through DSL. In respect to low investment intensive access policies they have a negative impact on the adoption of both broadband and alternative access technologies diffusion. Finally, for access policies that require low investment, the effect on broadband penetration depends on the intensity of market competition.

Chapter 2 studies the relationship between various industry, socioeconomic and demographic factors and fixed broadband diffusion in a worldwide setting. Our main results demonstrate that the liberalization of the fixed telecoms market and the privatization of the main telecoms operator have positively influence fixed broadband diffusion. In addition, of e-services and internet content have incited the proliferation of fixed broadband, as well as lower cost of fixed broadband services.

Chapter 3 examines again, the factors that affect mobile broadband diffusion in a worldwide setting. Our main results demonstrate that the fixed and mobile broadband are complimentary and multiple mobile standards enhance mobile broadband diffusion. Finally, e-services and internet content drive mobile broadband diffusion.

Περίληψη

Η ανάπτυξη των Τεχνολογιών Πρόσβασης Πληροφορίας έχει ως αποτέλεσμα ο κόσμος μας να περιέλθει σε μια νέα εποχή που έχει ως αλλάξει τον τρόπο ζωή μας. Η ευρυζωνικότητα έχει ένα σημαίνοντα ρολό σε αυτή την μεταμόρφωση καθώς, αυξάνει την παραγωγικότητα και την ανάπτυξη της οικονομίας, έχει συντελέσει στην εισαγωγή νέων υπηρεσιών και έχει επιταχύνει την διάχυση της πληροφορίας και της γνώσεις.

Η παρούσα διατριβή στοχεύει να αναγνωρίσει τους καθοριστικούς παράγοντες που επηρεάζουν τόσο την σταθερή όσο και την κινητή ευρυζωνικότητα. Επίσης επιδιώκει να προσδιορίσει εκτός από πως συγκεκριμένες ρυθμιστικές πολίτικες έχουν επηρεάσει την διάχυση της σταθερής ευρυζωνικότητας, πως διάφοροι κοινωνικοοικονομική παράγοντες έχουν επηρεάσει την υιοθέτηση της σταθερής και κινητής ευρυζωνικότητας.

Το Κεφάλαιο 1, εξετάζει την επίδραση της ρυθμιστικής πρόσβασης στην διάχυση της σταθερής ευρυζωνικότητας καθώς και στην διάχυση εναλλακτικών τεχνολογιών πρόσβασης σε 28 μέλη της Ευρωπαϊκής Ένωσης. Το κύριο συμπέρασμα μας είναι ότι ενώ το η ρυθμιστική πολιτική πρόσβασης της αποδέσμευσης του τοπικού βρόγχου διευκολύνει την διείσδυση της συνολικής σταθερής ευρυζωνικότητας, την ιδιά στιγμή περιορίζει την διάχυση των ευρυζωνικών γραμμών που παρέχονται μέσω εναλλακτικών υποδομών. Αυτό το αντίθετο αποτέλεσμα οφείλετε στη θετική επίδραση της πολιτικής αποδέσμευσης του τοπικού βρόγχου στης ευρυζωνικές DSL γραμμές που, ιστορικά έχει εφαρμοστεί. Σε σχέση με τις ρυθμιστικές πολίτικες πρόσβασης που απαιτούν χαμηλά επίπεδα επενδύσεων, έχουν αρνητική επίδραση στην υιοθέτηση τόσο της συνολικής ευρυζωνικής διάχυσης όσο και στην διάχυση των τεχνολογιών εναλλακτικής πρόσβασης. Τέλος, καταλήγουμε ότι για τις ρυθμιστικές πολιτικές πρόσβασης που απαιτούν χαμηλές επενδύσεις η επίδραση στην συνολική διάχυση εξαρτάται από το βαθμό ανταγωνισμού στην αγορά σταθερών τηλεπικοινωνιών.

Το Κεφάλαιο 2 ερευνά την σχέση μεταξύ διάφορων κλαδικών, κοινωνικοοικονομικών, και δημογραφικών παραγόντων και της διάχυσης της σταθερής ευρυζωνικότητας παγκοσμίως. Τα κύρια αποτελέσματα μας δείχνουν ότι η απελευθέρωση της αγοράς των σταθερών τηλεπικοινωνιών και η ιδιωτικοποίηση της κύριας τηλεπικοινωνιακής εταιρείας σταθερής τηλεφωνίας έχουν θετικά επιδράσει στην διάχυση της σταθερής ευρυζωνικής διάχυσης. Επιπλέον, το επίπεδο των ηλεκτρονικών υπηρεσιών και το διαδικτυακό περιεχόμενο υποκινούν την διάδοση της σταθερής ευρυζωνικότητας, όπως και το χαμηλό κόστος αυτής.

Το Κεφάλαιο 3 εξετάζει επίσης τους παράγοντες που επηρεάζουν την διάχυση της κινητής ευρυζωνικότητας. Τα κύρια αποτελέσματα μας δείχνουν ότι η σταθερή και κινητή ευρυζωνικότητα είναι συμπληρωματικές και τα πολλαπλά τεχνικά πρότυπα ενισχύουν την κινητή ευρυζωνικότητα. Τελικά η ηλεκτρονικές υπηρεσίες και το διαδικτυακό περιεχόμενο επιδρούν θετικά στην κινητή ευρυζωνικότητα.

Table of contents

List of Tables

Appendix C

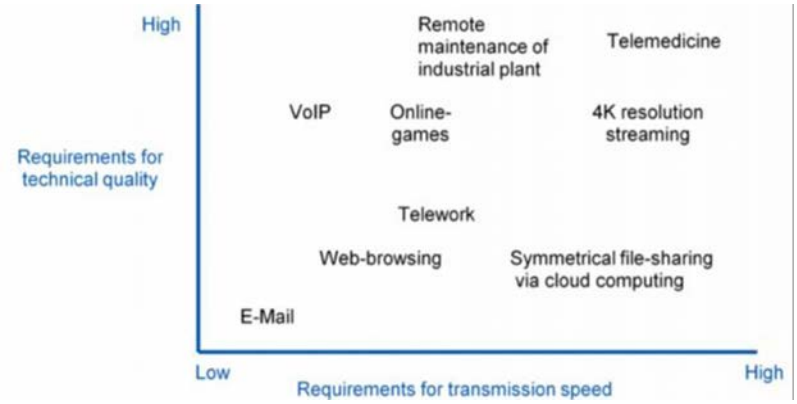
List of Graphs

List of Figures

Introduction

In the former years of the development of the internet the dominant technology was narrowband, as telecommunication networks technology was only capable of sustaining limited bandwidth, utilizing mostly the pre-existing telephone network of the incumbent fixed telecommunication operator. In later years, with the advancement of technology, broadband speeds of over 144 Kbits[1] per second (download speed) were made capable, allowing for a wider range of more bandwidth intensive internet applications (such as video on demand, cloud computing, e-commerce, e-health services, e-banking, among others) to flourish. For instance, Figure 1.1, portrays the scale of the intensity of internet applications according to technical quality and transmission speed requirements. The proliferation of digital technologies has radically transformed organizations, as well as individual's lifestyles. Digital

Figure 1.1- Requirements of online applications in respect to quality and speed of network.



Source: European Parliamentary Research service (2015).

technologies, like the internet and the mobile phone, have been crucial in revolutionizing the dissemination of knowledge and information (ITU, 2006). In order to participate in this revolution, countries around the world have nominated broadband as a crucial infrastructure to achieve their social, economic and scientific goals (ITU, 2003). Broadband encourages innovation, stimulates growth in an economy, and attracts foreign investment (ITU, 2003). Moreover, other than strictly economic goals, Information and Communication Technologies (ICT) facilitate the achievement of other societal goals, such as promoting higher education, enhance healthcare services and promote better career opportunities (Zhang, 2017). In addition, it has facilitated the arrival of a digital economy that affects various aspects of the world economy such as banking, retail, energy, transportation, education, publishing, media or health (OECD, 2015). Especially accessibility to broadband networks is widely

[1] There are many definitions of broadband according to its' bandwidth, used by different organizations. The definition supplied here is of the European Commission (European Parliamentary Research service, 2015).

considered to be an important driver for the development of both social and economic development (Kleinn et al., 2014). The association between broadband penetration and economic growth has been confirmed by several empirical studies. For instance, Roller and Waverman (2001) found a significant positive relationship between broadband and economic development, where an increase of 10% in broadband penetration results in an increase of 2.8% increase in GDP on average. Similarly, Koutroumbis (2009), using data from 15 European countries for a period of 2002 to 2007, finds that the growth of broadband infrastructure had an average impact of 0.63% on GDP, an almost 17% of the total overall increase in GDP in that period. In addition, Greenstein and McDevitt (2009) in their study of the US market concluded that the deployment of new broadband infrastructure adds approximately 8.3 to 10.6 billion dollars to the economy.

The above discussion serves to highlight the importance of broadband infrastructure in the development of the economy and its' spillover effects in employment, productivity, technological advancement, etc. It is therefore no surprise that broadband penetration is seen as a crucial component of communications infrastructure policy and a key economic indicator (Cambini and Jiang, 2009). Therefore, it is evident because of the importance of broadband it is essential to identify the factors that incite or hinder its' proliferation.

The remaining of this dissertation is organized as follows. Chapter 1 focuses on the impact of access regulation policies have on fixed broadband diffusion. Chapter 2 examines the determinants of fixed broadband diffusion worldwide and identifies differences between developed and developing countries. Finally, Chapter 3 studies the factors that influence mobile broadband diffusion and the differences between developed and developing countries.

Chapter 1

The impact of Access Regulation on Fixed Broadband and Alternative Infrastructure diffusion

1.1 Introduction.

For countries to achieve optimal broadband penetration, significant investments in current and additional broadband infrastructure are required. That is because telecommunications is an industry where the network is an essential input for the supply of services (Cambini and Jiang, 2009). This holds especially true today with the emergence of Next Generation Access[2] (NGA) networks, where they generally require significant technology investment, upgrade of current networks, enlargement of capacity, or the deployment of completely new infrastructure. Normally the issue of the optimal investment in networks would be a matter of private markets to solve. However, the fixed telecommunication industry, which is characterized by huge sunk costs and marginal costs which are roughly minimal and constant, is a natural monopoly. That is that telecommunications exhibit very high economies of scope and scale relative to the size of the market that in many cases prevent an economically viable duplication of the network. This creates very high barriers to entry which in many cases prevent potential competitive operators to enter the market. Therefore, in an effort for consumer welfare to be maximized and competitive entry to occur, typically the telecommunication market has been regulated. According to Cave and Doyle (1994), there are three aims that regulators must simultaneously attain for the telecommunications industry to flourish. First .it should promote competition through an efficient structure of access prices that puts downward pressure on prices and increases consumer surplus, thus increasing static efficiency. Second it should foster dynamic efficiency through efficient entry and encouragement of entrants to invest in parts of the network that do not exhibit large economies of scale. Finally, it should allow for the incumbent to earn an optimal return on investment in order to meet any social obligations.

In the beginning of the liberalization of the telecommunications market, where many public monopoly telecoms where privatized and the prospect of competition was not imminent, an appropriate regulatory framework was required in order to provide the necessary incentives to incite the incumbent to make the necessary investments that reduce its production cost. Traditional Rate-of Return (RoR)

[2] Next Generation Access Networks are defined by the European Commission as any technology that can offer download speed of greater than 30 Mbits/sec (European Parliament Research Service, 2015).

contracts were found to result in overinvestment by the monopoly operator. Therefore, the theory of price caps and of regulatory clearance for a fixed time period was developed. Several studies indicated that price cap regulation provided superior incentives to the incumbent operator to increase production efficiency and invest efficiently (Cabral and Riordan,1989; Biglaiser and Riordan, 2000, among others). However, price cap regulation was considered only an initial step and inferior to the introduction of competition in the telecoms market.

1.1.1 Serviced based and facility-based competition.

There are generally two ways for competitive entry to occur. First is through serviced- based competition. In serviced-based competition the competitive operator provides services to the retail market by using the already established network of the incumbent operator. The incumbent is typically mandated to allow access to its network by a regulatory agency and is compensated from the entrant by an access price that is determined again by the regulator. Second through facility-based competition, in which entrants invest in their own infrastructure in order to service the retail market. Facility-based competition is preferred because it is argued, that encourages innovation and since it entails the existence of rival networks it forfeits the need for regulation (Dkhil, 2014b). However, the issue that arises with facility-based regulation is again the high sunk costs required that impede entry. The impediment of high sunk costs of entry has created a dilemma for regulators in which competition "mode" (serviced-based versus facility-based) to promote. This dilemma is exacerbated by the relative trade off that may exist between static and dynamic efficiency. Laffont and Tirole (2000) argue that there is a trade-off between promoting service-based competition in order to attempt to maximize social welfare once investment in infrastructure has taken place and providing the incumbent with the necessary incentives to invest in upgrading this infrastructure. More specifically Laffont and Tirole (2000) state, that an inverse relationship exists between providing access to facilitate competitive entry and providing the necessary incentives for the telecommunications companies to develop their own networks. Access price regulation increases static efficiency by facilitating entry and thus reducing the incumbents' market power, resulting in lower prices and more surplus for the consumers. Competition also disciplines operators for inefficient use of inputs and thus provides incentives for lower production costs. In the short-run, it may also provide the incumbent operator with incentives to increase its' investment in order to either to reduce productions costs or to product differentiate its' services in order to compete in the market more effectively. However, in the long run, it may also provide disincentives for investments in existing or developing networks by reducing ex-post rents for the incumbent operator, thus lowering dynamic efficiency. That is, the incumbent decision to invest would

be affected by the access regulation of current or future infrastructure because it is expected to reduce any future profits realized by the investment. Similarly, in the long run, access regulation may provide disincentives for entrants to invest in their own infrastructure. The profits that entrants earn from competing through serviced-based competition may exceed any future profits from investing in their own infrastructure. Especially in the presence of high sunk costs and the risk of future regulation of their own infrastructure. That is, there is an opportunity cost that entrants must consider when investing in their own facility-based network, and that opportunity cost is greater the lower the access price is set. Some studies have suggested that a more complex relationship exists and is characterized by an inverted U relationship (for instance, Friederiszick et al., 2008). According to Friederiszick et al. (2008), the theoretical justification for the observance of such a relationship is the interaction between two opposite effects. Initially, the introduction of competition will incentivize the incumbent operator to differentiate its' services so to retain some of its' market power and therefore its' profits, resulting in increasing investment. However, intensification of competition, at some point increases the difficulty of service differentiation to a degree that post-investment profits are insufficient for the incumbent to recoup its investment. Thus, competition disincentivizes the pre-investment decision of the firm. The exact shape of the figure that characterizes the relationship would be expected to be determined by specific market conditions in each telecoms market, such as the intensity of competition, the demand for new products and services, as well as the cost of innovation (Friederiszick et al., 2008).

1.1.2 History of Regulation in the US and the EU.

The dilemma of regulators of how to facilitate competition in the telecom's markets, serviced-based vs facility-based, can been seen in the different regulatory approaches that regulators have taken. Initially in the US market, with the passing of the 1996 Telecommunications Act, the Federal Communication Commission (FCC) regulator required incumbent operators to unbundle their networks through local loop unbundling[3] (LLU) and allow access to competitive operators through regulated access prices. However, after much deliberation, the local loop unbundling (LLU) regime was eventually seen as inappropriate for offering the appropriate incentives for the incumbents to upgrade their network and for competitive operators to build their own, and was eventually abolished by the FCC in 2005 (Cambini and Jiang, 2009). The fact that there was strong platform competition in the US market between cable television and traditional telephone networks may have contributed to the decision of the FCC to

[3] Local loop unbundling (LLU) is the regulatory process of allowing multiple telecommunications operators to use connections from the telephone exchange of the incumbent to the customer's premises. The physical wire connection between the local exchange and the customer is known as a "local loop" (Singh, 2018).

deregulate the US market. In the EU, regulatory policy is directed by the European Commission. In 2002 with the approval of the "New Regulatory Framework", the European Commission set the overall regulatory framework, upon which the national regulatory authorities could act in order to spur competition in the telecoms market. At the heart of this Regulatory Framework, according to Huigen and Cave (2008), "lies the principle that markets should be regulated only in so far there is a risk that operators may have significant market power (SMP) which may result in dominant positions or (SMP) over customers and competitors". With platform competition to be relatively weak comparing to the US market, with approximately 30% of households passed by internet capable cable networks in Europe[4] (Huigen and Cave, 2008), almost all incumbent operators were found to have significant market power, at least in some telecoms sub- markets. Therefore, national regulatory authorities subsequently imposed local loop unbundling to allow access to competitive carriers to the incumbents' network[5].

1.1.3 The Theory of the "ladder of investment".

The European Commission approach to regulation of the telecoms market lies on the assumption that the introduction of serviced-based competition is a pre-requirement for the later introduction of facility-based competition. The justification of this approach is primarily based in the theory of the "ladder of investment", first proposed by Martin Cave in a report in 2001 to the European Commission (Bourreau et al., 2010). The basic premise of the ladder of investment (LoI), or stepping stone theory, is to offer entrants increasingly "higher-tier" levels of access to the incumbents' network. The "higher" levels of access are characterized by increasing levels of investment that the entrants must partake in each level. Initially the competitive operators are encouraged to enter the market at a level of access that requires little investment (often at just resale level). The rational of the theory is that the entrants in order to step into the next level of access require the acquisition of "market experience" from the previous step. The "market experience" is related to factors such as, for example, increased market shares, marketing experience, technical know-how etc. A crucial component of the LoI strategy is that the regulator encourages the entrants to invest to the next level of access, while at the same time they are discouraged to remain in the current level for a prolonged time period. The regulator achieves that by progressively worsening the access conditions that entrants "enjoy" in the current level of access. According to Cave (2006) the regulator has mainly two regulatory tools in order to deteriorate the

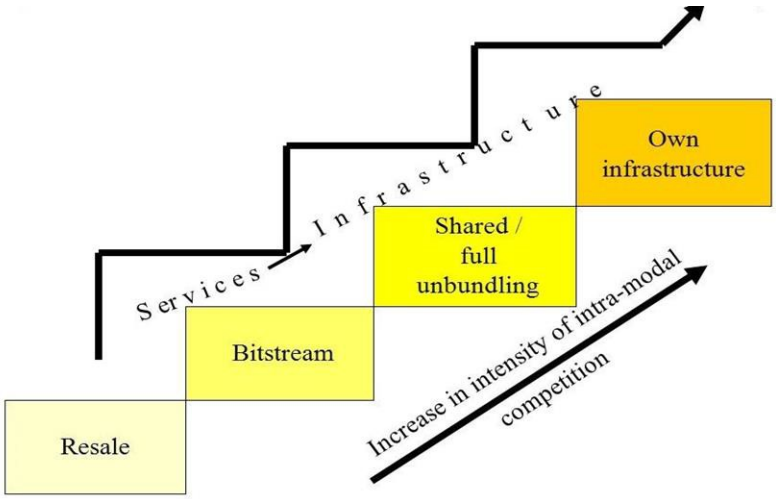
[4] The situation in Europe regarding the availability of cable networks varies considerably, where in some member states, like Greece or Italy, to be not available at all.

[5] The timeframe of the imposition of the mandatory local loop unbundling in the various member states varies. In general, local loop unbundling was applied earlier in the "old" 15 EU countries than in the new accession states that entered the EU in 2004 and subsequently.

access conditions. First by implementing a dynamic access price regime, where the access price, at each stage, progressively rises and second, by taking a more drastic approach, by making a credible regulatory commitment to cease mandatory access to the incumbent network in a certain date[6]. Proponents of the LoI theory view this approach as a realistic way for competitive carriers to progressively invest in their own infrastructure, with the ultimate purpose, being to build their own network. Figure 1.2, presents the ladder of investment or "stepping stone" theory. Each stage signifies for the entrant a step towards building its' own infrastructure and requires increasing investment levels.

However, since its' introduction., the LoI theory has not been received without its fair share of criticism. Oldale and Padilla (2004) question the efficacy of the LoI approach on the grounds that effective intervention, on each stage of the ladder, requires complete information for market conditions, where information asymmetries exist between the regulator and the regulated operators, in an industry that is technology driven and rapidly changing. Thus, puts an excessive burden on the regulator, in terms of resources, to effectively provide the necessary incentives, in a timely manner, for operators to climb the

Figure 1.2- Illustration of the theory of the ladder of investment.



Source: Groebel A. (2005)

ladder of investment. Furthermore, they doubt the ability of the regulator to make prior credible commitments when the presence of an entrant in the market depends on favorable regulatory conditions. Moreover, while there is some support from theoretical studies for the ability of increasing access prices, as a regulatory tool, to positively influence the decision of the entrant to invest in facility-based networks (Avenali et al., 2010, for example, in a setting of dynamic access pricing but without a

[6] The suspension of access in a certain date by the regulator, is often referred as the "sunset clause" in the literature.

sunset clause), others for instance, show that commitments by the regulator to suspend access regulation, may be counterproductive and dilute the investment incentives of the entrants. In conclusion the issue of the applicability and ability of the LoI approach to incite facility-based competition is still debated in the relevant literature.

In general, the introduction of competition that resulted in the retail market from the requirement of the incumbent to provide access to competitors in its network, resulted as consequence, that the relevant literature focused in the effect that access regulation had on total investments in telecommunication networks.

The remaining of the chapter is organized as follows. Section 1.2 presents the theoretical and empirical literature on the effect of access regulation on broadband adoption and investment. Although by no means exhaustive, the studies discussed are representative of the issue and the debate. Section 1.3 discusses the data and the methodology employed in the analysis, section 1.4 presents the results and finally section 1.5 provides a discussion and conclusions.

1.2 Literature Review.

In order to examine the relationship between access regulation and investment, a growing number of studies have been carried out, using theoretical models as well as empirical research, often with conflicting conclusions. This is due mainly, as discussed above, to the complex nature of the relationship which is characterized by two contrasting forces. Chang et al. (2003) for example, states that access price regulation reduces investment incentives for the incumbent as the introduction of competition prevents it for maximizing its' surplus. However, on the other hand, may spur investment as access price regulation (through lower access prices and the introduction of competition) leads to lower retail prices for consumers, increases demand for telecommunication services, and thus may lead to increased levels of investment for both the incumbent and entrants.

1.2.1 Theoretical Literature.

In the examination of this relationship, the theoretical literature has employed various modelling frameworks trying to capture the dynamics of the regulated telecoms market, employing different assumptions about market conditions (such as product differentiation or the degree of regulatory commitment).

1.2.1.1 The relationship between access regulation and the incumbents' investment.

Foros, (2004) examines a case of competition between two firms, a vertically integrated incumbent

operator and a rival which requires access to the incumbents' network in order to serve the retail market. Furthermore, he assumes that the firm invests to upgrade its' network before an access price is set, when the access price is regulated without regulatory commitment[7]. In this setting the regulator would set the access price equal or close to the marginal cost. If the services of the incumbent and rival are not sufficiently differentiated, the incumbent would not be able to recoup its' investment costs and therefore its' investment incentives would be reduced, compared to the unregulated case. In contrast, if the incumbent ability to offer a highly differentiated service through greater value-added, is much higher than that of its rival he increases its' investment levels to limit the quantity supplied by the rival and potentially overinvest to drive the rival out of the market.

Sarmento and Brandao (2007) similarly, investigate market outcomes and investment decisions when an incumbent operator and a competitive firm compete in the market without differentiated services. They consider, among others, the cases where there is regulated access price without commitment, and where access price is unregulated, in a setting where the incumbent competes in the retail market (vertical integration) or is vertically separated. They conclude that in the case of vertical integration and access regulation the investment incentives of the incumbent firm are reduced. Contrary, in the case of vertical separation the most probable outcome is that the investment of the incumbent is greater with regulation. Moreover, in the absence of regulation and when the incumbent competes in the retail market the exclusion of the competitive firm from the market is not a necessary outcome. Vareda, (2007) develops a model with an incumbent operator and an entrant with differentiated services and where the incumbent can invest in upgrades of the network and (or) in cost reduction. In a context that the regulator can commit ex ante, the incentives of the incumbent to invest in production costs are increased, however the investment incentives for quality upgrades are decreased. The overall effect is ambiguous. In the case of ex-post regulation, the incumbent does not invest as does not gain any benefits from the investment due to access regulation.

Brito et al. (2010) instead, examine both situations, where the regulator can make credible commitments before the investment occurs or when he cannot. They study a duopoly with a vertically integrated incumbent and a competitive entrant, with differentiated services and a two way[8] access

[7] Ex ante regulation refers to when the regulator can make a credible regulatory commitment that would not change the regulatory framework after the investment occurs. Ex post regulation refers when the regulator cannot make credible commitment that would not intervene after the investment. The distinction between ex ante and ex post regulation is important because it affects the incentives of the operator to invest.

[8] A two-way access price refers when the regulator sets an access price with an additional fixed fee irrespective of the cost curve of the incumbent.

price. They find in the case of non-commitment that only when the investment cost is low, optimal investment occurs. In contrast, in the case of high investment costs, investment is not optimal and for it to occur the regulator must set a high access price that may be not politically feasible. Finally, when the regulator can commit ex-ante a socially optimal level of investment may emerge.

Following from the discussion of the studies examined above, we can draw the following conclusions. First, there is generally a consensus, that in the case where the regulator cannot credible commit, access regulation reduces the vertically integrated incumbent incentives to invest as it cannot fully realize the benefits from its' investment (apart from Brito et al, 2010, in specific market conditions). Instead, when the regulator can commit ex-ante the effect on the investment of the incumbent is either ambiguous (Vareda J., 2007) or may be optimal in some circumstances (Brito et al., 2010). Furthermore, for entry to occur access regulation is required, as otherwise the incumbent forecloses the market (with Sarmento and Brandao, 2007, as an exception in some cases).

1.2.1.2 The relationship between access regulation and the entrants' investment.

Except of the examination on incumbent investment incentives, authors also concentrated their efforts in investigating the effect on competitive operators' incentives to invest in their own networks. The main motivation stemmed from testing the ladder of investment hypothesis that serviced based competition is in an essential step for facility-based competition (Dkhil, 2014b).

In this regard, Bourreau and Dogan (2005) study how the presence of the option to access the incumbents' network via local loop unbundling affects the competitive carriers' incentives to invest in alternative infrastructures Examining an unregulated setting and assuming that initially the investment cost for the entrant to build alternative infrastructure is too high, but decreasing over time, they show that the initially the incumbent would set an access price too high in order to prevent the competitor from entering the market. However, when the "threat" of the entrant to build its' alternative network is credible, the incumbent would lower its' access price to increase the opportunity costs of the entrant. The authors conclude that unbundling of the local loop may delay facility-based competition in an unregulated environment and that in a regulated setting, neither sunset clauses or an increasing access price may be sufficient for facility-based entry.

Avenali et al. (2010) consider a model where investment costs do not decrease over time. Assuming, that service-based competition is a prerequisite for the entrant to build its' network, they show that a rising access price can foster efficient investment by the entrant to build its' own facilities. However, the entrant cannot "climb" the ladder of investment when access regulation is suspended too early due to

the enforcement of a sunset clause.

Bourreau and Drouard (2010) again, investigate how serviced based competition affects the entrant's incentives to build an alternative infrastructure. In order to test the theory of the ladder of investment they construct a model framework where the entrant progressively acquires market experience and market shares, in the phase of service-based competition. They conclude that if investment in entrants' facilities in the short term is viable, then serviced based competition would delay the entrants' investment in its' network, because the entrant has incentives to extend the initial phase in order to gain more market experience. However, when investment is feasible only in the long run, then the ability of the entrant to have access to incumbents' network accelerates facilities-based investment. Vareda J. (2011) is one study that simultaneously examines the incentives of both incumbent and entrant in the presence of access regulation. He considers a case where the entrant can enter the market either by the regulated provision of access by the incumbent or by building its' own facilities. He finds that the entrants' investment decision is delayed when the incumbent invests in the upgrade of its' own network but the "threat" of the entrant to invest has a positive effect on the investment incentives of the incumbent. Therefore, the overall effect of access regulation on both incumbents' and entrants' incentives is not clear.

There is no firm conclusion to be drawn regarding the entrants' incentives. Bourreau and Dogan (2005) argue that access regulation with an increasing access price may be not sufficient for the entrant to invest in its' own infrastructure, while Avenali et al. (2010) think that it can foster efficient investment. Bourreau and Drouard (2010) report contrasting results depending on if investment is viable in the short-run or if it is viable in the long run, while Vareda J. (2011) states that the entrants' investment is delayed. Finally concerning, when the regulator suspends regulation due to a sunset clause, most studies seem to agree to not be sufficient to drive the entrant to facility-based entry, (Bourreau and Dogan, 2005; Avenali et al., 2010).

In summary**,** most of the studies in the relevant literature seem to agree that access regulation has a negative impact on the incumbent incentives while there is no consensus on the entrants.

1.2.2 Empirical Literature.

In part, due to the ambiguity of the theoretical research many researchers focused on empirical based studies in order to clarify the nature of this relationship. The empirical literature is diverse in terms of the methodologies applied, models constructed, and the data samples considered in order to investigate the relationship between access regulation and investment. Due to the scarcity of desegregated data

on investment, authors have employed various measures of telecommunications performance in order to investigate the relationship between access regulation and investment, such as tangible fixed assets or broadband penetration or some measure of facility-based infrastructure penetration. The reason for investigating the effect of access regulation on various measures of broadband penetration is that if access policies increase (decrease) broadband penetrations then an increase (decrease) in investment levels is to be expected (Waverman et al., 2007).

The literature can be classified, in broad terms, according to two main access regulation measures that are utilized in order to investigate this relationship. The first is the access price that is imposed on the market externally by the regulator and second is the penetration of access policies that are affected, among other factors, by the access price.

1.2.2.1 The relationship between access price and investment.

Chang et al. (2003) employing a panel data set from 41 operators in the US market from 1994 to 1998, investigate the relationship between investment and access price regulation by looking at the impact of the access price on the fibre-optic lines share and digital lines share of each operator. They discover that the access price is negatively correlated to the penetration of these technologies, and conclude that a more "stringent" (lower) access price policy overall enhances demand for services and the revenue of operators, and thus increases investment.

Ford and Spiwak (2004) using data from the USA telecommunications market for the period from 2002 to 2003, show that the access price of the unbundled local loop has a negative relationship to both the availability of broadband services in general, and to the availability of competitors' broadband services specifically. Therefore, they conclude that the setting of lower access prices can facilitate the proliferation of broadband deployment.

Similarly, Wilig R. (2006) using again data from the US market, for the incumbent operators, estimate that a 1% reduction in the price of unbundled network elements (UNE) has consequently an approximate 2.1%-2.8% increase in the incumbent operator level of investment. Therefore, the author concludes that increasing the price of the (UNE) would not only result on hindering competitive alternatives to consumers but also reduce incumbent operators' investment on their own network.

In contrast to the previous studies, Distaso et al. (2006), uses panel data with a larger time series of quarterly data from a period of 2000 to 2004, from 14 European countries. They show that the price of the local loop has a negative relationship to broadband penetration and thus lower access prices have a positive effect on broadband adoption. However, they find that facility-based competition is the most

important driver of broadband diffusion, while serviced-based competition does not play a significant role.

Similar results are found by Waverman et al. (2007), when employing in their analysis, data from 12 European countries from 2002 to 2006. The authors suggest that lower prices of the unbundled local loop, has as an effect a significant reduction in facilities-based lines, measured by the subscribers' share of alternative infrastructure (shares of technologies other than DSL). Moreover, they also find that the price of the local loop is negatively correlated to the broadband diffusion and thus lower access prices promote overall broadband proliferation (both facility-based and service-based).

Crandall et al. (2004) employing data from 50 US states for years 2001 and 2002, they attempt to assess the impact of unbundling policies to the competitive operators' facility-based investment. In their conclusion, they state, that competitive operators' lines that are facilities-based is lower in states where UNE prices are lower, which implies that unbundling decreases facilities-based competition in the short term. Therefore, they argue that the notion that lower unbundling prices spur facility-based investment is undermined by the evidence.

From the above studies examined, we can infer two main conclusions. Firstly, that the relative literature is dichotomized concerning the overall impact of access price regulation in investment. Secondly that the time periods that these studies examine are considerably short, with few years in the sample. However, according to Cambini and Jiang, (2009), "new technology diffusion is a dynamic process that evolves over time". Access price regulation may have a delayed effect on the investment decisions of firms. Therefore, a larger time series would provide more robust results concerning the relationship between access price regulation and investment in the long run.

1.2.2.2 The relationship between access policies and investment.

Garcia-Murillo (2005) examines the impact of unbundling on broadband deployment. The author constructs a cross-sectional data sample of 100 international countries for the year 2001 and finds that unbundling (measured by a dummy variable when mandatory unbundling is present or not) of the incumbents' network can substantially increase broadband penetration for medium income countries, but not for high income ones.

Grosso (2006) reaches similar conclusions, using a panel data set from 30 OECD countries from a period of 2001 to 2004. The author shows, after controlling for other variables, that there is significantly higher broadband penetration in countries that unbundling is available. He concludes that unbundling policy reduces entry costs and therefore enhances competition and reduces prices of retail services, which in turn drives demand for broadband. Finally, he finds that increased inter-platform competition has a

positive influence on broadband diffusion.

Gruber and Koutroumpis (2012) examine the effect of unbundling policy (measured by the number of unbundling lines), among other factors, by incorporating in their study a panel data set of 167 international countries for a period of 2000 to 2010. They show that the introduction of competition through unbundling increases the speed of diffusion of broadband adoption. They also conclude that intra platform competition between operators has a positive impact on broadband diffusion but inter-platform competition across different technologies does not a significant effect.

A recent paper from Ovington et al. (2017) again supports, in general, the conclusions of the previous studies. The authors used a panel data set of 27 EU countries for the period of 2004 to 2011 in a semi-annual basis. By applying a variety of estimators, they show that unbundling (measured by the share of unbundling local loop lines to the total broadband lines) has a positive impact on broadband penetration, although this effect becomes smaller for higher shares of unbundled lines and in areas that have high shares of alternative broadband lines (share of entrants non-DSL lines).

Instead a study that reaches different conclusions is that of Bouchaert et al. (2010). Their study focuses on the effect that different modes of competition have on broadband penetration for 20 OECD countries for a period from December 2003 to March 2008. The modes of competition that they consider are i) inter-platform competition, ii) facilities-based intra-platform and iii) serviced-based intra platform. They conclude that inter-platform competition is the main driver of broadband adoption, however serviced-based intra-platform competition is an impediment to broadband penetration.

Similarly, Crandall et al. (2013) investigate the relationship of unbundling to broadband adoption. Their study consists of panel sample of 28 OECD countries from 2001 to 2010. They show that the long- run effect of unbundling (constructed as a dummy variable with a value of 1 when unbundling is mandated) on household broadband penetration is negative. In other words, unbundling has hindered the proliferation of broadband.

Bacache et al. (2013) explore the impact of access policies on broadband investment, specifically, by entrants. The authors construct a panel data set of 15 EU countries that are semi-annual, for a period from July 2002 to July 2010. They find that service-based competition (measured by the number of local loop unbundling and bitstream lines of competitive operators) has no significant effect on the share of broadband lines owned by entrants, and thus these access policies do not promote entrants' investments.

Nardatto et al. (2014) research produced mixed results. They focused on the effect of unbundling policies on two telecoms performance indicators, namely broadband penetration and broadband speed

in the UK market. The authors use data from about five thousand different operators (incumbent and entrants) for a period from December 2005 to December 2009. They found that unbundling (measured by a dummy variable that takes the value 1 when introduced in the UK, and the number of unbundled lines) had no effect on broadband penetration but incited greater broadband speeds, implying that promoted existing network upgrades. Also, they showed that competition between networks had a strong positive effect on both broadband penetration and speed.

Finally, Cincera et al. (2012) also investigates the impact of access policies on broadband diffusion. The main variables of interest are defined as serviced based competition (which is defined as Reselling plus Bitstream access lines) and facility-based competition (defined as Shared lines plus Full LLU lines). They conclude, by utilizing data from 18 EU countries for a period of 2003 to 2010, that serviced based access intra-platform competition has not yet any accelerating effect on broadband diffusion. In contrast, facilities-based fuels broadband adoption.

Again, in the empirical literature that examines the effect of access policies on broadband penetration produced mixed results. The studies that argue for a positive association include Garcia Murillo (2005), Grosso (2006), Gruber and Koutroumpis (2012), Ovington et al. (2017), while those that find a negative association include Crandall et al. (2013). Bouchaert et al. (2010). Nardatto et al. (2014), Bacache et al. (2013) and Cincera et al. (2012) did not find a significant association.

Except on the impact of access policies on broadband penetration, there are studies that investigate the impact of access policies on alternative measures of telecommunication performance. For instance, Friederiszick et al. (2008) examine the effect of access policies (measured, among other factors by an index[9] consisting of different forms of access, such as full unbundling, line sharing, bitstream[10] access and subloop[11] unbundling, of the fixed-line incumbent's local loop are present) to the level of tangible fixed assets of telecoms operators. Friederiszick et al. (2008) using a comprehensive panel data sample of 180 fixed operators from 25 European countries from 1997 to 2006 conclude that access regulation has a negative impact on infrastructure investment by entrants in fixed-line telecommunications. They conclude that introduction of regulated access to incumbents' networks, costs a lost investment in the

[9] The index is constructed from information of the regulatory index of Plaut Economics (Zehnhäusern et al., 2007).
[10] Bitstream access refers to the situation where an incumbent makes available a broadband access link to the customer's premises to a competitor operator but retains control of the copper line at the local loop. Bitstream access is a wholesale product that consists of the provision of transmission capacity in such away as to allow new entrants to offer their own, value-added services to their clients.
[11] Sub loop unbundling is a type of unbundled access whereby a sub-section of the local loop is unbundled. This often requires the competitor to place a small street cabinet with a DSLAM next to the incumbent cabinet.

amount of 111.5% of the entrants' infrastructure stock, cumulatively over five years.

Wallsten and Haulsaden (2009) investigate the effect of unbundling and bitstream lines per capita on the adoption of different broadband technologies (such us cable, wireless local loop, fibre and DSL over entrants' own facilities) on 27 European countries for a period from July 2002 to July 2007. They conclude that the number of unbundled lines has a significant negative correlation to the number of lines across alternative broadband technologies, suggesting that unbundling has a negative effect on investment on new networks.

In summary, from the presentation of the above studies, we can discern that the relevant literature reaches heterogeneous conclusions. However, we can conclude that studies that employ as a dependent variable some proxy for investment (Friederiszick et al., 2008) or a measure of facilities-based infrastructure (Wallsten and Haulsaden, 2009) show either that there is a negative relationship or there is no association between access policies and investment.

1.3 Empirical Model and Data.

1.3.1 Empirical Model.

In order to investigate the relationship between the adoption of broadband and access regulation, a linear regression model with fixed effects is implemented. An individual effects model can be described by equation (1) where y_{it} is the dependent variable, x_{it} are the regressors, α_i are the random country specific effects, and ε_{it} is an idiosyncratic error. Country specific effects represent time invariant unobservable heterogeneity, which may be for instance, the culture, political structure or the geological features that make line deployment relative costlier in a country, in our specific study.

$$y_{it} = a_i + x_{it}'\beta + \varepsilon_{it} \quad (1)$$

In a fixed effects (FE) model the time unvarying component α_i can be correlated to the regressors but not with the idiosyncratic error, a limited form of endogeneity. In a random effect model (RE) the time unvarying component is assumed completely random and uncorrelated to the regressors. In this study we mainly consider a richer form of endogeneity where a regressor is assumed to be correlated to the idiosyncratic error and appropriate instrumental variable (IV) techniques are applied. A z_{it} instrumental variable is appropriate if it is uncorrelated to the idiosyncratic error ε_{it} and correlated to the endogenous variable conditional to all other exogenous variables in the model.

First, we consider the impact of access regulation on overall broadband penetration. Studies that have used as a dependent variable broadband penetration include among others, Garcia-Murillo (2005), Grosso (2006), Distaso et al. (2006), Waverman et al. (2007), Cincera. et al. (2012), Gruber and

Koutroumpis (2012) Crandall et al. (2013), Nardatto et al. (2014), and Ovington et al. (2017). Secondly, we consider the impact on alternative infrastructure technologies penetration. Studies that have used some measure of alternative infrastructure include for example, Waverman et al. (2007), and Wallsten and Haulsaden (2009). Thirdly, we look at the impact of access regulation within the technology that has been historically applied, that is DSL broadband penetration. The reason that we study the effect on these similar but distinct measures of telecommunication performance is threefold. Firstly, we want to look the effect of these access policies on the overall broadband market. Secondly, we want to investigate if there is any difference of the effect in the adoption of alternative infrastructure technologies. If the goal of regulation is to promote investment of operators on their own networks, which alternative infrastructure technologies typically represent, then the effect of access regulation on them has significant implications for policymakers. Thirdly if there is a difference, between broadband penetration and alternative infrastructure penetration, we want to examine if this disparity is caused due to the effect that access regulation has within the technology typically applied, that is to DSL Broadband. Lastly if the primary goal of access regulation is to promote market competition, then it is of interest, if the effect of access regulation policies depends on the intensity of market competition.

From the discussion above and the related literature we formulate the following hypothesis.
Hypothesis 1: *What is the effect of current access policies on broadband penetration?*
Hypothesis 2: *What is the effect of the same access policies on alternative infrastructure penetration and if there are any differences in comparison to overall broadband?*
Hypothesis 3: *If there are differences, are they caused because of the effect of these policies on the technology that they are typically applied?*
Hypothesis 4: *Does the effect of these access policies is dependent on the intensity of market competition in a country?*

In order to test these hypotheses, we formulate three linear models. The first one described by equation (2) examines the impact that access regulation policies have on the overall broadband penetration. While the second one described by equation (3) and third described by equation (4), examine the effect on the alternative infrastructure and the DSL penetration respectively. Our specification is closest to that of Cincera et al. (2012) and that of Ovington (2017), with the main difference that these two studies examine only the effect of these access policies on overall Broadband penetration. Furthermore, in respect to Ovingthon et al. (2017), we consider a significantly larger sample period and we include the *price of the LLU* covariate and a measure of overall market competition.

$$ln\,(Broadband\ Penetration)_{it} = b_0 + b_1(ln\ price\ of\ LLU)_{it} + b_2(LLU)_{it} + b_3(Bitstream)_{it} + b_4(Resale)_{it} + b_5(Inter\text{-}platform)_{it} + b_6(Market\ competition)_{it} + b_7(ln\ Income)_{it} + b_8(Education)_{it} + b_9(urban)_{it} + b_{10}(trend)_t + \alpha_{it} + \varepsilon_{it} \quad (2)$$

$$ln\,(Alternative\ Infrastructure)_{it} = b_0 + b_1(ln\ price\ of\ LLU)_{it} + b_2(LLU)_{it} + b_3(Bitstream)_{it} + b_4(Resale\ lines)_{it} + b_5(market\ competition)_{it} + b_6(ln\ Income)_{it} + b_7(education)_{it} + b_8(urban)_{it} + b_9(trend)_t + \alpha_{it} + \varepsilon_{it} \quad (3)$$

$$ln\,(DSL\ Penetration)_{it} = b_0 + b_1(ln\ price\ of\ LLU)_{it} + b_2(LLU)_{it} + b_3(Bitstream)_{it} + b_4(Resale\ lines)_{it} + b_5(Market\ competition)_{it} + b_6(ln\ Income)_{it} + b_7(Education)_{it} + b_8(Urban)_{it} + b_9(Trend)_t + \alpha_{it} + \varepsilon_{it} \quad (4)$$

The dependent variable in equation (2) is defined as broadband penetration and its measurement is total Fixed broadband subscriptions per 100 inhabitants. This includes subscriptions from several fixed broadband technologies such as DSL, Cable, Fibre to the Home/Building/Cabinet and others. In equation (3) the dependent variable is defined as the alternative broadband subscriptions per 100 inhabitants of broadband technologies other than DSL, while in equation (4) the dependent variable is DSL Penetration and is defined as the DSL broadband subscriptions per 100 inhabitants. The covariate variables for the models include ten overall factors, which are the following: i) price of the local loop unbundling, ii) the percentage of local loop unbundled lines (%), iii) the percentage of bitstream lines (%), iv) the percentage of simple resale lines (%), v) a measure of the level of inter- platform competition in the market, vi) a measure of market competition, vii) income, viii) a measurement of the level of education, ix) the percentage of urban population (%), and ix) a linear time trend, which are further elaborated below.

Note that for models (3) and (4) we do not include the covariate *inter-platform* competition. Because of the way the variable is defined (as the percentage of alternative infrastructure subscriptions), is, by definition, associated with the two dependent variables in the models. First because, for example, an increase in the share of alternative infrastructure subscriptions would increase the level of alternative infrastructure subscriptions (ceteris paribus) and second would mean a decrease on the level of DSL broadband penetration (since, DSL penetration = Broadband penetration – Alternative infrastructure). Therefore, the inclusion of the covariate in these models, would cause a problem of reverse causality. Finally, in order to prevent problems of positive skewness, some of the variables were transformed to their natural logarithms.

1.3.2 The Data and Variables.

The data set involves a panel data set of the 28[12] EU countries covering a period, from 2005 to 2015. The data set is unbalanced[13]. Most of the data come from reports published by the European Commission, concerning broadband access in the EU. Table 1.1 summarizes the measurement of each variable and its data source.

The covariate *price of the local loop* controls for the degree that the access price of the local loop affects broadband, DSL, and alternative infrastructure penetration in the three models. According to Waverman et al. (2007), a more intense access price regulation, signified by a lower access price of the local loop may positively affect broadband penetration as it may spur intra-platform competition and therefore lead to lower retail prices. However, at the same time may lead to lower alternative infrastructure subscriptions as a lower access price may cause a "migration effect" of subscribers from alternative infrastructure technologies to the DSL.

The variables *LLU, Bitstream, Resale*, are a measure of the intra-platform competition that exists within the DSL market. Resale occurs when the entrant simple repackages the service of the incumbent and sells it to the end users with no possibility of value-added features to the DSL part of the service or significant competition on price. Bitstream access occurs where an incumbent operator installs a high-speed access link to the customer's premises and then rents this access link to entrants. Bitstream access is a wholesale product which allows the competitor operators to differentiate their product through value-added services without access to the copper wire on the local loop. Local loop unbundling refers to the situation where the incumbent rents the copper wire on the local loop (the physical connection between the local telephone exchange and the consumer's premises) and allows the entrant to differentiate even further its services. Each step from simple resale to local loop unbundling is a step

[12] The 28 EU countries are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

[13] For the variable broadband penetration there are missing observations for Bulgaria for years 2005;2006, for Croatia for 2005;2006, and for Romania for 2005. For the variables DSL penetration, alternatives infrastructure, and inter-platform for Bulgaria for 2005;2006, for Croatia for 2005 to 2012, and for Romania for 2005;2006. For the variable price of the LLU for Bulgaria for 2005;2006, for Croatia for 2005 to 2012, for Luxembourg 2015;2016, and for Romania for 2005;2006. For the variable LLU for Bulgaria 2005;2006;2008;2013 to 2016; for Croatia for 2005 to 2012, for Cyprus for 2005, for Finland for 2012 to 2016, for Hungary for 2005; for Malta for 2009, for Poland for 2005, for Romania for 2005;2006 and for Slovakia for 2005. For the variable Bitstream for Bulgaria 2005;2006;2008;2013 to 2016; for Croatia for 2005 to 2012, for Cyprus for 2005, for Finland for 2012 to 2016, for Malta for 2009, for Netherlands for 2008 for Poland for 2005, for Romania 2005;2006, and for Slovakia for 2005. For the variable Resale for Bulgaria 2005;2006;2008;2013 to 2016; for Croatia for 2005 to 2012, for Cyprus for 2005, for Finland for 2012 to 2016, for Malta for 2009, for Poland for 2005, for Romania 2005;2006, and for Slovakia for 2005. For the variable market competition there are for Bulgaria for 2005;2006, for Croatia for 2005;2006, for Cyprus for 2005, for Finland for 2012 to 2016, and for Romania for 2005.

Table 1.1 Variables, Measurement and data sources.

Variable	Measurement	Data Source
Broadband Penetration	Fixed broadband Internet subscriptions per 100 inhabitants.	European Commission-Communication Committee: Broadband connectivity Reports in the EU[14]. European Commission-COMCOM: Broadband access in the EU (2006-2010) Reports.
DSL Penetration	DSL broadband Internet subscriptions per 100 inhabitants.	EC-COMCOM and Broadband connectivity Reports.
Alternative Infrastructure	Sum of Broadband subscriptions offered through alternative infrastructure, including technologies such as Cable, Fibre, WiMax, WiLL etc. per 100 inhabitants.	EC-COMCOM and Broadband connectivity Reports.
Price of the LLU	Average of the sum of the average price of the Full LLU total cost per year and average price of the shared local loop (€).	European Commission Reports on the Implementation of the Regulatory Framework, 11th Report to 20th Reports (2006-2016).
LLU	Percentage (%) of sum of fully unbundled lines and shared access lines of the local loop of entrants, over total DSL broadband lines.	EC-COMCOM and Broadband connectivity Reports.
Bitstream	Percentage (%) of bitstream lines of entrants over total DSL broadband lines.	EC-COMCOM and Broadband connectivity Reports
Resale	Percentage (%) of simple resale lines of entrants over total DSL broadband lines.	EC-COMCOM and Broadband connectivity Reports
Inter-platform	Percentage (%) of broadband subscriptions accessed through alternative networks.	EC-COMCOM and Broadband connectivity Reports.
Market Competition	Percentage (%) of entrants' broadband lines over total broadband lines.	EC-COMCOM and Broadband connectivity Reports.
Income	GDP per capita (constant 2011) PPP (US$).	The World Bank World Development Indicators database.
Education=	Percentage (%) of 15-64 years old with tertiary (after secondary school) education.	Eurostat database.
Urban	Percentage (%) of Urban population over total population.	The World Bank World Development Indicators database.

in the ladder of investment and requires respectively increased levels of investment from behalf of the entrants. The variables of intra-platform competition may be correlated with broadband penetration and alternative infrastructure, as they are a measure of serviced based competition which allows for the introduction, as well, as the intensification of competition in the market. Furthermore, it potentially (according to the Lol Theory) allows the entrants to gain market experience that could make easier the transition in building their own network (climbing the ladder of investment). However, it may also decrease the incentives of the incumbent entrants to invest in their own networks. Therefore, the overall expected impact of intra-platform variables cannot be predetermined.

[14] Available from https://ec.europa.eu/digital-single-market/en/connectivity.

The variable *Inter-platform* may impact broadband penetration as it is a measure of facility-based competition and thus operators, that own their own network, are able to offer more differentiated and higher "value added" services to subscribers, thus spurring demand for broadband. In addition, alternative technologies are generally superior in terms of quality and require high levels of investment. Moreover, inter-platform competition allows for "true" competition between operators as it alleviates the need of regulation of access to the incumbent network. For these reasons the *Inter- platform* variable is expected to have a positive relationship to broadband penetration.

The variable *Market competition* is expected to have a positive relationship to the dependent variables in all models as economic theory suggests that increased competition leads to lower retail prices. The variable *Education* is a proxy for the education level of the citizens of a country at a particular year. People with higher education are more likely to have more advanced e-skills and more willing to pay for broadband services. The covariate *Urban* is a proxy of the costs of deploying infrastructure. A higher urban population in a country would result in the operator requiring reduced costs to serve the same number of subscribers, ceteris paribus, and therefore is expected to be positively associated with broadband penetration.

Finally, a linear time trend is added to the market. As technology advances in production costs are reduced and quality of service improves, resulting in broadband uptake to increase even when the other factors remain constant. In addition, the linear time tend captures to some extent other factors such as the level of market experience gained by the entrants since the date access regulation was established in each country.

1.4 Results and Analysis.

For the investigation of the models (2), (3), and (4) a panel data set from 28 EU countries covering a period from 2005 to 2015, as was discussed above, was utilized. Table 1.2 presents descriptive statistics of the untransformed variables. A novelty of this study, compared to the relative literature is that tests for unit roots. If potential non-stationarity of the variables is not accounted for, in the analysis, the results can be severely biased.

Section 1.4.1 tests for cross sectional dependence in order to select an appropriate test of stationarity. Section 1.4.2 discusses the test for unit roots and section 1.4.3 provides a discussion and test for multi-collinearity.

1.4.1 Cross Sectional Dependence.

One of the problems of having panel data in contrast to the case of pure time series is the probability

that the variables or the random disturbances are correlated across the panels (Halkos and Polemis, 2017). Early literature on unit root tests assumed that no cross-sectional dependence was present, whereas when it exists, the power and size of the tests can be distorted (Halkos and Polemis, 2017). In order to test for the presence of cross-sectional dependence we use the test proposed by Pesaran (2004) and Pesaran (2015). Results are presented in Table 1.3. The test strongly rejects the null hypothesis of cross-sectional independence or weak cross-sectional dependence for all variables (P-values close to zero) except for the variable *Bitstream*.

Table 1.2 Descriptive statistics of the untransformed variables.

Variables	Observations	Mean	Standard dev.	Min	Max
Broadband Penetration	303	22.52747	9.208481	0.845146	42.5872
DSL Penetration	296	14.1556	7.765978	0.8128722	34.89863
Alternative Infrastructure	296	8.591762	5.926543	0.0169029	23.51131
Price of the LLU	296	7.369127	2.446784	1.106104	21.33244
LLU	283	15.14558	15.25111	0	56.51801
Bitstream	283	6.987099	8.056009	0	35.0752
Resale	284	2.928242	7.75862	0	61.3008
Inter-platform	296	37.90281	21.98588	0.2125823	88.4
Market Competition	298	51.115	14.28966	1.46343	93.6563
Income	308	33889.43	14622.7	12680.96	97864.2
Education	308	23.13149	7.294633	9.1	39.6
Urban	308	72.48874	12.28672	49.65	97.858

Table 1.3 Cross sectional Dependence Test.

Variables	CD Test	P-Value	Correlation	Absolute
Broadband Penetration	61.84***	0.000	0.97	0.97
DSL Penetration	49.32***	0.000	0.775	0.835
Alternative Infrastructure	55.71***	0.000	0.91	0.911
Price of the LLU	29.004***	0.000	0.46	0.55
LLU	6.845***	0.000	0.11	0.46
Bitstream	0.027	0.979	0.00	0.47
Resale	2.132**	0.033	0.03	0.21
Inter-platform	26.331***	0.000	0.43	0.71
Market Competition	6.896***	0.000	0.11	0.60
Income	23.658***	0.000	0.37	0.54
Education	59.441***	0.000	0.92	0.92
Urban	10.469***	0.000	0.16	0.97

Under the null hypothesis of cross sectional independence weak cross sectional dependence, the CD-statistic is distributed as a standard normal ~ N(0,1). **,***, Significant at 5%, 1%, respectively.

1.4.2 Unit Roots.

If potential non-stationarity of the variables is not accounted for in the analysis, the results can be severely biased. The presence of a unit root in the dependent and independent variables in the model can result in the problem of spurious regression, where statistically significant relationships are inferred

when actually do not exist (due to, for example, a third unaccounted factor that influences the variables). If it is unaccounted for it can result to very misleading findings. In order to test if the variables in our model are stationary, we perform a Fisher test as proposed by Maddala and Wu (1999). This test does not require a balanced panel data set and explicitly considers cross sectional dependencies (Halkos and Polemis, 2017). The null hypothesis is that all series in a panel are non-stationary, against the alternative that at least one series is stationary. Table 1.4 shows the results of the test. The test assumes

Table 1.4 Unit Root test of Maddala and Wu.

Variables	Statistics			
	P	Z	L*	Pm
Broadband Penetration	861.0633*** (0.0000)	-22.5115*** (0.0000)	-44.2782*** (0.0000)	76.0713*** (0.0000)
DSL Penetration	378.9230*** (0.0000)	-9.8106*** (0.0000)	-17.9908*** (0.0000)	30.5134*** (0.0000)
Alternative Infrastructure	374.4956*** (0.0000)	-11.2618*** (0.0000)	-18.8478*** (0.0000)	30.0950*** (0.0000)
Price of the LLU	96.8190*** (0.0004)	1.9510*** (0.0255)	-2.6457*** (0.0046)	3.8570*** (0.0001)
Inter-platform	162.4597*** (0.0000)	-3.3276*** (0.0004)	-6.0098*** (0.0000)	10.0595*** (0.0000)
LLU	210.0897*** (0.0000)	-4.6713*** (0.0000)	-8.3775*** (0.0000)	14.5601*** (0.0000)
Bitstream	299.0098*** (0.0000)	-6.0320*** (0.0000)	-13.4251*** (0.0000)	22.9623*** (0.0000)
Resale	615.1885*** (0.0000)	-19.0014*** (0.0000)	-33.1556*** (0.0000)	52.8383*** (0.0000)
Market Competition	365.7922*** (0.0000)	-9.0565*** (0.0000)	-16.8680*** (0.0000)	29.2726*** (0.0000)
Income	115.0272*** (0.0000)	0.1389 (0.5552)	-1.5063* (0.0671)	5.5775*** (0.0000)
Δ.Income	96.5739*** (0.0006)	-2.4984*** (0.0062)	-3.0457*** (0.0014)	3.8339*** (0.0001)
Education	58.2790 (0.3915)	2.2677 (0.9883)	1.9542 (0.9737)	0.2153 (0.4148)
Δ.Education	200.9447*** (0.0000)	-8.4730*** (0.0000)	-9.7420*** (0.0000)	13.6960*** (0.0000)
Urban	592.2489*** (0.0000)	-13.0394*** (0.0000)	-28.8186*** (0.0000)	50.6708*** (0.0000)

The null hypothesis assumes that the variable contains a unit root. The Phillips-Perron test is used which is robust in the presence of unspecified homoscedasticity and autocorrelation. The number of lags has been set to two and panels have been demeaned. The statistics are the following: P is the inverse chi-squared statistic, Z is the inverse normal statistic and L* denotes the inverse logit statistic, while Pm stands for the modified inversed chi-squared statistic. P-values in parenthesis. **,*** signifies a 5%, 1% level of significance respectively.

that all series are non-stationary under the null hypothesis against the alternative, that at least one series in the panel is stationary. From the results on table 1.4 we can observe that the null hypothesis is

rejected for all variables and all statistics except for the *Education* and *Income* variables. For the *Income* variable the statistics reject the null for all statistics except the Z statistic. However, according to (Choi I., 2001), the Z statistic has the best tradeoff between power and size. Finally, the first differences of the two variables are stationary and therefore we incorporate the first differences of the variables in the models.

Table 1.5 Multi-collinearity Diagnostics for Broadband Penetration Model.

Dependent Variable	Broadband Penetration			
Variables	VIF	VIF-Squared	Tolerance	R-Squared
Price of the LLU	1.49	1.22	0.6734	0.3266
LLU	4.46	2.11	0.2242	0.7758
Bitstream	1.65	1.28	0.6078	0.3922
Resale	1.72	1.31	0.5807	0.4193
Inter-platform	6.26	2.50	0.1598	0.8402
Market Competition	3.22	1.79	0.3104	0.6896
Δ.Income	1.11	1.05	0.8986	0.1014
Δ.Education	1.10	1.05	0.9122	0.0878
Urban	1.30	1.14	0.7671	0.2329
Trend	1.72	1.31	0.5831	0.4169
Mean VIF	**2.40**			

Table 1.6 Multi-collinearity Diagnostics for DSL and Alternative Infrastructure Model.

Dependent Variable	Alternative Infrastructure or DSL Penetration			
Variables	VIF	VIF-Squared	Tolerance	R-Squared
Price of the LLU	1.43	1.20	0.6983	0.3017
LLU	1.17	1.08	0.8548	0.1452
Bitstream	1.12	1.06	0.8936	0.1064
Resale	1.36	1.17	0.7349	0.2651
Market Competition	1.25	1.12	0.7976	0.2024
Δ.Income	1.11	1.05	0.8986	0.1014
Δ.Education	1.09	1.04	0.9187	0.0813
Urban	1.30	1.14	0.7679	0.2321
Trend	1.53	1.24	0.6556	0.3444
Mean VIF	**1.26**			

1.4.3 Multi-collinearity.

In order to investigate the presence of multi-collinearity in the variables used in the model a variable inflation factor (VIF) for each variable was calculated. The presence of severe multi-collinearity between the covariates can increase the value of standard errors and thus can reduce the efficiency of the model[15]. Moreover, estimates of the coefficients of the model tend to be sensitive to alternation on the data or specification of the model. VIF does not have critical values where results can be compared, but

[15] Although multi-collinearity is less likely to be a factor in panel data (Hsiao C., 2003).

a common rule is that variables that exhibit VIF values greater than 10 and a mean VIF greater than 6 may be problematic (Belsley et al., 1980). Table 1.5 and Table 1.6 presents the results, for Eq. (2) and Eq. (3), (4) models, respectively. None of the variables in each model exhibit a value of VIF greater than 10 and the overall model has a mean VIF value of considerably less than 6. Therefore, the model does not seem to suffer from severe multi-collinearity. However, taking a conservative approach we test if the exclusion of the variable *Inter-platform* in Eq. (2) model, which has the highest VIF, changes substantially the coefficients of the regression. In addition, we test if the inclusion of the *price of the LLU* variable changes again our results since it is the price of one of the intra-platform variables (the *LLU* variable) and potentially correlated with it. Table A.1 in the Appendix A, presents these results. There are not substantial differences in the coefficients or significance levels between specifications. (except for the *Urban* variable that becomes significant in one specification).

1.4.4 Empirical Results.

Table 1.7 presents the results of the regressions using a simple fixed effect estimator (FE), fixed effects with instrumental variables (FEIV) and the two stages least squares estimator (FEIV-2SLS), for comparison reasons. A robust Hausman test is calculated using the approach described by Arellano (1993) and Wooldrige (2002) to choose between fixed and random effects. The null hypothesis that the two estimators are equivalent is rejected and that the alternative hypothesis that the fixed effects estimator is appropriate is accepted. Moreover, a modified Wald test for the presence of heteroscedasticity and a Lagram-Multiplier test for the presence of serial correlation are performed. The tests confirm the presence of both heteroscedasticity and serial correlation.

In the instrumental variables' estimation, the variable price of the LLU, is considered endogenous. The fact that the regulator has an incentive to set access prices according current levels of market performance and market structure in order to influence them presents a problem of endogeneity. According to Grajek and Roller (2012), "That regulatory outcomes such as unbundling policies and mandated access prices are subject to political and administrative processes gives rise to a fundamental endogeneity problem". In other words, for instance, the regulator has an incentive to set lower access prices in order to promote market entry, if the competitive conditions in the market are far from optimal or if broadband penetration is low, in order to affect the level of prices in the retail market and boost adoption. Furthermore, the variable *Income* is considered endogenous due to, as stated in the introduction, broadband diffusion having a considerable impact on the growth of an economy. Moreover, *Inter-platform* and *Market competition* are considered endogenous because of the way they

are constructed (as % of broadband penetration) and therefore again arises, a relationship of reverse causality. Finally, for the same reasons, the variables of intra-platform competition (*Resale, Bitstream, LLU*) are considered endogenous, in equation (3), as they are defined as a % of DSL penetration.

Table 1.7 Results of Regression Analysis for Broadband, DSL and Alternative infrastructure Penetration.

Dependent Variables	Broadband Penetration		DSL Penetration		Alternative Infrastructure Penetration	
Variables	FE	FEIV(2SLS)	FE	FEIV(2SLS)	FE	FEIV(2SLS)
Price of the LLU	**-0.376*****	**-0.571*****	**-0.371*****	**-0.382*****	-0.045	-0.083
	(-3.46)	(-5.80)	(-3.72)	(-2.69)	(-0.25)	(-0.32)
LLU	0.005	-0.002	**0.015****	**0.017****	**-0.016****	**-0.031*****
	(0.83)	(-0.37)	(2.16)	(2.06)	(-2.13)	(-2.98)
Bitstream	**-0.013***	**-0.0024*****	-0.006	-0.009	-0.012	**-0.031*****
	(-1.98)	(-3.14)	(-0.68)	(-1.03)	(-1.33)	(-2.72)
Resale	-0.009	**-0.019*****	-0.003	-0.002	**-0.021****	**-0.038*****
	(-1.12)	(-2.98)	(-0.27)	(-0.17)	(-2.42)	(-3.22)
Inter-platform	0.004	0.005	-	-	-	-
	(0.91)	(0.80)				
Market Competition	**0.012****	**0.023*****	0.0014	0.0014	**0.036*****	**0.057*****
	(2.35)	(3.13)	(0.19)	(0.24)	(2.86)	(3.37)
Δ.Income	**-1.427*****	**-1.051*****	**-1.582*****	**-1.133*****	**-1.69*****	**-1.125*****
	(-5.08)	(-4.66)	(-3.57)	(-4.03)	(-4.67)	(-4.48)
Δ.Education	-0.0031	0.001	-0.0027	0.0024	-0.017	-0.006
	(-0.39)	(0.891)	(-0.27)	(0.27)	(-0.71)	(-0.32)
Urban	-0.03	-0.028	-0.0105	-0.0023	-0.108	**-0.117***
	(-1.60)	(-1.47)	(-0.38)	(-0.10)	(-1.55)	(-1.76)
Trend	**0.056*****	**0.031*****	**0.032****	**0.023****	**0.133*****	**0.108*****
	(4.10)	(3.08)	(2.36)	(2.21)	(5.14)	(4.49)
Modified Wald test	204.81		106.60		4513.03	
(P-value)	(0.0000)		(0.0000)		(0.0000)	
Lagram-Multiplier test	881.398		544.670		106.701	
(P-value)	(0.0000)		(0.0000)		(0.0000)	
Hausman-test	33.240		14.817		23.410	
(P-value)	(0.0002)		(0.0961)		(0.0053)	
Sargan-Hansen test		0.160		2.281		1.583
(P-value)		(0.6892)		(0.3196)		(0.4531)
Diff.-in-J Endog. test		9.660		15.087		11.453
(P-value)		(0.0466)		(0.0196)		(0.0095)
F test	44.97	93.23	14.04	11.37	51.05	75.40
(P- value)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
R^2	0.8239	0.8102	0.6378	0.6532	0.7634	0.7450
Numb. of observations.	260	256	260	250	260	256

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

Considering our findings in table 1.7, in the instrumental variables estimator models the Sargan-Hansen test of over-identifying restrictions fails to reject the null that the instruments are jointly valid. Furthermore, the Difference-in-J endogeneity test justifies our choice to use instrumental variables

methods. Thus below, are presented the findings of the Fixed Effects Instrumental Variables estimator (FEIV- 2SLS) as the appropriate econometric estimator to infer the models.

1,4,4.1 Results on overall broadband penetration.

Concerning the variables that control for the effect that local loop unbundling has on broadband penetration, that is *price of the LLU* and *LLU*, *price of the LLU* is significant at a 1% level while the *LLU* variable is not significant. The coefficient of the *price of the LLU* is negative suggesting that a higher (lower) access price of the local loop would decrease (increase) broadband penetration. A 1% decrease(increase) in the access price would increase(decrease) by approximately 0.57% the level of broadband adoption. In respect to, the covariates concerning intra-platform competition, *Bitstream* and *Resale* both are significant at a 1% level and negative, suggesting an inverse relationship exists between them and broadband adoption. A 1 unit increase in the percentage of entrants Bitstream lines in the DSL market would have as an effect an 2.4% decrease in broadband diffusion. Similarly, a 1 unit increase(decrease) in the percentage of entrants

Resale lines in the DSL market would have as an effect a 1.9% decrease(increase) respectively. Regarding the variable *inter-platform,* it has the expected positive sign, however we do not find to be significantly related to broadband penetration. This contrasts with most studies (for instance, Denni and Gruber, 2005; Grosso M., 2006; Bouchaert et al., 2010). Our results are more in line with studies such as, Gruber and Koutroumpis (2012), which did not find a significant relationship, or Ovington et al. (2017) which did not find that inter-platform competition impacts broadband diffusion for some specifications[16].

The variable *Market Competition* is positive and significant at a 1% level of significance suggesting that increased market competition facilitates the diffusion of broadband. A 1 % increase(decrease) in the percentage of entrants total fixed broadband lines would have as an effect a 2.3% increase(decrease) in the level of broadband adoption.

The variable *Δ.Income* is significant at a 1% level of significance. The negative sign of the coefficient implies that a 1-unit increase(decrease) in the percentage level of growth (or decrease on the percentage level of decline) of income from one period to the next has as an effect an approximate 1% decrease(increase) in the level of broadband penetration. This is a not an expected result that may be due to little within variation of the variable over time. The variables *Δ.Education* and *Urban* are not significant, while the variable *Trend* is positively associated with broadband penetration at a 1% level. The positive sign of the coefficient of *Trend* shows that broadband penetration rises over time due to

[16] As in this study, Ovington et al. (2017) did not find a significant relationship in specifications with (FE) estimators.

factors such as technological advancement.

From the presentation of the results of the broadband penetration the following observations arise. First simple resale of the service of the incumbent, or bitstream access which both are access policies with little service differentiation and relative minimal investment requirements, have a negative effect on overall broadband penetration. This may be due to reducing the investment incentives of incumbents, through lowering its' ex-post profits, or reducing the entrants' incentives to invest in alternative infrastructure because it increases their opportunity cost. In addition, such unbundling policies do not offer significantly higher value-added services for subscribers, which could stimulate demand. In respect to the unbundling of the local loop policy our results suggest that it facilitates broadband adoption as shown by the price of the local loop[17]. Finally, market competition is a significant factor that positively affects broadband diffusion.

1.4.4.2 Results on DSL broadband penetration.

Regarding the DSL broadband penetration, the *price of the LLU* and the *LLU* covariates sign (negative and positive respectively) suggest that unbundling policy has a positive influence on DSL broadband. A 1% decrease(increase) in the access price would increase(decrease), by approximately 0.38%, the level of DSL broadband adoption. Moreover a 1 unit increase(decrease) in the percent of *LLU* lines would again increase(decrease) DSL broadband by 1.7%. The covariates *Bitstream* and *Resale* are not significant, implying that the respective access policies did not have a significant impact on DSL broadband proliferation. The *Market Competition* variable has become insignificant even at a 10% and *Δ.Income* is significant at a 1% level. A 1% increase(decrease) has as an outcome an approximate 1.1% decrease(increase) in DSL penetration. The positive sign of the coefficient of *Trend* captures again the other factors that cause DSL broadband penetration to increase over time.

1.4.4.3 Results on Alternative infrastructure penetration.

Turning now to the alternative infrastructure regression, the variable *price of LLU* is insignificant. In other words, the access price of the local loop has not any significant effect on the diffusion of alternative infrastructure. Instead the intra-platform variables, *LLU*, *Bitstream* and *Resale* are all significant at a 1% level and all have a negative impact on alternative infrastructure adoption. A 1%

[17] A somewhat surprising result is that the variables price of the LLU and LLU which represent the local loop unbundling policy, are not both significant. However, it is possible that they are not equal measures of the impact of the local loop unbundling on broadband. For example, price of the local loop is directly influenced by the regulator and is part of the operators' decision, among other factors, for the entrants to provide DSL services through local loop unbundling while the number of LLU lines offered is a direct result of this decision.

increase(decrease) in the level of entrants LLU lines in the DSL market has as a result an 3.1 % decrease(increase) in the level of alternative infrastructure diffusion. Similarly, a 1% increase(decrease) in the level of entrants Bitstream lines in the DSL market has as a result an 3.1 % decrease(increase) in the level of alternative infrastructure diffusion. Furthermore, a 1% increase(decrease) in the level of entrants' resale lines in the DSL market has as a result an 3.8 % decrease(increase) in the level of alternative infrastructure diffusion. The variable *Market Competition*, again, has a positive relationship to alternative infrastructure with a 1 unit increase(decrease) in the *Market Competition* variable signifying a 5.7% increase(decrease) in the level of alternative infrastructure adoption. The variable *Δ.Income* is again significant at a 1% level, with a 1% increase(decrease) in the variable resulting in an approximate 1.1% decrease(increase) in alternative infrastructure. Moreover, the variable *Urban* is significant and negative, an opposite outcome from that expected. The reason could be again, little within variation as urban population tends not to change significantly with time in the sample period for each country. Finally, the variable *Trend* is again positive and significant indicating the increase in alternative infrastructure subscriptions with time.

The main conclusion that can been drawn from the alternative infrastructure regression is that the three measures of intra-platform competition (*LLU, Bitstream and Resale*) negatively impact alternative infrastructure adoption. The policy of enforcing access to the incumbent network by the regulator has hindered the proliferation of subscriptions of alternative access technologies. Also, as it is evident by the coefficients of the intra-platform covariates, simple resale has the most negative impact, while the other two have approximately the same negative effect. Moreover, comparing the intra platform variables coefficients between the two regressions, it shows that intra-platform competition has a greater hindering effect on the alternative infrastructure adoption than on overall broadband penetration. Similarly, market competition is more important driver for the proliferation of alternative infrastructure technologies than in the case of overall broadband.

1.4.4.4 Results of regression analysis with interactions between access policies and market competition.

In order to investigate, if the impact of access policies depends on the intensity of market competition, we interact the intra-platform competition variables as well as the *price of LLU* with the *Market Competition* variable. Table 1.8 presents the results. For the Broadband Penetration regression, the interactions of *price of LLU*, *Bitstream* and *Resale* with the *Market Competition* variable are significant, while for alternative infrastructure only the interaction of *Resale* with *Market Competition* is significant. The opposite signs between the interactions (positive) and the main effects of the intra-platform

Table 1.8 Results of the FEIV(2SLS) regression with interaction terms.

Dependent Variables	Broadband Penetration	DSL Penetration	Alternative Infrastructure
Variables	FE-IV(2SLS)	FE-IV(2SLS)	FE-IV(2SLS)
Price of the LLU	**-0.56*****	**-0.674*****	-0.21
	(-3.23)	(-2.27)	(-0.71)
LLU	-0.003	**0.014** *	**-0.021*****
	(-0.72)	(1.99)	(-2.99)
Bitstream	**-0.024*****	-0.007	**-0.025*****
	(-3.43)	(-0.60)	(-3.09)
Resale	**-0.027*****	**-0.028***	**-0.067*****
	(-5.26)	(-1.94)	(-4.69)
Inter-platform	0.003	-	-
	(0.45)		
Market Competition	**0.023*****	0.008	**0.055*****
	(3.23)	(0.84)	(4.33)
Δ.Income	**-1.342***	**-1.114****	-1.2
	(-1.80)	(-2.51)	(-0.54)
Δ.Education	-0.0049	-0.014	-0.021
	(-0.72)	(-0.84)	(-1.52)
Urban	-0.028	0.0007	**-0.105***
	(-1.15)	(0.03)	(-1.69)
Trend	**0.036****	0.0123	**0.107*****
	(2.55)	(0.86)	(4.06)
Price of the LLU* Market Competition	**0.015*****	**0.048***	0.001
	(3.24)	(1.76)	(1.37)
LLU*Market Competition	-0.00003	0.0005	0.0002
	(-0.38)	(0.72)	(0.23)
Bitstream*Market Competition	**0.0009****	0.0008	-0.001
	(2.22)	(1.55)	(-1.17)
Resale*Market Competition	**0.0005*****	**0.0015***	**0.002*****
	(2.82)	(1.90)	(3.26)
Sargan-Hansen test	2.947	4.204	0.929
(P-value)	(0.2292)	(0.1222)	(0.6285)
F test	201.86	18.36	32.06
(P- value)	(0.0000)	(0.0000)	(0.0000)
R^2	0.8435	0.4468	0.7817
Numb. of observations	256	224	256

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.
(iv) The interaction term variables are centered around their mean.

variables and price of the local loop (negative) indicate that the main effects are "diminishing" with the rise of competitive intensity. In other words, for low values of the *Market Competition* variable the main effects have the strongest inverse effect on the dependent variables. In contrast for higher values of market competition the main effects impact on broadband penetration and alternative infrastructure decreases. For instance, in the broadband penetration regression, for access policies which require lower investment, such as *Resale* and *Bitstream* the negative effect that they have on broadband

penetration is higher for less intense competition. In addition, the positive impact on broadband penetration by local loop unbundling policies is greater in the case again, of lower market competition. Similarly, in the case of the DSL penetration regression the effect of *price of the LLU* and *Resale* are more impactful when market competition is weaker, as it is in the case of the alternative infrastructure regression in respect of the simple resales' effect.

1.5 Discussion and Conclusions.

There has been considerable debate about the impact of access regulation on broadband. This debate has intensified currently with the roll out of Next Generation Access (NGA) technologies, in regard to, which are the best policies to promote them. In this study we have examined how access regulation affects first, overall broadband diffusion, and second the diffusion of DSL and alternative infrastructure technologies. We have considered these similar but distinctive measures of telecommunications performance in order to identify if there are significant differences on how access regulation influences them. This distinction is important because it has policy implications if access regulation has different effect on alternative technologies diffusion. While many studies have examined the impact of access regulation on either broadband penetration or a different measure of telecommunications performance, often with conflicting results, none (to the best of our knowledge) have considered the impact on both overall broadband and alternative access technologies penetration employing the same dataset and near identical specifications (except that of Waverman et al, 2007). Our main finding is that while access regulation of the local loop unbundling facilitates overall broadband penetration at the same time hinders the proportion of broadband lines that are accessed through alternative technologies. This contrasting effect is due to a facilitating effect of unbundling on broadband lines within the technology that is applied, which is broadband lines accessed through DSL. In respect to policy implications regulators are in front of a dilemma. If regulators primary priority is to expand the overall broadband market then local loop unbundling has been successful in promoting it. However, if their priority is to promote alternative access technologies which are typically superior in quality of service then they need to rethink their approach. If history is to be repeated this finding has ramifications for the access regulation of NGA technologies such as fibre. Fibre local loop unbundling may incite fibre adoption but at the same time may impede diffusion and thus investment on future technologies.

In respect to the low investment intensive access policies, such as simple resale and bitstream, they hinder the adoption of both overall broadband diffusion and alternative infrastructure. The policy of the European Commission to promote entrants to build their own network and invest in alternative access

technologies, through moving up the ladder of investment, has not been effective. This is due to all access regulation policies (each step in the ladder of investment) having a negative impact on alternative infrastructure penetration.

We have also considered if the effect of these access policies is dependent on the degree of market competition that exists in the market. We have found that for low investment access policies (Resale and Bitstream) the negative effect on broadband penetration is higher in the case when competition is weaker, while the positive impact of the local loop unbundling is again stronger when competition is less intensive. This finding provides valuable information to policy makers in each country depending on the intensity of competition is in their market. Given the opposite impact of low investment access policies in contrast to the positive impact of unbundling (assuming regulators have prioritized the overall broadband market) the overall ambiguous effect of the access policies would also depend on the competitive conditions in each country. Finally, for countries where competition is intensive the lower overall effect of these access policies (either facilitating or impeding) renders access regulation less relevant.

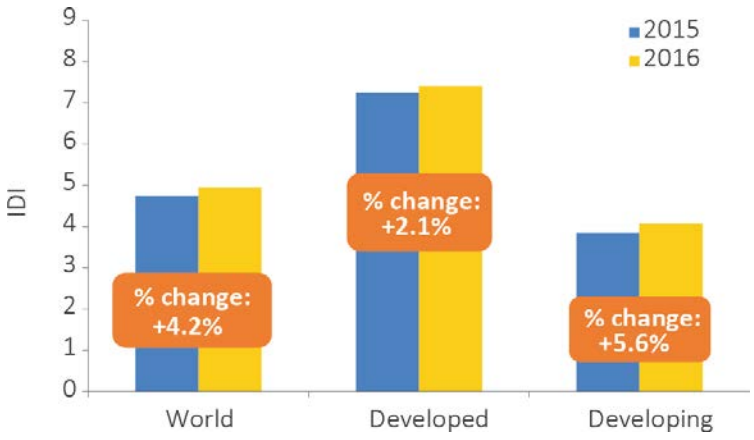
Chapter 2

Determinants of Fixed broadband diffusion

2.1 Introduction

The virtues of broadband for economic and societal development are well documented. It is no surprise then, due to the critical importance of broadband networks, that many countries have designed efforts in order to facilitate the adoption of broadband. For example, the European Commission, published in 2010 the Digital Agenda for Europe[18] that sets a seven-pillar strategy and a set of objectives to be achieved till 2020 by EU countries (European Commission 2010). However, the experiences that each country has concerning the proliferation of broadband differs substantially. For instance, broadband adoption differs considerably between developed, developing and least developed countries. The ICT Development Index (IDI) published by the International Telecommunications Union (ITU), which is a measure of the development of Information Communications Technologies (ICT) (IDI uses for its' construction a variety of infrastructure, access and skills measures that impact the proliferation of ICT), is considerably lower for least developed and developing countries (ITU 2016). For instance, for the year 2016 the IDI index takes a value of 7.25, 3.85 and 1.91 for developed, developing and least developed countries respectively (ITU, 2016). Thus, a digital divide exists between advanced and less developed economies which reinforces the developmental gap between them. For this digital divide to be

Figure 2.1- IDI index for Developed and Developing countries for years 2015,2016.



Source: International Telecommunications Society (2016)

[18] See European Commission, (2010).

alleviated, it is important for policymakers, as well as private organizations to be aware of the factors that influence broadband uptake, so to design appropriate policies.

The remaining portion of this chapter is organized as follows. Section 2.2 discusses the relevant literature for the determinants of broadband[19] adoption. Section 2.3 discusses the dataset and relevant variables, section 2.4 presents the results from regression analysis and finally section 2.5 provides a discussion and conclusions derived, based on the main findings.

2.2 Related Literature.

There is considerable empirical literature investigating the determinants of broadband adoption. These empirical studies have focused on either cross country or within a country datasets. Due to the scope of this study we will focus on cross country studies that examine a wider range of factors (comparing to studies that concentrate on the effect of certain regulatory policies on broadband penetration).

One of the first studies to explore broadband deployment in a cross-country setting, considering a variety of socioeconomic and industry related variables, is that of Murrillo-Garcia (2005). The authors conclude that income per capita and population size increases the probability of subscribers in a country having access to broadband services. Furthermore, among industry factors, the author shows that market competition and internet content positively affect the percentage of internet users to subscribe to a broadband service. Concerning Local Loop Unbundling (LLU) she finds that positively affects broadband penetration in one specification (using a logit model) while it does not have a significant effect on another (using OLS).

Cava-Ferreruela et al. (2006), together with regulatory policies, examined a variety of socioeconomic factors that potentially affect cable modem and DSL coverage for 30 OECD countries during a sample period from 2000 to 2002. Their main conclusion is that broadband infrastructure development in a country is primarily explained by its economic level. Moreover, competition between different access platforms drives broadband deployment. They did not find evidence that market competition, internet content or local loop unbundling significantly affects broadband infrastructure. Regarding demographic variables, they argue that the percentage of urban population and household density have a positive relationship to Cable and DSL coverage, while education was not found to be significant.

One of the studies that uses a large sample of international countries is that of Lee (2008). The author employed a sample of 107 countries for a period from 2002 to 2005 and examined an extensive set of

[19] For the remaining of this chapter, when we refer to broadband, we refer to fixed broadband.

various socioeconomic and industry factors. He concludes that the unbundling of the local loop, platform competition, lower cost of fixed broadband, higher mobile price, political freedom, bandwidth, and the percentage of internet users, positively contribute to broadband diffusion.

Lee et al. (2011a), in a following study, focused on the determinants of broadband diffusion for 30 OECD countries for a period between 2001 to 2008. They concluded that income, inter-platform competition, education and a lower cost of broadband are important drivers of broadband diffusion.

Another study that employs a large set of countries in the sample is that of Andres et al (2010). Using data from 214 countries for a period between 1990 and 2004, concluded that GDP per capita, computers per capita and previous internet users contribute to internet users' uptake. A more recent study is that of Lin and Wu (2013), which focuses on the impact of factors on broadband penetration in each stage of the diffusion process. They used data from 1997 to 2009 from 34 OECD countries. They found that income, lower price, inter-platform competition, internet content and previous broadband penetration are key drivers for broadband deployment and that education facilitates diffusion on its' initial stages.

Finally, Ovington et al (2017) using a dataset for 27 European countries for a period of 2004 to 2011 they conclude that unbundling, income, inter-platform competition, education, previous broadband penetration and population density have a significant effect on broadband adoption.

From the above presentation of studies occurs that earlier studies included a relatively small number of countries focusing on either OECD countries or a subset of European countries. This is probably due to data limitations. First because broadband diffusion in these studies mostly was at its' earlier stages and secondly data were more likely to be available from major organizations such as the OECD or the European Commission. Among the factors that were identified by the relevant literature that influences broadband diffusion include market competition, competition between access technologies, local loop unbundling, income, internet content, cost, population density, population size, political freedom, education, bandwidth and mobile price.

This study uses a similar approach but attempts to complement the relative literature by including a large set of countries in the analysis than most studies that examine the determinants of broadband diffusion (the exceptions being Lee, 2008 and possibly Andres et al 2010 as their scope was internet diffusion rather than broadband). This provides the advantage of being able to conduct an analysis for countries of different levels of development, that is for both developed and developing countries.

2.3 Empirical Model and Data.

2.3.1 Empirical Model.

Equation (5) describes the linear relationship between the independent and dependent variables of the model examined in this study. It includes both demand side and supply side variables. In order to prevent problems of positive skewness that may affect the analysis, some variables[20] were transformed to their natural logarithms.

$$ln\ (Broadband\ penetration)_{it} = b_0 + b_1(ln\ Fixed\ Broadband\ price)_{it} + b_2(Liberalization\ Part\ Comp)_{it} + b_3(Liberalization\ Full\ Comp)_{it} + b_4(Education)_{it} + b_5(Economic\ Freedom)_{it} + b_6(ln\ Income)_{it} + b_7(ln\ Content)_{it} + b_8(ln\ Bandwidth)_{it} + b_9(ln\ E\text{-}Services)_{it} + b_{10}(Urban\ Population)_{it} + b_{11}(Privatization)_{it} + b_{12}(LLU)_{it} + b_{13}(Age)_{it} + b_{14}(Trend)_t + \alpha_{it} + \varepsilon_{it} \quad (5)$$

The terms α_{it} refers to the specific unobservable country effects that are not included as variables and ε_{it} is the standard error term. The covariates were primarily selected according to the findings of the relevant literature and data availability. The dependent variable is defined as broadband penetration and its measurement is total fixed broadband subscriptions per 100 inhabitants. This includes subscriptions from several fixed broadband technologies such as DSL, Cable, Fibre to the Home/Building and others[21]. The independent variables include overall fourteen factors which are the following: i) *Fixed Broadband price*, ii) *Liberalization Part Comp*., iii) *Liberalization Full Comp.,* iv) *Education*, v) *Economic Freedom*, vi) *Income*, vii) *Content*, viii) *Bandwidth*, ix) *E-services*, x) *Urban Population*, xi) *Privatization,* xii) *Local Loop Unbundling* (LLU), xiii) *Age* and xiv) a linear time *Trend*, which are further elaborated below.

2.3.2 The Data and Variables.

The data set involves a panel data set of 140 international countries covering a period, from 2008 to 2015[22]. The panel data set is unbalanced[23] and the time frame is yearly. The main portion of the data

---

[20] Except the *Liberalization*, Privatization and *LLU* variables which are binary, as well as the *Economic freedom* and *Education* variables which are indexes, and the urban population and age covariates which are percentages.

[21] Others, include Ethernet Lan, and broadband over powerline communications.

[22] See Table B5 in Appendix B for a list of countries included in this study.

[23]. For the dependent variable broadband penetration there are missing observations for Côte d'Ivoire for years 2010;2011, for Guatemala for 2011, for Honduras for 2008;2009 and for Philippines for 2010. For the variable fixed broadband price, for Bahamas for 2008, for Belarus for 2008, for Brunei Darussalam for 2008, for Burundi for 2008 to 2012, for Ecuador for 2008, for Gabon for 2008 to 2011, for Gambia for 2012, for Georgia for 2010, for Honduras for 2008;2009, for Israel for 2008, for Kazakhstan for 2008; for Kyrgyzstan for 2008;2012, for Mongolia for 2008, for Suriname for 2008 and for Turkey for 2008. For the variables Liberalization Partial Comp. and Liberalization Full Comp, for Lesotho 2009;2015, and for Venezuela for 2012 to 2014. For the variable Education, for Bhutan for2008;2009, for St. Lucia for 2008, and for St. Vincent and the Grenadines for 2008.) For the variable economic freedom, for Bhutan for 2008, for Brunei Darussalam for 2008 to 2013, for Comoros for 2008, for Maldives for 2008, for Montenegro for 2008, for Serbia for 2008, for Seychelles for 2008, for St. Lucia 2008,(continued in page 38)

comes from the "ITU World Telecommunication/ICT Indicators (WTI)" database and the "The World Bank World Development Indicators (WDI)" database. Table 2.1 summarizes the type of variable, its measurement and its data source.

2.3.2.1 Fixed Broadband Price.

Fixed broadband price as demand theory predicts, is expected to have an inverse relationship with broadband diffusion. For instance, higher prices of broadband plans offered (ceteris paribus), are expected to hinder the adoption of broadband services and vice versa. Several studies have showed that lower cost of broadband services increases demand for them (Distaso et al., 2006; Lee S., 2008; Lee et al., 2011a; Lin et al., 2013, among others).

2.3.2.2 Liberalization Part Comp. and Liberalization Full Comp.

Liberalization is a category variable which refers to, if the regulator restricts licenses to one monopoly operator serving all subscribers in a country at a specific year, or partial competition when licenses are restricted to few operators or full competition when the issuing of licenses is completely unrestricted. The covariate *Liberalization Part Comp*. takes the value of 1 when licenses are restricted to few operators, while the covariate *Liberalization Part Comp.* takes the value of 1 when there are no restrictions. Note, that in order to avoid the dummy variable trap we do not include in the model the reference case when licensees are restricted to a single operator. The liberalization variables can also, to some extent, thought of as a proxy for the level of competition that exists in the market. If entry in the market is restricted, this is going to directly impact the number of firms that can offer broadband services. Thus, liberalization allows for the introduction of competition which increases allocative efficiency, leads to lower prices, and thus is expected to facilitate broadband diffusion. However, It is noteworthy to mention that although when licenses are restricted to a dominant monopoly, then the *Market liberalization* variable is a perfect proxy for the competitive forces (or lack of) that exist in the market, in contrast it is an imperfect proxy in the case of partial or full competition. In other words, the

23 (continued for St. Vincent and the Grenadines for 2008, and for Vanuatu for 2008. For the variable income, for Venezuela for 2015. For the variable Content, for Montenegro for 2008, and for Serbia for 2008. For the variable Bandwidth, for Guatemala for 2011, for Seychelles 2009 and for Suriname for 2011. For the variable e-services, for Bhutan for 2008, for Comoros for 2014;2015, for Lesotho for 2011;2012, for Montenegro for 2008, for Oman for 2009, for Serbia for 2009, and for United Kingdom for 2009. For the variable Privatization for Armenia for 2013, for Belize for 2013, for Canada 2013, for Gambia for 2013, for Georgia for 2013, for Hong Kong, China for 2008 to 2013, for Iceland for 2013, for Iran for 2013, for Israel for 2013, for Italy for 2013, for Jamaica for 2013, for Jordan for 2013., for Malaysia for 2013, for Montenegro for 2013, for Netherlands for 2013, for Niger for 2013, for Poland for 2013, for Rwanda for 2013;2015, for Vanuatu for 2013 and for Zambia for 2013. For the variable local loop unbundling, for Fiji for 2008 to 2010, and for Kazakhstan for 2008;2009.

allowance of additional entry in the mobile market with no restrictions in granting of additional licenses, does not necessarily mean that entry will occur, or signifies the degree that will occur.

Table 2.1 Variables, Measurement and data sources.

Variable	Measurement	Source
Broadband penetration	Total Fixed broadband Internet subscriptions per 100 inhabitants.	ITU World Telecommunication/ICT Indicators (WTI) database.
Fixed Broadband price	Fixed broadband Internet monthly subscription charge (US$).	ITU World. Telecommunication/ICT Indicators (WTI) database.
Liberalization Partial Comp.	A binary variable, whereas takes the value of 1 if the market of fixed line telephony is restricted to a few licenses (partial competition) or 0, if the market is restricted to one license (monopoly) or there are no restrictions (full competition).	ITU ICT/Eye Regulatory database and The Little Data Book on Information and Communication Technology Reports (2010-2017).
Liberalization Full Comp.	A binary variable, whereas takes the value of 1 if the market of fixed line telephony is not restricted (Full competition) or 0 otherwise.	ITU ICT/Eye Regulatory database and The Little Data Book on Information and Communication Technology Reports (2012-2017).
Education	UNDP Education Index. It takes theoretically values from 0 to 100, with higher values signifying a higher level of education.	UNDP Human Development Reports (2010-2016).
Income	GDP per capita (constant 2011) (US PPP $).	The World Bank World Development Indicators database.
Economic Freedom	Index of economic freedom. It takes theoretically, values from 0 to 100, with higher values signifying higher economic freedom.	Heritage Foundation.
Content	Number of Internet hosts per 100 people.	Internet System Consortium, Internet Domain Survey.
Bandwidth	International Internet Bandwidth per internet user; in bit/s.	ITU World Telecommunication/ICT Indicators (WTI) database. Internet Systems Consortium (2017).
E-Services	Number of secure online servers per 100 people.	The World Bank World Development Indicators database.
Urban Population	Percentage of Urban population to total population.	The World Bank World Development Indicators database.
Privatization	A binary variable, it takes the value 1 if the main fixed telecommunications operator is fully privatized or 0 otherwise.	The Little Data Book on Information and Communication Technology Reports (2010-2017).
LLU	A binary variable, it takes the value 1 if the local loop unbundling is obligatory in a country at a particular year or 0 otherwise.	ITU ICT/Eye Regulatory database.
Age	Percentage of population between 15-64 years old.	The World Bank World Development Indicators database.

2.3.2.3 Education.

The *Education* variable is measured by the education index published each year by the United Nations Development Program. It is a proxy for the level of development of human capital that exists in a country. The education index is calculated by combining two indices (UNDP, 2016). One from expected

years of schooling (that is number of years a child of school entrance age can expect to spend in a given level of education), and the other from mean years of schooling (that is average number of completed years of education of the population above 25 years of age). The inclusion of education in the model as a possible determinant may be relevant, because people with higher education are more likely to have the skills required for using information technologies (Murrillo-Garcia M., 2005). Moreover, people who are more educated are likely to demand a higher amount of services to be made available through the internet (van Dijk, J., 2005).

2.3.2.4 Income.

As the level of income constraints consumption of products and services of potential subscribers, it is expected that higher income shifts upwards the demand curve for broadband services and thus facilitates broadband diffusion. Several studies have showed that the level of income has a significant positive effect on broadband adoption (for example, Murrillo-Garcia M., 2005; Cava-Ferreruela et al., (2006); Bouckaert, et al., 2010; Lee et al., 2011a; Lin and Wu, 2013; Ovington et al., 2017).

2.3.2.5 Economic Freedom.

The variable *Economic Freedom* is measured by the economic freedom index published yearly by the Heritage Foundation (The Heritage Foundation, 2018). The index is consisted of four sub-indexes which are respectively i) rule of law, ii) government size, iii) regulation efficiency and iv) market openness. It is a measure of several distinct freedoms such as namely, property rights, judicial effectiveness, government integrity, tax burden, government spending, fiscal health, business freedom, labor freedom, monetary freedom, trade freedom, investment freedom and financial freedom. Lee, (2008) explored the relationship between broadband penetration and economic freedom but did not find evidence of correlation.

2.3.2.6 Content.

Content relates to internet content, and is measured by the number of internet hosts per 100 people. Internet hosts are used as a proxy for internet content. An Internet host can be a machine or an application connected to the Internet that has an Internet Protocol address (IP address) and can provide several services such as email, web server, websites etc. The main motivation for adopting broadband services is access to internet content. In the early days of broadband emergence, the Director of the Cable and satellite Broadcasting Association of Asia (CASBAA) stated that users' willingness to pay for high speed networks is dependent on their ability to access specialized applications and entertaining content (Wilhelm and Bickers, 2000). Although each internet user can access the internet globally,

internet hosts located in a specific country is a proxy measure for the internet content relevant to this country internet users. This is because of language, relevant websites content etc. Therefore, internet content may be related to the diffusion of broadband. *Content* is expected to have a positive relationship to broadband adoption as it increases the value of the service for broadband subscribers. Murrillo-Garcia M. (2005) and Lin and Wu (2013) found that internet content is a significant driver of broadband adoption, while Cava-Ferreruela et al. (2006) did not find an association.

2.3.2.7 Bandwidth.

Bandwidth is measured by international Internet bandwidth per internet user in Kbit/s. It refers to as the maximum quantity of data transmission from a country to the rest of the world per internet user. *Bandwidth* may be a relative factor for the diffusion of broadband, because bottlenecks may exist for internet traffic, between a specific country and the rest of the world. Moreover, bandwidth capacity is an indicator of the overall performance of the telecommunications sector in each country (Fransman, 2006).

2.3.2.8 E-Services.

The *E-services* variable is measured as the number of secure on-line servers in each country. Secure online servers are used in order to implement secure transactions between parties. It is thus a proxy, on the supply side, of the development of e-services such as e-commerce, e-government, e-health services or e- banking in a country. Better development of e-services enhances the utility of potential and existing subscribers for broadband services and thus are expected to incite broadband adoption.

2.3.2.9 Urban Population.

Urban population is a proxy of the cost of deployment of networks infrastructure in order to service a fixed amount of the population. Cava-Ferreruela and Alabau-Munoz (2006) argue, “that in urban areas where house household and population density is high, operators can take the maximum benefit for the infrastructure deployment cost as the number of possible customers is also high”. Therefore, operators can supply more potential subscribers with same level of investment. In contrast, in areas of low urbanization and population density the investment required to service the same number of subscribers is higher.

2.3.2.10 Privatization.

Private firms are for-profit organizations and therefore have a greater incentive to be more efficient in their allocation of resources in order to increase productivity and increase profits. Moreover, are less vulnerable comparing to public firms, to political interference, that can have a negative impact on the

performance of the firm.

2.3.2.11 LLU.

LLU (Local loop Unbundling) refers to the regulatory policy of permitting competitive telecommunications operators' access to the local loop of the incumbent operator in order to provide services to customers. This policy was implemented by regulators in many countries in order to facilitate entry of competitive operators in the telecoms market. In this study the *LLU* covariate is a dummy variable which takes the value of 1 if local loop unbundling is mandatory for a country in each time period and zero otherwise.

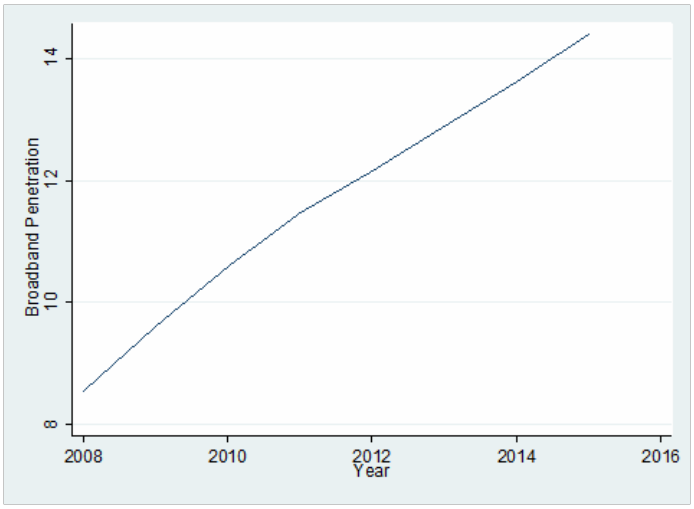
2.3.2.12 Age and Trend.

The *Age* variable corresponds to the percentage of the population that are between 15-64 years old. It measures the percentage of the population in a country that are more likely to seek internet content and to have the necessary e-skills. Moreover, as this age range approximates the working population age in many countries which uses internet services for job-related purposes. Thus, it is expected that this percentage of the population is more willing to pay for the consumption of broadband services. The *Trend* variable is a linear time trend. It is added to the model as to capture the rapid technological innovation that the telecom industry exhibits. Constant technological innovation reduces costs of deployment and improves the quality of broadband services.

2.4 Results and Analysis.

Table 2.2 presents the descriptive statistics of the untransformed variables. From Graph 2.1 we can

Graph 2.1- Broadband Penetration for all countries



Source: ITU World Telecommunication/ICT Indicators (WTI) database. Calculated.

Table 2.2 Descriptive statistics of the untransformed variables.

Variables	Observations	Mean	Standard dev.	Min	Max
Broadband Penetration	1114	11.66492	11.92927	0.0017924	45.10761
Fixed Broadband Price	1096	35.16401	50.50739	0.9234297	635.0171
Liberalization Partial Comp.	1115	0.1363229	0.3432851	0	1
Liberalization Full Comp	1115	0.6538117	0.4759676	0	1
Education	1116	66.06576	16.2581	16.53911	93.9
Income	1119	19799.56	19638.18	748.4153	129349.9
Economic Freedom	1105	62.82054	9.350938	34.3	90.1
Content	1118	12.78174	22.99816	0.0001343	175.205
Bandwidth	1117	91211.19	451189.6	82.24581	7186378
E-services	1111	0.0289166	0.0563639	3.61e-06	0.3406738
Urban Population	1120	59.98663	22.38125	8.445	100
Privatization	1094	0.2239488	0.4170788	0	1
LLU	1115	0.5596413	0.4966529	0	1
Age	1120	64.81578	6.573721	47.24444	85.8724

observe that broadband penetration exhibits an upward trend typical of a technological diffusion process before it reaches its' mature stages. The estimators utilized in order to infer the model, are fixed effects (FE), fixed effects with instrumental variables and the two-stage least squares estimator (FEIV-2SLS) and fixed effects with instrumental variables and the two-stage general method of moments estimator (FEIV-GMM2s). The FEIV-GMM2s estimator is considered a general case of the FEIV-2SLS estimator and in the presence of heteroscedasticity, when the model is over-identified and the and the number of observations is large, as in this study, GMM is more efficient than the 2SLS estimator (Baum, 2014, Dkhil, 2014a).

Table 2.3 Cross sectional Dependence Test.

Variables	CD Test	P-Value	Correlation	Absolute (correlation)
Broadband Penetration	232.852***	0.000	0.84	0.87
Fixed Broadband Price	55.421***	0.000	0.20	0.50
Liberalization Partial Comp.	0.329	0.742	0.00	0.01
Liberalization Full Comp	0.971	0.332	0.00	0.02
Education	181.406***	0.000	0.65	0.74
Income	106.935***	0.000	0.38	0.67
Economic Freedom	3.969***	0.000	0.01	0.48
Content	149.349***	0.000	0.54	0.68
Bandwidth	198.791***	0.000	0.71	0.77
E-services	205.803***	0.000	0.74	0.80
Urban Population	142.766***	0.000	0.51	0.92
Privatization	3.083***	0.002	0.002	0.02
LLU	0.863	0.388	0.00	0.01
Age	20.32***	0.000	0.01	0.02

Under the null hypothesis of cross sectional independence / weak cross sectional dependence, the CD-statistic is distributed as a standard normal ~ N(0,1). ***, significant at 1%.

Following, Section 2.4.1 tests for cross sectional dependence. Section 2.4.2 discusses the test for unit roots, section 2.4.3 tests for multi-collinearity and finally section 2.4.4 presents the results.

2.4.1 Cross Sectional Dependence.

In order to test for the presence of cross-sectional dependence we apply the test proposed by Pesaran (2004) and Pesaran (2015). Results are presented in Table 2.3. The test strongly rejects the null hypothesis of cross-sectional independence or weak cross-sectional dependence (P-values close to zero) for all variables, except the dummy variables *Liberalization Partial Comp., Liberalization Full Comp.* and *LLU.*

2.4.2 Unit Roots.

In order to test if the variables in the model are stationary, we perform a Fisher type test as proposed by Maddala and Wu (1999). Table 2.4 presents the results of the test. The test assumes that all series are non- stationary under the null hypothesis. We can observe that the null hypothesis is rejected for all variables and all statistics, except for the variable *E-services* where statistics report contradictory results. However, for samples with large number of panels, as is the case in this study, the Pm statistic is preferred (Choi, 2001). Therefore, we can conclude that all variables in the model are stationary.

Table 2.4 Unit Root test of Maddala and Wu.

Variables	Statistics			
	P	Z	L*	Pm
Broadband Penetration	2216.7031*** (0.0000)	-22.7204*** (0.0000)	-46.3869*** (0.0000)	81.8406*** (0.0000)
Fixed Broadband Price	817.7828*** (0.0000)	-8.2581*** (0.0000)	-13.2015*** (0.0000)	22.7255*** (0.0000)
Education	520.0684*** (0.0000)	-5.6498*** (0.0000)	-7.3250*** (0.0000)	10.1447*** (0.0000)
Income	778.1664*** (0.0000)	-2.6123** (0.0045)	-22.1819*** (0.0000)	45.1006*** (0.0000)
Economic Freedom	634.6024*** (0.0000)	-4.9087*** (0.0000)	-7.7540*** (0.0000)	15.1233*** (0.0000)
Content	951.7567*** (0.0000)	-10.3143*** (0.0000)	-16.4539*** (0.0000)	28.3869*** (0.0000)
Bandwidth	1262.9875*** (0.0000)	-9.5955*** (0.0000)	-21.1865*** (0.0000)	41.5388*** (0.0000)
E-services	506.2362*** (0.0000)	0.0723 (0.5288)	-2.1250 ** (0.0170)	9.5602*** (0.0000)
Urban Population	4201.4988*** (0.0000)	-49.3586*** (0.0000)	-109.7658*** (0.0000)	165.7136*** (0.0000)
Age	667.7375*** (0.0000)	5.9918 (1.0000)	1.1652 (0.8778)	16.3849*** (0.0000)

The null hypothesis assumes that the variable contains a unit root. The Phillips-Perron test is used which is robust in the presence of unspecified homoscedasticity and autocorrelation. The number of lags has been set to two and panels of variables that have cross-section dependence have been demeaned. The statistics are the following: P is the inverse chi-squared statistic, Z is the inverse normal statistic an L* denotes the inverse logit statistic, while Pm stands for the modified inversed chi-squared statistic. P-values in parenthesis. *** denotes significant at a 1% level.

2.4.3 Multi-collinearity.

In order to investigate the presence of multi-collinearity in the variables used in the model a variable inflation factor (VIF) for each variable was calculated. As we observe from table 2.5 none of the variables exhibited a value of VIF greater than 10 and the overall model has a mean VIF value of considerably less than 6. However, we test if the coefficients and significance levels change considerably when each three variables with the highest VIF are excluded. Table B.1 in the Appendix B presents the results. The coefficients and significant levels for the (3) and (4) specifications do not change considerably except in the (2) specification where the variable *E-services* is excluded, the variables *Trend* and *Income* become significant, while the variables *Privatization* and *Economic Freedom* become insignificant. However, we do not remove the covariate from the model as the exclusion of *E-services* could result in bias due to the omission of a relevant factor.

Table 2.5 Multi-collinearity Diagnostics.

Variables	VIF	VIF-Squared	Tolerance	R-Squared
Fixed Broadband Price	1.50	1.23	0.6647	0.3353
Liberalization Partial Comp.	1.61	1.27	0.6207	0.3793
Liberalization Full Comp.	1.90	1.38	0.5250	0.4750
Education	5.50	2.34	0.1819	0.8181
Income	8.19	2.86	0.1220	0.8780
Economic Freedom	2.27	1.51	0.4402	0.5598
Content	3.53	1.88	0.2834	0.7166
Bandwidth	3.41	1.85	0.2931	0.7069
E-services	8.32	2.88	0.1202	0.8798
Urban Population	2.51	1.59	0.3978	0.6022
Privatization	1.24	1.11	0.8056	0.1944
Age	2.67	1.64	0.3740	0.6260
LLU	1.46	1.21	0.6845	0.3155
Trend	1.42	1.19	0.7032	0.2968
Mean VIF	**3.25**			

2.4.4 Empirical Results.

Table 2.6 presents the results of the regression model using different estimators, for comparison reasons. A robust Hausman test is conducted as to choose between fixed and random effects. The test shows that FE is the appropriate estimator. In the instrumental variables' estimation one of the endogenous variables is considered *Fixed Broadband price* because price affects broadband penetration, however simultaneously telecom operators set their price according to demand for broadband services. Moreover, there is an issue of reverse causality between income and broadband penetration, as broadband incites economic growth in a country. The same applies for industry factors such as internet content, international bandwidth and e- services. While these factors may impact broadband

Table 2.6 Results of Regression Analysis for the determinants of Broadband Penetration

Dependent Variable Broadband Penetration.			
Independent Variables	FE	FEIV-2SLS	FEIV-GMM2s
Fixed Broadband price.	**-0.291***** (-3.14)	**-0.273***** (-3.02)	**-0.192***** (-3.34)
Liberalization Partial Comp.	0.229 (1.65)	**0.259*** (1.75)	**0.231*** (1.86)
Liberalization Full Comp.	**0.260**** (2.10)	**0.263**** (2.19)	**0.250**** (2.26)
Education	-0.009 (-0.59)	-0.011 (-0.67)	-0.007 (-0.63)
Income	**0.839*** (1.71)	0.570 (1.31)	0.425 (1.56)
Economic Freedom	**-0.023*** (-1.71)	**-0.025*** (-1.84)	**-0.022**** (-2.27)
Content	**0.102**** (2.17)	**0.140***** (2.60)	**0.155***** (2.37)
Bandwidth	0.093 (1.60)	0.059 (1.04)	**0.069*** (1.73)
E-Services	**0.142*** (1.71	**0.280***** (2.95)	**0.292***** (4.00)
Urban Population	0.052 (1.45)	0.047 (1.28)	**0.049*** (1.80)
Privatization	0.128 (1.44)	**0.157*** (1.70)	**0.143**** (2.04)
LLU	-0.098 (-1.04)	-0.103 (-1.13)	-0.106 (-1.38)
Age	**0.129***** (3.19)	**0.129***** (3.18)	**0.128***** (4.64)
Trend	**0.041*** (1.75)	0.028 (1.19)	0.025 (1.41)
Hausman test robust (P-value)		26.998 (0.0193)	
Sargan-Hansen test (P-value)		2.808 (0.2457)	2.843 (0.2414)
Difference-in-J Endogeneity test (P-Value)		27.653 (0.0000)	41.305 (0.0000)
Modified Wald test (P-value)		6.0e+05 (0.0000)	
Lagram-Multiplier test (P-value)		62.887 (0.0000)	
F test (P- value)	26.67 (0.0000)	28.53 (0.0000)	53.30 (0.0000)
R^2	0.5921	0.5841	0.5792
Numb. of observations	1032	1032	1032

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

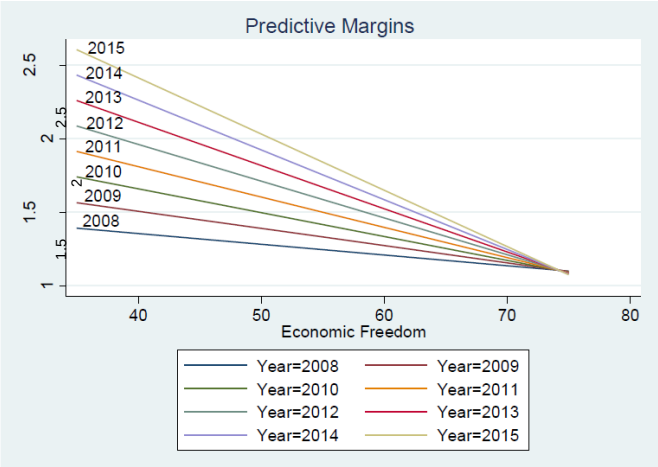
adoption, they also in turn are affected by the level of broadband adoption, presenting again an issue of reverse causality. For example, the supply of e-services or internet content is tied to the development of the telecommunications infrastructure in a country. The more developed it is, the more likely is

governments or businesses to offer such services as there is a larger customer base to consume them. Therefore, all these factors are considered endogenous in this study. Considering our findings in table 2.6, in both instrumental variables estimators the Sargan-Hansen test of over-identifying restrictions fails to reject the null that the instruments are jointly valid. Lastly, the Difference-in-J endogeneity test justifies our choice to use instrumental variables methods.

2.4.4.1 Empirical Results of regression analysis for all countries.

The variable *Fixed Broadband price* is significant and with the appropriate sign, for all estimators. Looking at the FE-GMM2s estimation a 1% decrease (increase) in *Fixed Broadband Price* would have as an effect an approximate 0.2% increase (decrease) in broadband diffusion. Concerning the variables *Liberalization Partial Comp*. and *Liberalization Full Comp.* are both significant and positive. This result indicates that countries which have liberalized the market of fixed local telephony and issued additional licenses have significantly higher broadband penetration than countries which did not allow for the introduction of competition (the reference category). We do not find evidence that education impacts broadband adoption as the variable *Education* is not significant. Our finding matches that of Lee, (2008) but in contrast to other studies that have examined the impact of education (for instance, Lee, 2011a; Lin and Wu, 2013; Ovington et al., 2017). Similarly, we do not find that the level of income impacts the level of broadband adoption as is evident by the insignificance of the *Income* variable for the FE-IV regressions. A surprising result is that the covariate *Economic Freedom* has the opposite sign from the one expected and is significant, suggesting that a 1-unit decrease (increase) in the economic freedom index has as an outcome an approximate 0.02% increase (decrease) in broadband diffusion. In order to investigate further, we estimated a model (results are presented on Table B.2 on the Appendix B.) including an interaction term between the economic freedom variable and the time trend in order to examine if the marginal effect of economic freedom on broadband penetration is dependent on the time dimension. We find that the interaction term is negative and significant. Moreover, from Graph 2.2 we can observe that the negative effect of economic freedom on broadband penetration becomes stronger with time, as the slopes of the marginal effect becomes steeper. The variables *Content* and *E-services* are both positive and significant indicating that the level of internet content and supply of e-services play a positive role in the diffusion of broadband. A 1% increase (decrease) in the covariate *Content* has as a result an approximate 0.15% increase (decrease) to the level of broadband penetration. This finding corresponds to that of studies such as Murrillo-Garcia (2005) and Lin and Wu (2013). A 1% increase (decrease) in the covariate *E-services* results in an approximate 0.29% increase (decrease) in the level of broadband diffusion. The covariates *Urban population* and *Bandwidth* have both the

Graph 2.2- Marginal Effects of Economic Freedom on Broadband Penetration (for various values of Economic Freedom and Years=2010 to 2015).



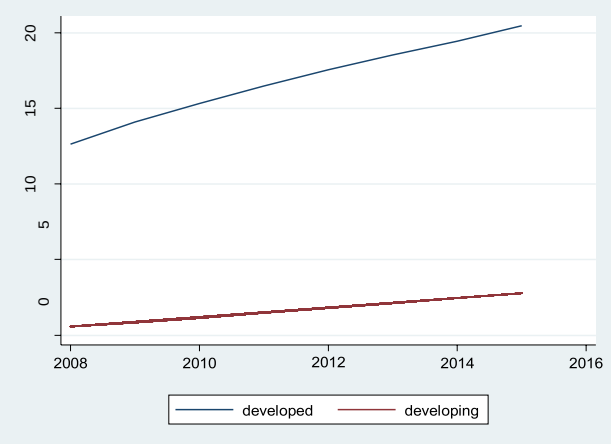
expected sign and are significant for the FE-GMM2s regression. However caution is warranted in interpreting the results since the covariates are insignificant for the FE-2SLS regression. An 1% increase (decrease) in the level of bandwidth has as an outcome an approximate 0.07% increase (decrease) in the level of broadband penetration, while a 1-unit increase (decrease) in the percentage of urban population causes an approximate 0.05% increase (decrease) to broadband. The dummy variable *Privatization* is positive and significant suggesting that in countries where the main fixed telecoms operator is privatized, they have significant higher levels of broadband penetration than those countries which did not. We do not find evidence that countries which have implemented mandatory local loop unbundling significantly differ in their levels of broadband penetration comparing to countries which have not. This result is similar to the studies of Cava-Ferreruela et al. (2006) or Nardatto et al., (2014) where they did not find a significant relationship between local loop unbundling and broadband penetration but contrary to studies that have concluded that local loop unbundling has either a positive relationship (Garcia-Murillo, 2005; Grosso, 2006; Gruber and Koutroumpis, 2012; Ovington et al., 2017) or negative one (for instance, Crandall et al., 2013) to broadband penetration. Lastly, the variable *Age* is significant and positive indicating that countries with a greater percentage of population between 15 to 64 years old have significantly higher broadband diffusion. A 1-unit increase (decrease) in the covariate *Age* signifies an approximate 0.13% increase (decrease) in broadband diffusion.

2.4.4.2 Empirical Results of regression analysis for developed and developing countries.

The countries in the sample are separated to different groups, according to their level of income, in developed and developing countries, in order to investigate if there are significant differences in the factors that impact broadband penetration. The separation of the countries into the two groups was

done according to the classification of the World Bank. The World Bank separates the countries into four groups, low, lower-middle, upper-middle, and high-income countries[24]. Developed countries are those that generally have achieved a higher level of industrialization and have higher GDP per capital. According to the World Bank developed countries are those that are classified as high and upper-middle income and developing are those of lower-middle and lower income (The World Bank, 2017).

Graph 2.3- Broadband Penetration for Developed and Developing countries.



Source: ITU World Telecommunication/ICT Indicators (WTI) database. Calculated.

Graph 2.3 presents broadband penetration through the sample period for developed and developing countries, respectively. As we can observe, broadband penetration for both groups exhibit an upward trend, but the level of penetration for developing countries is considerably lower.

Table 2.7 presents our findings. *Fixed Broadband price* has the expected negative sign for both developed and developing countries, however we only find to be significant for the developing countries group. The price elasticity was expected to be more elastic (larger negative coefficient) for countries with lower income where potential subscribers have tighter budgetary constraints, however the insignificance of the covariate for developed countries is somewhat unexpected. The Liberalization of the telecoms market differs significantly only for the case were additional licensees are partially restricted, for developed countries (and only for the FE-GMM2s estimator, as signified by the variable *Liberalization Partial Comp.)* comparing to the reference case where only a monopoly operator is licensed. In contrast the variable *Liberalization Full Comp,* which indicates the case where licensees are completely unrestricted significantly differs from the reference case only for developing countries. Moreover, the *Economic freedom* variable is negative and significant only for the developed countries

[24] The classification was made according to the fiscal year 2014, in order to match the sample period of this study.

group. The variable *Content* is significant and positive for both groups. However, the coefficient is significantly higher for developed countries (approximately 0.5 versus 0.12) suggesting that internet content has higher impact for countries that have higher income. *Bandwidth* is significant and positive only for developed countries and only for the FE-GMM2s specification. Finally, the variables *E-services*, *Privatization* and *Age* have significantly positively association to broadband penetration only for developed countries.

Table 2.7 Results of Regression analysis for Developed and Developing countries.

Dependent Variable Broadband Penetration.	FEIV-2SLS		FEIV-GMM2s	
Independent Variables	Developed	Developing	Developed	Developing
Fixed Broadband price	-0.058 (-0.59)	**-0.287**** (-2.38)	-0.047 (-0.62)	**-0.191**** (-2.17)
Liberalization Partial Comp.	0.308 (1.39)	0.398 (1.36)	**0.342*** (1.78)	0.347 (1.42)
Liberalization Full Comp.	0.024 (0.22)	**0.430*** (1.95)	0.029 (0.32)	**0.419**** (1.96)
Education	-0.002 (-0.13)	0.003 (0.08)	0.002 (0.18)	0.009 (0.38)
Income	-0.059 (-0.15)	0.768 (0.77)	-0.154 (-0.52)	0.392 (0.65)
Economic Freedom	**-0.019*** (-1.74)	-0.012 (-0.40)	**-0.018**** (-2.22)	-0.002 (-0.08)
Content	**0.477***** (2.80)	**0.113*** (1.77)	**0.529**** (3.47)	**0.124*** (1.66)
Bandwidth	0.088 (1.39)	0.100 (0.92)	**0.086*** (1.67)	0.112 (1.54)
E-Services	**0.291**** (2.57)	-0.063 (-0.51)	**0.260***** (2.93)	-0.078 (-0.81)
Urban	0.049 (1.18)	-0.034 (-0.44)	0.045 (1.60)	-0.043 (-0.77)
Privatization	**0.175***** (3.61)	0.148 (0.54)	**0.183***** (4.03)	0.089 (0.42)
LLU	-0.090 (-0.89)	-0.086 (-0.44)	-0.077 (-1.07)	-0.091 (-0.59)
Age	**0.104***** (3.57)	0.076 (0.67)	**0.099***** (4.57)	0.071 (0.92)
Trend	-0.023 (-1.38)	**0.159***** (2.77)	**-0.025*** (-1.75)	**0.176***** (4.14)
Sargan-Hansen test (P-value)	1.437 (0.4874)	3.984 (0.1364)	1.821 (0.4023)	3.640 (0.1620)
F test (P- value)	21.54 (0.0000)	24.25 (0.0000)	34.82 (0.0000)	33.07 (0.0000)
R^2	0.5271	0.6283	0.4935	0.6220
Numb. of observations	682	350	682	350

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(ii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

2.5 Discussion and Conclusions.

This study attempts to identify the factors that determine broadband penetration for a large sample of international countries. Moreover, it separates these countries according to developed and developing countries groups, in order to identify possible differences in the factors that affect broadband diffusion in countries with different income characteristics.

The study highlights the importance of e-services for the proliferation of broadband. It is important for policymakers to encourage the development of e-services in general and more specifically for governments to develop e-government or e-health services, as it increases the value of broadband services for subscribers. Furthermore, it is imperative for regulators to issue additional licenses as liberalization of the fixed telecoms market has provided benefits to broadband diffusion that allowed for the introduction of competition. Our finding is that economic freedom is negatively correlated to broadband diffusion and that the effect becomes stronger for the later years in our sample. It is possible that we observe this relationship due to a delayed effect caused by the shock of the economic crisis and its' deteriorating effect on economic freedoms worldwide. However, further research is required for this to be to be confirmed. The supply of relevant internet content is an important factor for the diffusion of broadband for both developed and developing countries. It increases the value of broadband to subscribers as the "consumption" of relevant internet content is the primary motivation for the subscription of broadband services. Privatization of the main fixed telecoms operator has enhanced broadband proliferation and thus governments should resist vested interests and public pressure that wants retainment of public ownership. However, we also find that there are some differences between country groups separated by their level of income. E-services do not impact broadband diffusion in the case of developing countries. It may be that a country must have reached a level of industrial development before e-services impact broadband adoption. The quality of e-services tends to be typically higher for higher income countries and this may be the reason why it only affects developed countries. If this is the reason, then developing countries must improve the quality and usefulness of such e-services in order to incite broadband adoption. We find that privatization of the main fixed telecoms operator again benefits broadband diffusion only for developed countries. In general, institutions in developing countries do not function as well as in developed ones, and phenomena like regulatory capture or the collusion of private interests with governments against the public interest are more common. Thus, this may be the reason why privatization has not resulted in the benefits that ensued in developed countries. Finally, the unrestricted issue of licenses positively impacts broadband

adoption only for developing countries. The reason for the fact that we do not find evidence of significant association for developed countries could be monopolies are more “efficient” and more likely to pass some of their surplus to consumers in developed countries, due to the quality of regulation.

Chapter 3

Determinants of Mobile Broadband Diffusion

3.1 Introduction.

The development of the mobile phone as a communication device has been rapid over the last two decades. Initially one of the major factors inhibiting the spread of the mobile internet was its' relative disadvantage in terms of speed of access comparing to fixed broadband, especially in developed countries (Westlund and Bohlin, 2008). However recent technology advancements have resulted in major increases in performance of the mobile phone, as well as at the same time significant cost reductions of equipment (Gruber, 2005). The mobile phone has evolved from offering only voice and limited internet connectivity in the early 2000 to a multipurpose device offering access to high quality video on demand (Kongaut and Bohlin, 2016). With the advancement of 3G and especially 4G mobile networks, where 4G can achieve theoretical speeds of greater than 100 Mbit per second (ITU, 2008), mobile broadband has come to rival fixed-line broadband services in terms of speed. Even at the later years of the last decade, mobile subscribers had come to surpass fixed line subscribers worldwide (OECD, 2007). Furthermore, mobile technology has even been seen as capable, due to its' lower infrastructure costs than fixed networks and the relative affordability of mobile phones comparing to personal computers, of bridging the digital divide that exists between people that have access to the internet and those that have not, especially for developing countries (Loo and Ngan, 2012).

The remaining portion of this chapter is organized as follows. Section 3.2 investigates the relevant literature of mobile broadband adoption. Section 3.3 discusses the empirical model and relevant variables, section 3.4 presents the results of the regression analysis, and finally section 3.5 provides a discussion and conclusions.

3.2 Related Literature.

As mentioned above, early mobile technology allowed mainly the transmission of voice-only information through the mobile networks. The transmission of data through the internet was a later development with the advance of mobile networks technology as well as the development of internet capable mobile handsets. Therefore, scholars initially focused in examining the factors that influence the diffusion of mobile telephony as mobile broadband penetration was at its' infancy. In examining the relevant literature, due to the nature of this study, we focus on cross-country studies of the determinants of

mobile diffusion (both for mobile telephony and mobile broadband), rather than studies that examine mobile diffusion in a specific country.

Early literature on the subject, concerning factors influencing mobile telephony adoption focused on the transition between analogue and digital telephony. One of the early studies was that of Ahn and Lee (1999). Investigating the factors that determine demand for mobile telephony networks they conclude that income and fixed line penetration promote mobile diffusion, implying that mobile and fixed telephony are complements.

Another early study, was that of Burki and Aslam (2000). Burki and Aslam (2000) utilized a panel data sample of 25 Asian countries from a 1986 to 1998 period. The authors show that the transition from analog to digital mobile technology, as well as the introduction of competition in the digital period enhanced the adoption of mobile phones. They did not find significant correlation between main fixed telephony infrastructure or GDP per capita, with mobile telephony penetration.

Gruben and Verboven (2001) employing a data set of 15 EU countries between 1992 to 1997 focused in three factors. Firstly, the importance of technology (analogue vs digital), secondly the effect of the timing of the first mobile licenses issued and thirdly the introduction of competition. They find that the transition of analogue to digital technology was a major factor for the diffusion of mobile telecommunications. Moreover, countries which granted licenses be-lately showed a significant but slow catching effect. Moreover, the introduction of competition, during both the analogue and digital periods, had a significant positive effect. Lastly, they find that fixed network services is a substitute to mobile communication services.

Expanding on their previous paper Gruben and Verboven (2001a) used a panel data set of 140 countries from 1981 to 1997. They conclude that introducing competition has a strong immediate impact on diffusion. In addition, setting a single technological standard of mobile networks accelerates substantially the diffusion of analogue technologies. Furthermore, they argue that the introduction of competition with the issuing of additional licenses, had a significant impact on the growth of mobile diffusion, especially for the digital period. Finally, income per capita has a significant positive effect on mobile adoption and fixed network penetration has a positive relationship to mobile diffusion, suggesting a complimentary effect.

Similarly, Koski and Kretschmer (2002) using a panel data set of 32 industrialized countries for a period between 1991 to 1999 find that the time of entry of digital mobile telephony, within standards competition, market competition and lower user cost are significant factors positively influencing digital

mobile telephony

Madden et al. (2004) examine the effect of cost and income on mobile telephone subscribers in a panel sample of 56 countries for a period from 1995 to 2000. They argue that income and cost significantly impacts mobile telephony penetration, as well as for the existence of network effects.

One further study that focused on the determinants of mobile diffusion employing a worldwide sample of countries, is that of Rouvinen (2006). The author included a panel data set of 165 countries from 1993 to 2000 in his analysis as to examine any differences in the determinants of digital mobile telephony diffusion between developed and developing countries. He argues that multiple mobile standards hinder diffusion and market competition promotes it for both developed and developing countries. In additionh, he concludes that some factors are more important for developing countries, such as having a high (non-telecom) technological level, being more open in terms of trade, having a larger market size and network effects. He does not find the income effect to be significant. Lastly he finds surprisingly that more democratic regimes are negatively correlated to mobile diffusion for developing countries.

Finally, Bohlin et al. (2010) concentrated on the factors that affect different generations of mobile telecommunications diffusion. In their investigation of third generation mobile (3G), Bohlin et al. (2010) utilized a panel of 62 international countries for a period from 2002 to 2007. The authors conclude that income, urbanization, broadband penetration, competition between firms as well as regulation, positively affect diffusion of the 3g generation mobile technology.

From the above discussion on early studies of the determinants of mobile telephony diffusion we can conclude that the general consensus is that market competition facilitates its' proliferation (Burki and Aslam, 2000; Gruben and Verboven, 2001; Gruben and Verboven, 2001a; Koski and Kretschmer (2002); Rouvinen P., 2006; Bohlin et al., 2010). Moreover, the level of income has a significant positive effect (Ahn and Lee, 1999; Gruben and Verboven, 2001a; Madden et al., 2004; Bohlin et al., 2010) and urbanization facilitates diffusion (Bohlin et al., 2010). The relevant literature is more contradictory in terms of its examination of standardization policy, whereas different studies either conclude that a single mobile standard positively impact diffusion (or that multiple standards hinders it) (Gruben and Verboven, 2001a; Rouvinen P., 2006) or that multiple standards are actually preferable (Koski and Kretschmer, 2002). Finally, in terms of whether mobile and fixed telephony are either substitutes or complements, Ahn and Lee (1999) concludes that are complements, Burki and Aslam (2000) that there is no significant association, or that they are substitutes (Gruben and Verboven, 2001). It is reasonable to assume that the contradictory results for some of the determinants, at least partly, are due to the

differences in sample periods, countries examined and the various estimators that these studies employed.

As mentioned before, as mobile broadband adoption picked up in various countries at later years and data became more readily available, studies shifted in the examination of determinants of mobile broadband. One of the first studies to examine specifically mobile broadband adoption was that of Lee (2008). Including a panel data sample of 54 countries for a period from 2004 to 2006, he shows that multiple standards and income positively affect mobile broadband penetration while 1G and 2G mobile penetration are negatively correlated to it.

Furthermore Lee et al. (2011b) exploring again the determinants of mobile broadband diffusion, they employed a panel of 26 OECD countries for a period of 2003 to 2008. They show that multiple standards and population density are the main factors positively affecting mobile broadband diffusion. They also conclude that mobile broadband services are complement to fixed broadband services as they find that fixed broadband price is negatively correlated to mobile broadband penetration.

A more recent study by Yates et al (2013) uses cross-sectional data from 103 developing countries for the year 2012. They conclude that competition among telecommunication service providers, effective public-sector governance and sound regulation positively affect mobile broadband diffusion.

Shinohara et al. (2014) using panel data set of six OECD countries from 2000 to 2012, conclude that the launch of Android smartphones, competition among telecommunication carriers, and FTTH adoption are positively associated to mobile broadband proliferation while price is negatively correlated.

Finally, Sagbansua et al. (2015) examines the determinants of mobile broadband penetration for 34 OECD countries during the years 2001 to 2011. They argue that GDP per capita and education are significant factors that positively affect the proliferation of mobile telephony penetration while price and mobile traffic per subscriber have a negative effect. Lastly, they find a significant network effect.

In regards to the literature of mobile broadband penetration the factors that they examined resemble the previous studies of mobile telephony. In summary they conclude that income positively impacts penetration (Lee, 2008; Sagbansua et al., 2015), market competition facilitates adoption (Yates et al., 2013; Shinohara et al., 2014), the level of education promotes mobile broadband (Sagbansua et al., 2015), sound regulation and good public governance promote diffusion (Yates et al., 2013), multiple standards positively affect mobile broadband penetration (Lee, 2008; Lee et al., 2011b) and fixed and mobile broadband are complements (Lee et al., 2011b).

From all the studies surveyed most of the studies use a panel data set with a relatively limited number

of countries (with the exception of studies such as, Gruben and Verboven, 2001a; Rouvinen P., 2006; Yates et al., 2013). Including in the analysis, a high number of countries does not only allow more robust results for the determinants of mobile penetration worldwide, but also allows comparisons to be made between different groups of countries, with different characteristics.

3.3 Empirical Model and Data.

3.3.1 Empirical Model.

In order to investigate the relationship between the adoption of mobile broadband services and its determinants, a linear regression model with country effects is implemented. Equation (6) describes the linear relationship between the independent and dependent variables of the model examined in this study. Furthermore, to prevent problems of positive skewness that may affect the analysis, most variables[25] were transformed to their natural logarithms.

$$\begin{aligned} &ln\,(Mobile\ Broadband\ penetration)_{it} = b_0 + b_1(ln\ Mobile\ Price)_{it} + b_2(ln\ Fixed\ Broadband\ price)_{it} \\ &+ b_3(Market\ Liberalization)_{it} + b_4(Education)_{it} + b_5(Economic\ Freedom)_{it} + b_6(ln\ Income)_{it} \\ &+ b_7(ln\ Content)_{it} + b_8(ln\ Bandwidth)_{it} + b_9(ln\ Urban\ Population)_{it} + b_{10}(ln\ E\text{-}Services)_{it} \\ &+ b_{11}(Standardization\ Policy)_{it} + b_{12}(Age)_{it} + b_{13}(Trend)_t + \alpha_{it} + \varepsilon_{it} \end{aligned} \quad (6)$$

The terms α_{it} refers to the specific unobservable country effects that are not included as variables and ε_{it} is the standard error term. The covariates were selected according to the relevant literature and data availability. The independent variables include overall thirteen factors which are the following: i) *Mobile price*, ii) *Fixed broadband price*, iii) *Market liberalization*, iv) *Education*, v) *Economic freedom*, vi) *Income*, vii) *Content*, viii) *Bandwidth*, ix) *Urban population*, x) *E-services,* xi) *Standardization policy,* xii) *Age* and xiii) a linear time *Trend,* which are further elaborated below.

3.3.2 The Data and Variables.

Table 3.1 summarizes the type of variable, its measurement and its data source. The data set involves a panel data set of 124 international countries covering a period from 2010 to 2015[26]. The panel data set is unbalanced[27]. Most of the data comes from ITU World Telecommunication/ICT Indicators (WTI) database and are yearly for each variable. The dependent variable is defined as mobile broadband penetration. Its' measurement is mobile broadband subscriptions per 100 population. It includes mobile subscriptions that

[25] Except for the *Standardization policy* and *Market liberalization* variables which are binary, *Economic freedom* and *Education* variables which are indexes, and the Urban population and Age covariates which are percentages.
[26] See table C.4 in the Appendix C for a list of countries included in this study.
[27] For the dependent variable Mobile Broadband penetration there are missing observations for (continued page 57)

use mobile broadband services to access the internet in a pay-per-use basis, subscriptions with prepaid broadband plans[28], as well as mobile broadband subscriptions with a monthly data plan for internet access with a recurring subscribers' fee.

Mobile price is defined as the mobile-cellular sub-basket in US dollars (adjusted for PPP) as published by the International Telecommunications Union[29]. The sub-basket refers to the price of a mobile standard monthly usage of 30 outgoing calls plus 100 SMS messages per month. Although, there were insufficient data on mobile broadband prices available to us, mobile price is expected to be correlated to the price that subscribers must pay for mobile broadband services, and thus it is used as a proxy for the latter. *Mobile price* is expected to have an inverse relationship to mobile broadband penetration. Several studies have concluded that lower user costs promote mobile penetration (Koski and Kretschmer, 2002; Madden et al., 2004; Shinohara et al., 2014; Sagbansua et al., 2015, for instance).

Fixed Broadband price is measured as the fixed broadband Internet monthly subscription charge in US dollars. Economic theory suggests that the relationship between the variable *Fixed Broadband price* and mobile penetration would depend on whether fixed broadband and mobile broadband are complements or substitutes. An inverse relationship is expected if they are complements and a positive relationship if they are substitutes. As mentioned before, studies are inconclusive as to whether they are complements (Ahn and Lee, 1999; Gruber H., 2001; Lee et al., 2011b) or substitutes (Gruben and Verboven, 2001; Grzybowski L., 2014). This is not surprising. According to OECD (2012), mobile and fixed line networks are both substitutes and complements. Subscribers may substitute fixed telephony for mobile telephony, while at the same time mobile networks increasingly rely on fixed broadband networks to meet subscribers demand for high speed data (OECD, 2012).

[27(continued)] Albania for 2010, for Algeria for 2010 to 2013, for Burkina Faso for 2010 to 2012, for Cameroon for 2010 to 2013, for Djibouti for 2010 to 2012, for Gabon for 2010 to 2013, for India for 2010, for Iran for 2010;2011, for Lebanon for 2010, for Suriname for 2010;2011, for Vanuatu for 2010 and for Yemen for 2010.For the Mobile price variable there are missing observations for Argentina for 2013 to 2015, for Azerbaijan for 2015, Belarus for 2015, Cameroon for 2012, Djibouti for 2013, Estonia for 2011, Gabon for 2010;2011, Hondurasfor 2012, Iran 2010;2011, Kyrgyzstan for 2011, Laos for 2012, Lebanon for 2013 to 2015, Malawi for 2011, Mongolia for 2010;2011, Rwanda for 2012, United Arab Emirates for 2013, Uzbekistan 2013 to 2015 and for Yemen for 2013;2015. For the Fixed Broadband price variable there are missing observations for Gabon for 2010;2011, Georgia 2010, Kyrgyzstan for 2012, Laos for 2012 and for Malawi 2011. For the Market Liberalization variable there are missing observations for Djibouti for 2010. For the Economic Freedom variable there are missing observations for Brunei Darussalam for 2010 to 2012, Iran for 2013, for Sri Lanka 2013, and for Switzerland for 2013. For the Income variable there are missing observations for Switzerland for 2015 and Vanuatu for 2015. For the Bandwidth variable there are missing observations for Guatemala for 2001 and Suriname for 2011.

[28] It includes only subscriptions where the users have accessed the internet in the previous three months.

[29] See ITU (2015).

Table 3.1 Variables, Measurement and data sources.

Variable	Measurement	Source
Mobile Broadband	Mobile broadband Internet subscriptions per 100 inhabitants.	ITU World Telecommunication/ICT Indicators (WTI) database.
Mobile Price	Mobile-cellular sub-basket (US PPP$).	ITU Measuring the Information Society Reports (2011-2016).
Fixed Broadband price	Fixed broadband Internet monthly subscription charge (US$).	ITU World. Telecommunication/ICT Indicators (WTI) database.
Market Liberalization	A binary variable, whereas takes the value of 0 if the market of mobile telephony is restricted to a single license (monopoly) or few (partial competition), and 1 if there are no restrictions (full competition).	ITU ICT/Eye Regulatory database and The Little Data Book on Information and Communication Technology Reports (2012-2017).
Education	UNDP Education Index. It takes theoretically values from 0 to 100, with higher values signifying a higher level of education.	UNDP Human Development Reports (2010-2016).
Income	GDP per capita (constant 2011) (US PPP $).	The World Bank World Development Indicators database.
Economic Freedom	Index of economic freedom. It takes theoretically, values from 0 to 100, with higher values signifying higher economic freedom.	Heritage Foundation.
Content	Number of Internet hosts per 100 people.	Internet System Consortium, Internet Domain Survey.
Bandwidth	International Internet Bandwidth per internet user, in bit/s.	ITU World Telecommunication/ICT Indicators (WTI) database.
E-Services	Number of secure online servers per 100 people.	The World Bank World Development Indicators database
Urban Population	Percentage of Urban population to total population. (%).	The World Bank World Development Indicators database.
Standardization Policy	It takes a value of 1 if multiple 3G standards (such as UMTS, CDMA2000, TD-SCDMA) exist concurrently in a country and 0 otherwise.	Various Sources[30].
Age	Percentage of population between 15-64 years old.	The World Bank World Development Indicators database.

Standardization policy refers to, if multiple mobile standards coexist in a country or a single standard dominates the market. It refers to the government policy of either allowing for a market orientated outcome where the market dictates if multiple standards coexist or not, or instead a government orientated outcome where the government dictates a single standard to be adopted by mobile operators. There are arguments in favor of both policies. Mobile telephony is a market that exhibits

[30] Information on mobile standards come from websites http://www.cdg.org/index.asp, http://www.spectrummonitoring.com/, www.gsmarena.com.

network effects. Gruber and Verboven (2001a) argue that for advocates of imposing a single standard, network effects can be realized sooner and technological uncertainty among customers can be reduced. On the other hand, they argue, that for advocates of allowing for competing standards, it is the best guarantee for avoiding the situation where an inferior standard may be imposed and that is the best policy for promoting technological innovation. Although they conclude that "free markets may also lead to lock in into inferior outcomes, thereby necessitating government intervention to cope with this network externality".

The *Market liberalization* variable takes the value of 0 if the market of mobile telephony is restricted to a single or few licensees, and 1 if there are no restrictions. Bohlin et al. (2010) argues that for second generation mobile technology, increasing the number of firms in the market "produced an unambiguously beneficial effect for the adoption of mobile telecommunications".

The *Education* covariate is measured by the education index published each year by the United Nations Development Program. Although few studies have showed that education is significantly related to mobile penetration (Sagbansua et al, 2015). Srinuan et al. (2012) and Sagbansua et al. (2015) have found that the education level is a significant positive factor.

Income is measured as GDP per capita in constant 2011 prices in US dollars (adjusted for PPP).

Economic Freedom is measured by the economic freedom index published its year by the Heritage Foundation. Lee (2008) explored the relationship between mobile broadband and economic freedom but he did not find it to be significantly correlated. Rouvinen, (2006) exploring how the openness of a country in terms of trade impacts penetration, shown that it boosts penetration for developing countries. *Content* is measured by number of internet hosts per 100 people. *Bandwidth* is measured by international internet bandwidth per internet user in Kbit/s. The *E-services* variable is measured as the number of secure on-line servers in each country. *Urban* population is a proxy of the cost of deployment of mobile networks infrastructure in order to service a fixed amount of the population. Yates et al., (2013) argues that "service providers are more likely to be successful in delivering mobile broadband service in urban areas, where the population is more concentrated and infrastructure for mobile devices and internet backbone connectivity is already in place". The *Age* variable corresponds to the percentage of the population that are between 15-64 years old while *Trend* is a linear time trend that captures technological advancement in the industry.

3.4 Results and Analysis.

Table 3.2 presents the descriptive statistics of the untransformed variables. Graph 3.1 presents graphically the development of Mobile Broadband penetration over the sample period. It is evident that

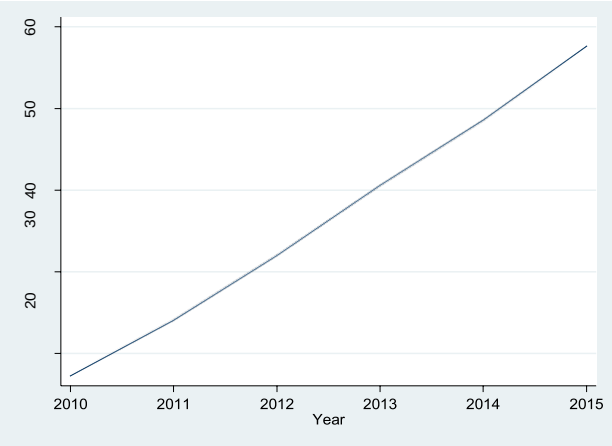
Table 3.2 Descriptive statistics of the untransformed variables.

Variables	Observations	Mean	Standard dev.	Min	Max
Mobile Broadband Penetration	744	36.67285	33.20953	0	149.3328
Mobile Price	716	23.99064	13.5875	2.1	78.21
Fixed Broadband Price	738	31.07994	44.26725	0.9234297	562.1761
Market Liberalization	743	0.6864065	0.4642658	0	1
Education	744	67.80806	16.33969	23.2	93.9
Income	744	21249.35	20441.63	917.7639	129349.9
Economic Freedom	738	62.39092	9.733965	28.5	90.1
Content	744	15.39597	25.34743	0.000163	175.205
Bandwidth	742	118339.2	542460	89.82797	7186378
E-services	744	0.0354571	0.0646492	0.0000125	0.3406738
Urban Population	744	62.61564	21.38771	14.492	100
Standardization Policy	744	0.311828	0.4635516	0	1
Age	744	65.22457	6.445335	48.47287	85.8724

mobile broadband exhibits a substantial, near linear upward trend. In order to infer the model, we applied different Fixed Effects estimators to infer the impact of the various determinants in mobile broadband penetration for all countries in the sample. The estimators considered were fixed effects (FE), fixed effects with instrumental variables and the two stage least squares estimator (FEIV-2SLS) and fixed effects with instrumental variables and the two-stage general method of moments estimator (FEIV- GMM2s).

Following the rest of Section 4, Section 3.4.1 tests for cross sectional dependence. Section 3.4.2 discusses the test for unit roots, section 3.4.3 provides a discussion and test for multi-collinearity and finally section 3.4.4 presents the results.

Graph 3.1- Mobile Broadband penetration for all countries.



Source: ITU World Telecommunication/ICT Indicators (WTI) database. Calculated.

3.4.1 Cross Sectional Dependence.

In order to test for the presence of cross-sectional dependence we use the test proposed by Pesaran

(2004) and Pesaran (2015). Results are presented in Table 3.3. The test strongly rejects the null hypothesis of cross-sectional independence or weak cross-sectional dependence (P-values close to zero) for all variables, except *Market Liberalization*, *Standardization policy* and *Age.*

Table 3.3 Cross sectional Dependence Test.

Variables	CD Test	P-Value	Correlation	Absolute (correlation)
Mobile Broadband Penetration	192.67***	0.000	0.901	0.901
Mobile Price	21.559***	0.000	0.11	0.50
Fixed Broadband Price	33.307***	0.000	0.16	0.51
Market Liberalization	0.505	0.613	0.00	0.02
Education	165.883***	0.000	0.78	0.82
Income	100.727***	0.000	0.47	0.78
Economic Freedom	7.796***	0.000	0.04	0.69
Content	62.592***	0.000	0.29	0.62
Bandwidth	131.049 ***	0.000	0.62	0.78
E-services	132.612***	0.000	0.60	0.77
Urban Population	129.924***	0.000	0.61	0.94
Standardization Policy	0.299	0.765	0.00	0.00
Age	0.799	0.424	0.00	0.88

Under the null hypothesis of cross sectional independence / weak cross sectional dependence, the CD-statistic is distributed as a standard normal ~ N(0,1). ***, significant at 1%.

3.4.2 Unit Roots.

In order to test if the variables in our model are stationary, we perform a Fisher type test as proposed by Maddala and Wu (1999). Table 3.4 shows the results of the test. The test assumes that all series are non-stationary under the null hypothesis against the alternative, that at least one series in the panel is stationary. From the results on table 4 we can discern that the null hypothesis is rejected for all variables and all statistics, except for the variable *E-services* where statistics report conflicting results. However, for samples with a significant number of panels, as is the case in this study, the P_m statistic is the most appropriate (Choi, 2001). Therefore, we conclude that all variables in the sample are stationary[31].

3.4.3 Multi-collinearity.

In order to investigate the presence of multi-collinearity in the variables used in the model a variable inflation factor (VIF) for each variable was calculated. From Table 3.5 we can observe that none of the variables exhibits a value of VIF greater than 10 and the overall model has a mean VIF value of considerably less than 6. Therefore, the model does not suffer from severe multi-collinearity. However, we test if the coefficients and significance levels of the regression analysis change considerably when each of the three variables with the highest VIF are excluded. Table C.1 in the Appendix presents these

[31] The variables *Market liberalization* and *Standardization policy* are not included since they are binary.

results. The coefficients and significant levels do not change considerably and therefore we can conclude that multi-collinearity does not severely affect our results.

Table 3.4 Unit Root test of Maddala and Wu.

Variables	Statistics			
	P	Z	L*	Pm
Mobile Broadband Penetration	1639.1862*** (0.0000)	-16.6028*** (0.0000)	-34.2772*** (0.0000)	62.4661*** (0.0000)
Mobile Price	964.8848*** (0.0000)	-6.9859*** (0.0000)	-16.6175*** (0.0000)	32.1891*** (0.0000)
Fixed Broadband Price	1843.9271*** (0.0000)	-19.9380*** (0.0000)	-40.3270*** (0.0000)	71.6592*** (0.0000)
Education	1262.3072*** (0.0000)	-12.5785*** (0.0000)	-25.5555*** (0.0000)	45.5437*** (0.0000)
Income	1252.4382*** (0.0000)	-8.2797*** (0.0000)	-22.1819*** (0.0000)	45.1006*** (0.0000)
Economic Freedom	530.7910*** (0.0000)	-9.5544*** (0.0000)	-10.4443*** (0.0000)	12.6977 *** (0.0000)
Content	2359.0842 *** (0.0000)	-23.1012*** (0.0000)	-52.1745*** (0.0000)	94.7905*** (0.0000)
Bandwidth	1131.6033*** (0.0000)	-9.7807*** (0.0000)	-21.0911*** (0.0000)	39.6750*** (0.0000)
E-services	381.1859*** (0.0000)	3.9825 (1.0000)	1.5608 (0.9404)	5.9802*** (0.0000)
Urban Population	5799.1508*** (0.0000)	-66.8565*** (0.0000)	-160.7413*** (0.0000)	249.2540*** (0.0000)
Age	1607.9008 (0.0000)	-13.6126 (0.0000)	-38.1569 (0.0000)	61.0613 (0.0000)

The null hypothesis assumes that the variable contains a unit root. The Phillips-Perron test is used which is robust in the presence of unspecified homoscedasticity and autocorrelation. The number of lags has been set to two and panels of variables that have cross- sectional dependence have been demeaned. The statistics are the following: P is the inverse chi-squared statistic, Z is the inverse normal statistic and L* denotes the inverse logit statistic, while Pm stands for the modified inversed chi-squared statistic. P-values in parenthesis*** denotes significant at a 1% level.

Table 3.5 Multi-collinearity Diagnostics.

Variables	VIF	VIF-Squared	Tolerance	R-Squared
Mobile Price	1.24	1.11	0.8086	0.1914
Fixed Broadband Price	1.53	1.24	0.6550	0.3450
Market Liberalization	1.16	1.08	0.8617	0.1383
Education	5.09	2.26	0.1966	0.8034
Income	8.82	2.97	0.1134	0.8866
Economic Freedom	1.68	1.30	0.5946	0.4054
Content	3.66	1.91	0.2730	0.7270
Bandwidth	3.27	1.81	0.3060	0.6940
E-services	8.26	2.87	0.1211	0.8789
Urban Population	3.22	1.79	0.3107	0.6893
Standardization Policy	1.09	1.04	0.9215	0.0785
Age	2.84	1.69	0.3516	0.6484
Trend	1.22	1.10	0.8191	0.1809
Mean VIF	**3.31**			

3.4.4 Empirical Results.

Table 3.6 presents the results of the regression model using different estimators. The robust Hausman test shows that Fixed Effects is the appropriate estimator, versus Random Effects. In the instrumental variables' estimation one of the endogenous variables is *Mobile Price*, because price affects demand, but simultaneously mobile carriers set their price according to demand for mobile broadband services. Moreover, there is an issue of reverse causality between income and mobile broadband penetration since broadband penetration affects economic development. The same issue of reverse causality, applies for industry factors such as internet content, international bandwidth and e-services, as the level of mobile broadband affects, in turn, the development of these factors. Considering our findings in table 3.6, in both instrumental variables estimators, the Sargan-Hansen test of over-identifying restrictions fails to reject the null that the instruments are jointly valid. Moreover, the Difference-in-J endogeneity test justifies our choice to use instrumental variables methods.

3.4.4.1 Empirical Results of regression analysis with all countries.

The *Mobile Price* variable has the expected negative sign however it is not significant even at a 10% level. This result is close to Lee et al. (2011b), where he did not find mobile price to be a significant factor, however this in contrast to most studies of mobile diffusion (Koski and Kretschmer, 2002; Madden et al., 2004; Shinohara et al, 2014; Sagbansua et al., 2015, among others). It may be because *Mobile price* is a proxy variable for the price of mobile broadband and may be not sufficiently correlated with the variable of interest. The *Fixed Broadband price* variable is significant and negative, in the FE and FEIV-GMM2s specifications, suggesting that mobile and fixed broadband are complements. Looking at the specification with the FEIV-GMM2s estimator, a 1% decrease(increase) in the price of fixed broadband would increase(decrease) mobile broadband diffusion by approximately 0.23%. This finding corresponds to studies such as Ahn and Lee, (1999), Gruber H., (2001), and Lee et al., (2011b), were they also found fixed and mobile broadband to be complements. We do not find evidence that market liberalization, education, bandwidth or economic freedom impact mobile broadband adoption, as these variables are not significant in any estimation. A somewhat surprising result is the insignificance of the *Income* variable. Our result is more in line with the findings of Burki and Aslam (2000) or Rouvinen P. (2006) for example where they also did not find significant correlation between income and mobile diffusion. The variable *Content* is significant and positive indicating that the amount of internet content in a country significantly affects diffusion. This conclusion confirms the importance of content for mobile broadband as some studies that have shown the importance of internet content for fixed broadband (Lee and Brown, 2010, Lim and Wu, 2013). A 1% increase(decrease) in the covariate *Content* has as an

Table 3.6 Results of Regression Analysis for the determinants of Mobile Broadband Penetration.

Dependent Variable Mobile Broadband Penetration			
Independent Variables	FE	FEIV-2SLS	FEIV-GMM2s
Mobile Price	-0.071 (-0.56)	-0.080 (-0.63)	-0.092 (-0.93)
Fixed Broadband price	**-0.249*** (-1.77)	-0.234 (-1.57)	**-0.229**** (-2.11)
Market Liberalization	-0.113 (-0.62)	-0.045 (-0.25)	-0.049 (-0.33)
Education	0.008 (0.19)	0.009 (0.23)	0.010 (0.33)
Income	1.004 (0.80)	0.355 (0.28)	0.463 (0.47)
Economic Freedom	-0.001 (-0.17)	-0.001 (-0.39)	-0.001 (-0.41)
Content	0.143 (1.30)	**0.501***** (3.86)	**0.510***** (3.16)
Bandwidth	0.003 (0.03)	-0.033 (-0.31)	-0.032 (-0.38)
E-Services	**0.356**** (2.56)	**0.532**** (2.56)	**0.537***** (3.02)
Urban Population	**0.232**** (2.48)	**0.264***** (2.75)	**0.264***** (3.68)
Standardization Policy	**0.440**** (2.28)	**0.465**** (2.13)	**0.469***** (2.65)
Age	**0.365***** (4.60)	**0.344***** (4.30)	**0.341***** (5.55)
Trend	**0.266***** (4.21)	**0.219***** (3.39)	**0.213***** (4.10)
Hausman test robust (P-value)		64.744 (0.0000)	
Sargan-Hansen test (P-value)		0.170 (0.6797)	0.286 (0.5931)
Difference-in-J Endogeneity test (P-Value)		16.447 (0.0057)	26.235 (0.0001)
Modified Wald test (P-value)		4.1e+06 (0.0000)	
Lagram-Multiplier test (P-value)		377.927 (0.0000)	
F test (P- value)	32.09 (0.0000)	29.13 (0.0000)	48.66 (0.0000)
R^2	0.6723	0.6542	0.6532
Numb. of observations	685	685	685

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) T-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

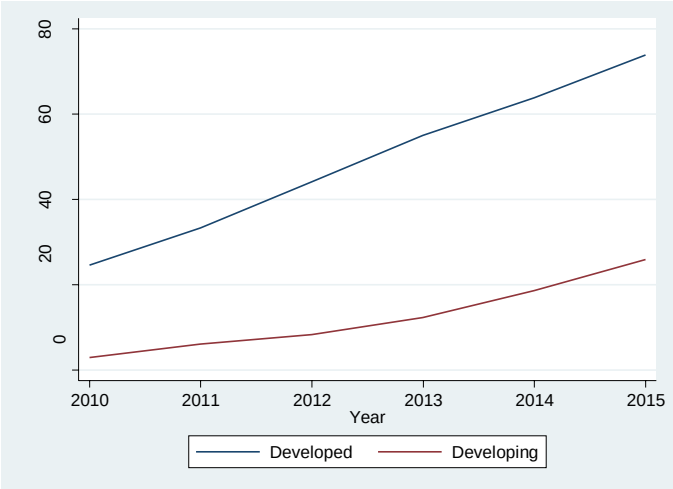
outcome, a 0.5% increase(decrease) in the mobile broadband penetration. The *E-services* variable is positive and significant. This highlights the importance of e-services in promoting mobile broadband, as they increase the willingness of subscribers to adopt mobile broadband services. A 1% increase (decrease) in the E-*services* variable signifies a 0.53% increase(decrease) in mobile broadband diffusion.

Urban population s positive and highly significant, reflecting the lower per potential subscriber cost in countries with higher urban population. A 1-unit increase(decrease) in the percentage of urban population, has as an effect, an approximate 0.26% increase(decrease) in mobile broadband. Similarly, to Koski and Kretschmer (2002,) we find that *Standardization policy* is positive and significant, signifying that multiple standards incite mobile broadband proliferation. The *Age* covariate as expected is positive and significant suggesting that countries that have a larger percentage of population of 15-64 years old's age, have significantly higher mobile broadband penetration. A 1-unit increase(decrease) in variable *Age* relates to an approximate 0.34% increase(decrease) in the level of mobile broadband penetration. Finally, the *Trend* variable is positive and significant signifying the importance of technological change, among other factors, in the mobile industry.

3.4.4.2 Empirical Results of regression analysis for developed and developing countries.

The countries in the sample are separated to different groups, according to their level of income, in developed and developing countries. Graph 3.2 presents Mobile Broadband penetration for developed and developing countries over the sample period. It is evident that mobile broadband adoption is higher for developed than developing countries, and that the mobile broadband market in developed countries has reached a higher level of maturity, with approximately 75 per 100 people being subscribers of a mobile broadband service. The separation of the countries into the two groups was done according to the classification of the World Bank. Although the countries could be separated according to their development using various criteria, the classification of the World Bank is exogenous and has been used by other studies (see for instance, Rouvinen P., 2006).

Graph 3.2- Mobile Broadband Penetration for Developed and Developing countries.



Source: Source: ITU World Telecommunication/ICT Indicators (WTI) database. Calculated.

Table 3.7 Results of Regression analysis for Developed and Developing countries

Dependent Variable Mobile Broadband Penetration	FEIV-2SLS		FEIV-GMM2s	
Independent Variables	Developed	Developing	Developed	Developing
Mobile Price	-0.033 (-0.32)	-0.383 (-0.98)	-0.032 (-0.40)	-0.399 (-1.32)
Fixed Broadband price	-0.148 (-1.19)	-0.215 (-1.28)	-0.149 (-1.32)	**-0.208*** (-1.70)
Market Liberalization	0.120 (0.80)	-0.139 (-0.41)	0.120 (0.91)	-0.165 (-0.57)
Education	0.001 (0.01)	0.079 (0.63)	0.001 (0.02)	0.085 (0.88)
Income	0.985 (0.77)	-2.032 (-0.83)	1.00 (1.11)	-1.757 (-0.96)
Economic Freedom	-0.003 (-1.14)	0.003 (0.45)	-0.003 (-1.12)	0.003 (0.43)
Content	**0.268**** (2.03)	**0.558**** (3.52)	**0.267**** (2.23)	**0.547***** (3.16)
Bandwidth	0.003 (0.36)	-0.050 (-0.07)	0.003 (0.04)	-0.048 (-0.40)
E-Services	**0.316**** (2.22)	0.361 (1.13)	**0.316***** (2.61)	(1.24) (1.26)
Urban Population	0.092 (1.39)	**0.604***** (3.23)	0.092 (1.86)	**0.601***** (3.97)
Standardization Policy	0.093 (0.73)	**1.580***** (4.24)	0.093 (0.85)	**1.584**** (2.11)
Age	**0.252***** (2.87)	0.180 (0.87)	**0.252***** (3.87)	0.168 (1.07)
Trend	**0.243***** (3.38)	**0.199*** (1.69)	**0.243***** (4.53)	**0.193*** (1.91)
Sargan-Hansen test (P-value)	0.001 (0.9807)	0.140 (0.7082)	0.001 (0.9753)	0.262 (0.6088)
F test (P- value)	24.38 (0.0000)	41.75 (0.0000)	37.74 (0.0000)	35.49 (0.0000)
R^2	0.6155	0.7516	0.6155	0.7521
Numb. of observations	463	222	463	222

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

In terms of the empirical results for developed and developing countries, referring to table 3.7 we can discern significant differences on the effect of the covariates on developed and developed countries. *Fixed broadband price* is negative and significant only for developing countries suggesting that mobile and fixed broadband are complements only for this group. However, this finding must be interpreted cautiously, since it is significant only in the specification with the FEIV-GMM2s estimator. *E-services* are significant only in the group of developed countries. Similarly, countries with a higher proportion of population between 15-64 years old, have significantly higher mobile broadband diffusion only in the case of developed countries. In contrast urban population is only significant for developing countries. If

urban population relates to the costs of deployment of mobile infrastructure then it is possible that the effect is higher for more lower income countries, since in general developing countries have underdeveloped telecommunications infrastructure and the costs of investment are typically higher. Moreover, the coefficient of the variable *content* is almost double in the case of the developing countries, suggesting that internet content has more substantial impact on the case of lower income countries. Finally, *Standardization* Policy is significant for developing countries suggesting that multiple standards positively impact mobile broadband only for relatively lower income countries.

3.5 Discussion and Conclusions.

The complementarity between mobile and fixed broadband (at least for the FE-GMM2s regression) indicates that lower fixed broadband prices will result in beneficial spillover effects for mobile broadband. Internet content is an important driver for both developed and developing countries while it has a higher impact for developing countries in inciting mobile broadband diffusion. This study shows the importance of e-services for the proliferation of mobile broadband. To the best knowledge of the authors, this is the first study to show its' significance in a cross-country setting for mobile broadband. The level of urban population positively affects mobile broadband penetration as it reduces infrastructure costs for mobile operators. Standards competition facilitates mobile broadband adoption. This finding has important implications for policymakers especially in the light of new mobile standards, such as for 5G mobile telephony. E-services do not impact broadband diffusion in the case of developing countries. As discussed in chapter 2, this may be due to higher quality of e-services in developed countries. Finally, standards competition facilitates mobile broadband adoption for the developing group of countries. A possible explanation is that developing economies are usually laggards in the selection of mobile standards. Therefore, they can gain from the experience of more advanced economies and choose the most promising standards enabling them to gain network effects earlier. with less consumer uncertainty

Limitations of this study, as in most studies, derive primarily from data limitations. For instance, mobile broadband prices would be a more accurate indicator of the cost effect, however sufficient data for analysis, were unavailable to the authors. Similarly, competitive forces in the market would be more accurately measured if detailed data were available on market shares of each mobile carrier. Finally, standardization policy refers to only 3G networks standards as insufficient data were available for 4G standards, although most mobile carriers have already implemented 4G networks.

Appendices

Appendix A.

Table A.1 Results of Regression Analysis with FEIV(2SLS) estimator with different specifications.

Dependent Variables	Broadband Penetration			DSL Penetration		Alternative Infrastructure	
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Price of the LLU	**-0.571***** (-5.80)	-	**-0.573***** (-5.60)	-0.382*** (-2.69)	-	-0.083 (-0.32)	-
LLU	-0.002 (-0.37)	-0.001 (-0.22)	-0.005 (-1.07)	**0.017**** (2.06)	**0.017**** (2.06)	**-0.031***** (-2.98)	**-0.026***** (-2.83)
Bitstream	**-0.024***** (-3.14)	**-0.02**** (-2.47)	**-0.025***** (-3.51)	-0.009 (-1.03)	-0.005 (-0.58)	**-0.031***** (-2.72)	**-0.024**** (-2.19)
Resale	**-0.019***** (-2.98)	**-0.015**** (-2.24)	**-0.02***** (-3.42)	-0.002 (-0.17)	0.002 (0.15)	**-0.038***** (-3.22)	**-0.032***** (-2.69)
Inter-platform	0.005 (0.80)	0.005 (0.76)	-	-	-	-	-
Market Competition	**0.023***** (3.13)	**0.022***** (2.62)	**0.026***** (5.08)	0.0014 (0.24)	-0.0011 (-0.14)	0.**057***** (3.37)	**0.048***** (3.34)
Δ.Income	**-1.05***** (-4.66)	**-1.1***** (-4.82)	**-1.06***** (-4.76)	**-1.13***** (-4.03)	**-1.16***** (-3.75)	**-1.13***** (-4.48)	**-1.38***** (-4.22)
Δ.Education	0.001 (0.891)	0.008 (1.04)	0.0005 (0.07)	0.0024 (0.27)	0.0083 (0.93)	-0.006 (-0.32)	-0.001 (-0.59)
Urban	-0.028 (-1.47)	**-0.069***** (-3.05)	-0.03 (-1.53)	-0.0023 (-0.10)	-0.025 (-0.97)	**-0.117*** (-1.76)	**-0.113**** (-2.21)
Trend	**0.031***** (3.08)	**0.064***** (5.47)	**0.038***** (3.82)	**0.023**** (2.21)	**0.045***** (4.66)	**0.108***** (4.49)	**0.122***** (7.33)
Sargan-Hansen test (P-value)	0.160 (0.6892)	0.030 (0.8629)	0.177 (0.6743)	2.281 (0.3196)	2.668 (0.2635)	1.583 (0.4531)	2.413 (0.2993)
F test (P- value)	93.23 (0.0000)	24.63 (0.0000)	99.91 (0.0000)	11.37 (0.0000)	9.19 (0.0000)	75.40 (0.0000)	24.29 (0.0000)
R^2	0.8102	0.7921	0.8014	0.6532	0.6294	0.7450	0.7531
Numb. of observations	256	257	256	250	251	256	259

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.
(iv) The (1), (4),(6) specifications are the originals while the (2), (3), (5) and (7), specifications are without the price of the LLU, and inter-platform covariates respectively.

Appendix B.

Table B.1 Results of Regression analysis with different specifications.

Dependent Variable Broadband Penetration				
Independent Variables	(1)	(2)	(3)	(4)
Fixed Broadband price	**-0.192***** (-3.34)	**-0.238***** (-3.85)	**-0.190**** (-3.31)	**-0.195***** (-3.36)
Liberalization Partial Comp.	**0.231*** (1.86)	**0.227*** (1.81)	**0.231*** (1.86)	**0.246*** (1.95)
Liberalization Full Comp.	**0.250**** (2.26)	**0.237**** (2.05)	**0.248**** (2.23)	**0.259**** (2.33)
Education	-0.007 (-0.63)	-0.001 (-0.08)	-	-0.007 (-0.59)
Income	0.425 (1.56)	**0.534*** (1.97)	0.438 (1.63)	-
Economic Freedom	**-0.022**** (-2.27)	-0.012 (-1.21)	**-0.022**** (-2.32)	**-0.019**** (-2.04)
Content	**0.155***** (2.37)	**0.163***** (2.41)	**0.155**** (2.38)	**0.150**** (2.25)
Bandwidth	**0.069*** (1.73)	**0.070*** (1.75)	**0.066*** (1.66)	**0.071*** (1.77)
E-Services	**0.292***** (4.00)	-	**0.290***** (3.98)	**0.304***** (4.14)
Urban Population	**0.049*** (1.80)	**0.053*** (1.93)	**0.047*** (1.82)	**0.054**** (2.01)
Privatization	**0.143**** (2.04)	0.107 (1.59)	**0.146**** (2.10)	**0.149**** (2.12)
LLU	-0.106 (-1.38)	-0.089 (-1.13)	-0.107 (-1.38)	-0.110 (-1.42)
Age	**0.128***** (4.64)	**0.126***** (4.52)	**0.129***** (4.75)	**0.128***** (4.54)
Trend	0.025 (1.41)	**0.066***** (4.59)	0.022 (1.34)	0.028 (1.50)
Sargan-Hansen test (P-value)	2.843 (0.2414)	2.284 (0.4037)	2.904 (0.2341)	2.643 (0.2668)
F test (P- value)	53.30 (0.0000)	51.33 (0.0000)	56.43 (0.0000)	56.58 (0.0000)
R^2	0.5792	0.5800	0.5802	0.5747
Numb. of observations	1032	1039	1033	1033

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.
(iv) The (1) specification is the original while the (2), (3), (4) specifications are without the e-services, education and income covariates respectively.
(v) All specifications are inferred using the FEIV-GMM2s estimator.

Table B.2	Results of Regression analysis with interaction term.	
Dependent Variable Broadband Penetration**.**		
Independent Variables	Coefficients	t-statistic
Fixed Broadband price	**-0.226*****	(-2.65)
Liberalization Partial Comp.	**0.265****	(1.96)
Liberalization Full Comp.	**0.271****	(2.42)
Education	-0.012	(-0.80)
Income	0.526	(1.26)
Economic Freedom	**-0.023***	(-1.74)
Content	**0.109****	(2.10)
Bandwidth	0.080	(1.44)
E-Services	**0.256****	(2.28)
Urban	0.016	(0.43)
Privatization	0.140	(1.49)
LLU	-0.079	(-0.92)
Age	**0.101****	(2.55)
Trend	**0.050***	(1.83)
Economic Freedom*Trend	**-3.39*****	(-3.02)
Sargan-Hansen test (P-value)	3.025 (0.2204)	
F test (P- value)	28.69 (0.0000)	
R^2	0.6056	
Numb. of observations	1,032	

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.
(iv) Inferred using the FE-2SLS estimator.
(v) The variables Economic Freedom and Trend are centered on their mean.

Table B.3 Descriptive statistics of the untransformed variables for developed countries.

Variables	Observations	Mean	Standard dev.	Min	Max
Broadband Penetration	736	16.8036	11.57516	.0151602	45.10761
Fixed Broadband Price	724	27.74599	16.47371	2.852522	163.1275
Liberalization Partial Comp.	733	0.1200546	0.3252473	0	1
Liberalization Full Comp	733	0.744884	0.436224	0	1
Education	734	74.3174	10.30281	41.04011	93.9
Income	735	27917.95	19785.63	5895.114	129349.9
Economic Freedom	724	65.97735	9.459534	34.3	90.1
Content	734	18.87442	26.33502	.0012344	175.205
Bandwidth	734	132178.8	552044.9	775.1528	7186378
E-services	732	0.0289166	0.0563639	3.61e-06	0.3406738
Urban Population	736	70.12555	22.38125	8.445	100
Privatization	718	0.2239488	0.449965	0	1
LLU	731	0.6990424	0.4589884	0	1
Age	736	67.45434	4.808577	50.29085	85.8724

Table B.4 Descriptive statistics of the untransformed variables for developing countries.

Variables	Observations	Mean	Standard dev.	Min	Max
Broadband Penetration	378	1.659455	2.643097	.0017924	15.54902
Fixed Broadband Price	372	49.60122	81.75557	.9234297	635.0171
Liberalization Partial Comp.	382	0.1675393	0.3739464	0	1
Liberalization Full Comp	382	0.4790576	0.5002164	0	1
Education	382	50.2105	13.64226	16.53911	80.3
Income	384	4260.455	2636.161	748.4153	11411.94
Economic Freedom	381	56.82178	5.358827	43.3	73
Content	384	1.135836	2.850182	.0001343	23.90917
Bandwidth	383	12698.87	23404.7	82.24581	162429.4
E-services	379	0.0009461	0.0023364	3.61e-06	.0223259
Urban Population	384	40.55371	16.08208	10.118	72.04
Privatization	376	0.1143617	0.3186741	0	1
LLU	384	0.2942708	0.4563088	0	1
Age	384	59.75853	6.546913	47.24444	74.33752

Table B.5 Countries in the sample

Albania	Chile	Hong Kong, China	Mexico	Singapore
Algeria	China	Hungary	Moldova[a]	Slovak Republic
Angola	Colombia	Iceland	Mongolia[a]	Slovenia
Argentina	Comoros[a]	India[a]	Montenegro	South Africa
Armenia[a]	Costa Rica	Indonesia[a]	Morocco[a]	Spain
Australia	Croatia	Iran, Islamic Rep.	Mozambique[a]	Sri Lanka[a]
Austria	Cyprus	Ireland	Namibia	.St. Lucia
Azerbaijan	Czech Republic	Israel	Nepal[a]	St. Vincent & Grenadines
Bahamas	Cote d' Ivoire[a]	Italy	Netherlands	Suriname
Bahrain	Denmark	Jamaica	New Zealand	Sweden
Bangladesh[a]	Dominican Republic	Japan	Nicaragua[a]	Switzerland
Barbados	Ecuador	Jordan	Niger	TFYR Macedonia
Belarus	Egypt[a]	Kazakhstan	Norway	Tanzania[a]
Belgium	El Salvador[a]	Kenya[a]	Oman	Thailand
Belize	Estonia	Korea, Rep.	Pakistan[a]	Trinidad & Tobago
Benin[a]	Ethiopia[a]	Kyrgyz Republic[a]	Panama	Tunisia
Bhutan[a]	Fiji	Latvia	Paraguay[a]	Turkey
Bolivia[a]	Finland	Lebanon	Peru	Uganda[a]
Bosnia and Herzegovina	France	Lesotho[a]	Philippines[a]	Ukraine[a]
Botswana	Gabon	Lithuania	Poland	United Arab Emirates
Brazil	Gambia[a]	Luxembourg	Portugal	United Kingdom
Brunei Darussalam	Georgia[a]	Madagascar[a]	Qatar	United States
Bulgaria	Germany	Malaysia	Romania	Uruguay
Burundi[a]	Ghana[a]	Maldives	Rwanda[a]	Vanuatu[a]
Cambodia[a]	Greece	Mali[a]	Saudi Arabia	Venezuela
Cameroon[a]	Guatemala[a]	Malta	Senegal[a]	Vietnam[a]
Canada	Guyana[a]	Mauritania[a]	Serbia	Yemen, Rep.[a]
Cape Verde[a]	Honduras[a]	Mauritius	Seychelles	.Zambia[a]

[a] signifies that a country belongs to the developing country group.

Appendix C.

Table C.1 Results of Regression analysis with different specifications.

Dependent Variable Mobile Broadband Penetration.				
Independent Variables	(1)	(2)	(3)	(4)
Mobile Price	-0.092 (-0.93)	-0.088 (-0.87)	-0.089 (-0.89)	-0.091 (-0.93))
Fixed Broadband price	**-0.229**** (-2.11)	**-0.268***** (-2.63)	**-0.230**** (-2.11)	**-0.225**** (-2.07)
Market Liberalization	-0.049 (-0.33)	-0.001 (-0.01)	-0.045 (-0.30)	-0.050 (-0.33)
Education	0.010 (0.33)	0.005 (0.15)	-	0.011 (0.36)
Income	0.463 (0.47)	-0.176 (-0.14)	.362 (0.28)	-
Economic Freedom	-0.001 (-0.41)	0.002 (0.62)	-0.001 (-0.42)	-0.001 (-0.45)
Content	**0.510***** (3.16)	**0.564***** (3.20)	**0.511***** (3.17)	**0.504***** (3.14)
Bandwidth	-0.032 (-0.38)	-0.037 (-0.44)	-0.031 (-0.37)	-0.036 (-0.44)
E-Services	**0.537***** (3.02)	-	**0.536***** (3.01)	**0.527***** (2.99)
Urban Population	**0.264***** (3.68)	**0.279***** (3.72)	**0.267***** (3.70)	**0.256***** (3.61)
Standardization Policy	**0.469***** (2.65)	**0.496***** (3.23)	**0.465***** (2.63)	**0.470***** (2.63)
Age	**0.341***** (5.55)	**0.348***** (5.92)	**0.340***** (5.52)	**0.339***** (5.67)
Trend	**0.213***** (4.10)	**0.272***** (5.40)	**0.218***** (4.74)	**0.208***** (4.21)
Sargan-Hansen test (P-value)	0.286 (0.5931)	0.697 (0.4037)	0.273 (0.6012)	0.288 (0.5916)
F test (P- value)	48.66 (0.0000)	50.61 (0.0000)	52.83 (0.0000)	46.16 (0.0000)
R^2	0.6532	0.6471	0.6531	0.6537
Numb. of observations	685	685	685	685

(i) *,** and *** denote significance at the 10%, 5% and 1%, respectively.
(ii) t-statistic is denoted in parenthesis.
(iii) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.
(iv) The (1) specification is the original while the (2), (3), (4) specifications are without the e-services, education and income covariates respectively which have the higher Variance Inflation factor.
(v) All specifications are inferred using the FEIV-GMM2s estimator.

Table C.2 Descriptive statistics of the variables for developed countries.

Variables	Observations	Mean	Standard dev.	Min	Max
Mobile Broadband Penetration	492	49.12584	33.18782	0	149.3328
Mobile Price	478	25.07084	13.57969	2.1	78.2
Fixed Broadband Price	490	25.63304	14.51401	2.852522	133.18
Market Liberalization	492	0.6605691	0.4739981	0	1
Education	492	75.92602	10.40756	41.8	93.9
Income	492	29817.5	20279.73	5895.114	129349.9
Economic Freedom	487	65.06201	10.01043	28.5	90.1
Content	492	22.51682	28.57215	.0014125	175.205
Bandwidth	491	170269.8	660772.7	1318.434	7186378
E-services	492	0.0530438	0.0735301	0.0000738	0.3406738
Urban Population	492	73.07668	15.18076	39.226	100
Standardization Policy	492	0.3170732	0.4658098	0	1
Age	492	67.71525	4.773028	50.32716	85.8724

Table C.3 Descriptive statistics of the variables for developing countries.

Variables	ObservationsMean		Standard dev.	Min	Max
Mobile Broadband Penetration	252	12.35989	14.58202	0	76.02032
Mobile Price	238	21.82118	13.36961	2.2	78.21
Fixed Broadband Price	248	41.84194	72.49027	0.9234297	562.1761
Market Liberalization	251	0.7370518	0.4411141	0	1
Education	252	51.95873	14.03755	23.2	80.3
Income	252	4521.07	2751.415	917.7639	11411.94
Economic Freedom	251	57.20837	6.60703	36.1	89.3
Content	252	1.493347	3.387453	.000163	23.90917
Bandwidth	251	16754.03	27593.85	89.82797	162429.4
E-services	252	.0011212	0.0023889	.0000125	.0223259
Urban Population	252	42.19171	16.43048	14.492	77.343
Standardization Policy	252	0.3015873	.4598604	0	1
Age	252	60.3618	6.519679	48.47287	74.33752

Table C.4 Countries in the sample

Albania	Croatia	Indonesia[a]	Mongolia[a]	Singapore
Algeria	Cyprus	Iran, Islamic Rep.	Montenegro	Slovak Republic
Angola	Czech Republic	Ireland	Morocco[a]	Slovenia
Argentina	Denmark	Israel	Mozambique[a]	South Africa
Armenia[a]	Djibouti[a]	Italy	Namibia	Spain
Australia	Dominican Republic	Japan	Netherlands	Sri Lanka[a]
Austria	Ecuador	Jordan	New Zealand	Suriname
Azerbaijan	Egypt[a]	Kazakhstan	Nicaragua[a]	Sweden
Bahrain	El Salvador[a]	Kenya[a]	Norway	Switzerland
Bangladesh[a]	Estonia	Korea, Rep.	Oman	TFYR Macedonia
Belarus	Ethiopia[a]	Kyrgyz Republic[a]	Pakistan[a]	Tanzania[a]
Belgium	Fiji	Lao PDR[a]	Panama	Togo[a]
Bhutan[a]	Finland	Latvia	Paraguay[a]	Tunisia
Bolivia[a]	France	Lebanon	Peru	Turkey
Bosnia and Herzegovina	Gabon	Lithuania	Poland	Uganda[a]
Brazil	Georgia[a]	Luxembourg	Portugal	Ukraine[a]
Brunei Darussalam	Germany	Madagascar[a]	Qatar	United Arab Emirates
Bulgaria	Ghana[a]	Malawi[a]	Romania	United Kingdom
Burkina Faso[a]	Greece	Malaysia	Russian Federation	United States
Cambodia[a]	Guatemala[a]	Maldives	Rwanda[a]	Uruguay
Cameroon[a]	Honduras[a]	Mali[a]	Sao Tome and Principe[a]	Uzbekistan[a]
Canada	Hong Kong, China	Malta	Saudi Arabia	Vanuatu[a]
Chile	Hungary	Mauritius	Senegal[a]	Vietnam[a]
China	Iceland	Mexico	Serbia	Yemen, Rep.[a]
Colombia	India[a]	Moldova[a]	Seychelles	

[a] signifies that a country belongs to the developing country group.

References:

Ahn H.., & Lee M., (1999). An econometric analysis of the demand for access to mobile telephone networks. *Information Economics and Policy*, 11(3), pp. 297-205.

Andres L., Cuberes D., Diouf M., & Serebrisky T., (2010). The diffusion of the Internet: A cross-country analysis. *Telecommunications Policy*. 34(5-6), 323-340.

Arellano M., (1993). On the testing of correlated effects with panel data*. Journal of Econometrics*, 59(1-2), pp. 87-97.

Arellano M., & Bond S., (1991*).* Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations*. Review of Economic Studies*, 58(2), 277–297.

Arellano M., & Bover O., (1995)*.* Another look at the instrumental variables estimation of error components models. *Journal of Econometrics*. 68(1), 29–51.

Avenali A., Matteucci G., & Reverberi P., (2010). Dynamic access pricing and incentives to invest in alternative infrastructures. *International Journal of Industrial Organization*, Volume 28, Issue 2, March 2010, pp. 167–175.

Baltagi H., B., (2013). Econometric Analysis of Panel Data, Wiley 5th Edition.

Baum F. C., (2014). IV and IV-GMM, EC 823: Applied Econometrics, Boston College. Retrieved from: http://fmwww.bc.edu/EC-C/S2014/823/EC823.S2014.nn02.slides.pdf (03/03/2018)

Bacache M., Bourreau M., and Gaudin, G., (2013). Dynamic entry and investment in new Infrastructures: empirical evidence from the fixed broadband industry. Telecom Paris Tech Working Paper N° ESS-11-01, 1-35. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1750217

Belsley D., A., Kuh E., Welsch R. E., (1980). Regression Diagnostics: Identifying Influential Data and Sources of Collinearity, New York: Wiley.

Bohlin A., Gruber H., & Koutroumpis P., (2010). Diffusion of new technology generations in mobile communications. *Information Economics and Policy*, 22(1), pp. 51-60.

Bourreau, M., & Dogan P., (2005). Unbundling the local loop. *European Economic Review*, 49(1), pp.173–199.

Bourreau M., & Druard P., (2010). Stepping stone or stonewall? Progressive entry and the incentives to invest in alternative infrastructures. Telecom Paris Tech Working Paper No. ESS-10-07. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1662402

Bourreau M., Dogan P., & Manant M., (2010). A critical review of the "Ladder of Investment" approach. *Telecommunication Policy* 34(11), pp. 683-696.

Biglaiser G., & Riordan M., (2000). Dynamics of price regulation. *RAND Journal of Economics*, 31(4), pp. 744–767.

Brito D., Pereira P., & Vareda J., (2007). On the regulation of next generation networks. Working Paper series, University of Lisbon.

Brito D., Pereira P., & Vareda J., (2010). Can two-part tariffs promote efficient investment on next generation networks? *International Journal of Industrial Organization* 28(3) , pp. 323-333.

Bouckaert J., Van Dijk T., & Verboven F., (2010). Access regulation, competition, and broadband penetration: an international study. *Telecommunication Policy* 34(11), pp. 661-671.

Burki A. A., & Aslam, S., (2000). The Role of Digital Technology and Regulations in the Diffusion of Mobile Phones in Asia. *Pakistan Development Review*, 39(4), pp. 741–748.

Cabral L.M.B., & Kretschmer T., (2007). Standards battle and public policy. In: Greenstein, S., Stango, V. (Eds.), Standards and Public Policy. Cambridge University Press, Cambridge, UK, pp. 329–344.

Cabral L., & Riordan M., (1989). Incentives for cost reduction under price cap regulation. *Journal of Regulatory Economics*, 1(2), 93–102.

Cava-Ferreruela I., & Alabau-Munoz A., (2006) Broadband policy assessment; Across-national empirical analysis. *Telecommunication Policy*, 30(8-9), 445-463.

Cave M., (2006), Encouraging infrastructure competition via the ladder of investment. *Telecommunications Policy*, 30(3-4) , pp 223-237.

Cave M., & Doyle C., (1994). Access pricing in network utilities in theory and practice. *Utilities Policy*, 4 (3), pp. 181-189.

Cambini L., & Jiang Y., (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, 33(10-11), pp. 559–574

Cincera M., Dewulf L., & Estache A., (2013). On the (In) Effectiveness of Policies to Promote Broadband Diffusion in Europe (2003-2010): An Econometric Assessment. ECARES working paper 2012-032. Retrieved from https://econpapers.repec.org/scripts/redir.pf?u=https%3A%2F%2Fdipot.ulb.ac.be%2Fdspace%2Fbitstream%2F2013%2F128909%2F1%2F2012-032-CINCERA_DEWULF_ESTACHE ineffectiveness.pdf;h =repec:eca:wpaper: 2013/128909

Choi I., (2001). Unit root tests for panel data. *Journal of International Money and Finance*, 20(2) pp. 249-272.

Crandall R., W., Eisenach J., A., & Ingraham A. T., (2013). The long-run effects of copper loop unbundling and the implications for fiber. *Telecommunications Policy*, 37(4-5), pp. 262-281.

Crandall W., Ingraham T., and Singer H. J., (2004), Do Unbundling Policies Discourage CLEC Facilities-Based Investment. *The B.E. Journals in Economic Analysis & Policy*, 4(1) pp. 1-25.

Chang H., Koski H., & Majumdar S., (2003). Regulation and investment behavior in the telecommunications sector: Policies and patterns in US and Europe. *Telecommunications Policy*, 27(10–11), pp. 677–699.

Denni M., & Gruber H., (2005). The diffusion of broadband telecommunications: The role of competition. Working Paper N°60, 1-24. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=829504

Distaso W., Lupi P., & Manenti F., (2006). Platform competition and broadband uptake: theory and empirical evidence from the European Union. *Information Economics & Policy*, 18(1), pp. 87-106.

Dkhil B. I., (2014a). Investment in Fixed Broadband Networks and Access Regulation in Developed and Developing countries: Panel Data Applications. MPRA Paper No. 59337. Retrieved from http://mpra.ub.uni-muenchen.de/59337/

Dkhil B. I., (2014b). Regulation and Investment in Telecom Network Infrastructure Facilities: The Recent Developments and Debates. MPRA Paper No. 72910. Retrieved from. https://mpra.ub.uni-muenchen.de/72910/

European Commission, (2010). *Digital Agenda for Europe*. Brussels. European Commission Directorate-General for Communication. Retrieved from http://eige.europa.eu/resources/digital_agenda_en.pdf

European Parliamentary Research Service (2015). Broadband infrastructure: Supporting the digital economy in the European Union. Retrieved from http://www.europarl.europa.eu/RegData/etudes/IDAN/2015/565891/EPRS_IDA(2015)565891_EN.pdf

Ford G., & Spiwak L., (2004). The positive effects of unbundling on broadband deployment. Phoenix Center Policy Paper No.19. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=600767

Foros O., (2004). Strategic Investments with Spillovers, Vertical Integration and Foreclosure in the Broadband Access Market. *International Journal of Industrial Organization*, 22(1), pp.1-24

Fransman M. (2006) 'Introduction', In Fransman, M. (Ed), Global Broadband Battles; Why the U.S. and Europe Lag While Asia Leads. Standford University Press, Stanford CA, pp. 1-58.

Friederiszick W. H., & Roeller R., H., (2008) Analyzing the Relationship between Regulation and Investment in the Telecommunications Sector, ESMT No. WP-108-01. Retrieved from http://static.esmt.org/publications/whitepapers/WP-108-01.pdf

Garcia-Murillo M., (2005). International broadband deployment: the impact of unbundling. Communications & Strategies. MPRA Paper No. 2442. Retrieved from https://mpra.ub.uni-muenchen.de/2442/1/MPRA_paper_2442.pdf

Grajek M., & Roller L. H., (2012). Regulation and investment in network industries. Evidence from European telecoms. *The Journal of Law and Economics* 55 (1), 189-216.

Greenstein S., & McDevitt P., (2009). The broadband bonus: Accounting for broadband internet's impact on US GDP. NBER Working Paper No. 14758. Retrieved from http://www.nber.org/papers/w14758.pdf

Grosso M., (2006). Determinants of broadband penetration in OECD nations. Working Paper. Regulatory Development Branch, Australian Competition and Consumer Commission. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.503.8715&rep=rep1&type=pdf

Gruber H., (2001). Competition and innovation: The diffusion of mobile telecommunications in Central and Eastern Europe. *Information Economics and Policy*, 13(1), pp. 19–34.

Gruber H., 2005. The Economics of the Mobile Telecommunications. Cambridge University Press, Cambridge.

Gruber H., & Verboven F., (2001). The Diffusion of Mobile Telecommunications Services in the European Union Countries. *European Economic Review*, 45(3), pp. 577–588.

Gruber H., and Verboven F., (2001a). The evolution of markets under entry and standards regulation —The case of global mobile telecommunications. *International Journal of Industrial Organization*. 19(7), pp. 1189-1212.

Gruber H., & Koutroumpis P., (2012). Competition enhancing regulation and diffusion innovation: the case of broadband networks. *Journal of Regulatory Economics*, 43 (2), pp. 168-195.

Grzybowski L., (2014). Fixed-to-mobile substitution in the European Union. *Telecommunications Policy*, 38(7), pp. 601–612.

Internet Systems Consortium (2017). Internet Domain Survey. Retrieved from https://www.isc.org/network/survey/

International Telecommunications Union (2003). Promoting Broadband: Background Paper for Workshop on Promoting Broadband. Retrieved from https://www.itu.int/osg/spu/ni/promotebroadband/PB03-PromotingBroadband.pdf

International Telecommunication Union (2005). The Internet of Things: ITU Internet Reports. Geneva, Switzerland. Retrieved from https://www.itu.int/net/wsis/tunis/newsroom/stats/The-Internet-of-Things-2005.pdf

International Telecommunications Union (2006). Digital life. Geneva, Switzerland. Retrieved from https://www.itu.int/osg/spu/publications/digitalife/docs/digital-life-web.pdf (04/03/2018)

International Telecommunication Union (2008). Requirements related to technical performance for IMT-Advanced radio interface(s), Geneva, Switzerland.

International Telecommunications Union (2009). International Bandwidth. Retrieved from https://www.itu.int/ITU-D/finance/work-cost-tariffs/events/tariff-seminars/Maputo-09/pdf/session2-Abosse-Internat_Bandwidth-en.pdf.

International Telecommunications Union, (2015). Measuring the information Society Report 2015. Geneva, Switzerland. Retrieved from https://www.itu.int/en/ITU-D/Statistics/Documents/publications/misr2015/MISR2015-ES-E.pdf (25/02/2018)

International Telecommunications Union, (2016). Measuring the information Society Report 2016. Geneva, Switzerland. Retrieved from https://www.itu.int/pub/D-IND-ICTOI-2016

International Telecommunication Union, (2017). *World telecommunication/ICT indicators database (21th edition)*. Geneva. ITU.

Halkos E. G., & Polemis L. M., (2017). Does Financial Development Affect Environmental Degradation? Evidence from the OECD Countries. *Business Strategy and the Environment*, 26(8), pp. 1162–1180.

Hsiao C., (2003). Analysis of Panel Data (2nd Edition). Cambridge, UK: Cambridge University Press.

Huigen J., & Cave M., (2008). Regulation and the promotion of investment in next generation networks—A European dilemma. *Telecommunications Policy*, 32(11) pp. 713– 721

Klein, G., & Wendel J., (2014). The impact of local loop and retail unbundling revisited, DICE Discussion Paper, No. 163.

Kongaut C., Bohlin E., (2016). Investigating mobile broadband adoption and usage: A case of smartphones in Sweden. *Telematics and Informatics*, 33, pp. 742-752

Koski, H., Kretschmer T., (2002). Entry, Standards, and Competition: Firm Strategies and the Diffusion of Mobile Telephony. ETLA Discussion Papers, 824. Retrieved from https://www.etla.fi/wp-content/uploads/2012/09/dp824.pdf (27/11/2017)

Koutroumpis S., (2009). The economic impact of broadband on Growth: A simultaneous approach. *Telecommunications Policy*, 33(9), pages 471-485.

Laffont J., & Tirole, J., (2000). Competition in telecommunications. Cambridge: The MIT Press.

Lee S., (2008). A cross-country analysis of ubiquitous broadband deployment: Examination of adoption factors, (Doctoral dissertation). University of Florida, Gainesville, FL. Retrieved from http://etd.fcla.edu/UF/UFE0022611/lee_s.pdf. (03/01/2018)

Lee S., Brown J., & Lee S., (2011a). *A Cross-Country Analysis of Fixed Broadband Deployment; Examination of Adoption Factors and Network Effect*. Journalism & Mass Communication Quarterly. 88(3), 580-596.

Lee S., Marcu, M. and Lee S., (2011b). An empirical analysis of fixed and mobile broadband diffusion. *Information Economics and Policy*, 23(3-4), pp. 227-233.

Lin M., & Wu F., (2013). Identifying the determinants of broadband adoption by diffusion stage in OECD countries. *Telecommunications Policy*, 37(4-5), 241-251.

Loo B.P.Y., Ngan Y.L., (2012). Developing mobile telecommunications to narrow digital divide in developing countries? Some lessons from China. *Telecommunications Policy* 36, pp. 888-900.

Maddala G. S., & Wu S., (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, 61, pp. 631-652.

Murrillo-Garcia M., (2005). International Broadband Deployment: The Impact of Unbundling. *Communications & Strategies*, 57(1) pp .83-105.

Nardatto M., Valleti T., & Verboven F., (2014). Unbundling the incumbent: evidence from UK broadband. CEPR Discussion Papers 9194, C.E.P.R. Discussion Papers. [Online] Retrieved from http://feb.kuleuven.be/public/NDBAD83/Frank/Papers/Nardotto,%20Valletti%20&%20Verboven,%202014.pdf

Oldale A., & Padilla J., (2004). From the state monopoly to the "investment ladder" competition policy and the NRF. LECG Europe Brussels-London-Madrid-Paris. Retrieved from http://www.konkurrensverket.se/globalassets/english/research/alison-oldale-and-a.-jorge-padilla-from-state-monopoly-to-the-investment-ladder-competition-policy-and-the-nrf.pdf

Organization for Economic Cooperation and Development, (2007). Communications Outlook. Paris, France. Retrieved from http://predipubcn.sistemaip.net:8096/intranet-tmpl/prog/img/local_repository/koha_upload/COMMS-OUTLOOK-2007.pdf

Organization for Economic Cooperation and Development, (2012). Fixed and Mobile Networks: Substitution, Complementarity and Convergence. OECD Digital Economy Papers, No. 206, OECD Publishing, Paris. Retrieved from http://www.oecd-ilibrary.org/docserver/download/5k91d4jwzg7b-en.pdf?expires=1520362007&id=id&accname=guest&checksum=08509B2EEB22AADA29A40C5103BF5C64

Organization for Economic Cooperation and Development, (2015). Digital Economy Outlook 2015. Paris: OECD. Retrieved from http://www.oecd.org/publications/oecd-digital-economy-outlook-2015-9789264232440-en.htm

Ovington T., Smith R., & Santamaria J., (2017). The impact of intra-platform competition on broadband penetration. *Telecommunication Policy*, 41(3), pp. 185-196.

Pesaran M. H., (2004). General diagnostic tests for cross sectional dependence in panels. Cambridge Working Papers in Economics 0435, Faculty of Economics, University of Cambridge. Retrieved from http://www.econ.cam.ac.uk/research-files/repec/cam/pdf/cwpe0435.pdf

Pesaran M., H., (2015). Testing Weak Cross-Sectional Dependence in Large Panels. *Econometric Reviews*, 34 (6-10) pp. 1089-1117.

Roller L. H., & Waverman L., (2001). Telecommunications infrastructure and economic development: a simultaneous approach. *American Economic Review*, 91(4), pp. 909–923.

Rouvinen P., (2006). Diffusion of digital mobile telephony: Are developing countries different? *Telecommunications Policy*, 30(1), pp. 46-63.

Qiang C. Z., & Rossotto C. M., (2009). Economic Impacts of Broadband. In Information and Communications for Development 2009: Extending Reach and Increasing Impact, 35–50. Washington, DC: World Bank.

Sarmento P., and Brandao A., (2009). Next generation access networks: the effects of vertical spillovers on access and innovation. FEP Working Papers 321. Retrieved from https://www.fep.up.pt/investigacao/workingpapers/09.04.07_wp321.pdf

Shinohara S., Morikawa H., and Tsuji M., (2014). Empirical analysis of mobile broadband adoption in major six countries from the view of competition policy. 20th ITS Biennial Conference, Rio de Janeiro, Brazil: The Net and the Internet - Emerging Markets and Policies.

Shrinuan C., Shrinuan P., Bohlin E., (2012). An analysis of mobile Internet access in Thailand: implications for bridging the digital divide. *Telematics & Informatics,* 29 (3), pp. 254-262.

Singh R., (2018). Unbundling the Local Loop and Regulatory Measures to Encourage Broadband. Retrieved from https://www.lirneasia.net/wp-content/uploads/2007/03/feb-28-wednesday-4-ras-unbundling-the-local-loop-and-regulatory-measures-to-encourage-broadband.pdf

The Heritage Foundation, (2018). Index of Economic Freedom. Retrieved from https://www.heritage.org/index/pdf/2018/book/index_2018.pdf.

The World Bank, 2017. World Bank Country and Lending Groups. Retrieved from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

United Nations Development Programme, (2016). United Nations Human Development Report 2016. New York, USA. Retrieved from http://hdr.undp.org/sites/default/files/2016_human_development_report.pdf.

Van Dijk J., (2005). The deepening divide: Inequality in the information society. Sage Publications, London, U.K.

Vareda J., (2007). Unbundling and incumbent investment in quality upgrade sand cost reduction. Portuguese Competition Authority, Working Paper 31. Retrieved from

https://econpapers.repec.org/scripts/redir.pf?u=http%3A%2F%2Fwww.concorrencia.pt%2Fdownload%2FWP31_unbundling.pdf;h=repec:pca:wpaper:31

Vareda J., (2011). Quality upgrades and bypass under mandatory access. *Journal of Regulatory Economics* 40 (2), pp. 177-197.

Yates J. D., Gulati. J. G., & Weiss W. J., (2013). Understanding the Impact of Policy, Regulation and Governance on Mobile Broadband Diffusion. 2013 46th Hawaii International Conference on System Sciences. Retrieved from http://ieeexplore.ieee.org/document/6480188/?reload=true

Westlund O., Bohlin, E. (2008). Mobile Internet adoption and use: results from a national survey in Sweden. Proceeding of the International Telecommunications Society 17th Biennial Conference, 24-27 June 2008, Montreal. Retrieved from
http://www.academia.edu/2984868/Mobile_internet_adoption_and_use_Results_from_a_national_survey_in_Sweden?auto=download

Willig R., (2006). Investment is appropriately stimulated by TELRIC. Retrieved from https://psc.ky.gov/pscecf/2003-00379/5200700_efs/04132004/MCI_ST_MTB_EX_14_04%2013%2004.pdf

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

Waverman L., Meschi M., Reillier B., & Dasgupta K., (2007), Access Regulation and Infrastructure Investment in the Telecommunications Sector: an Empirical Investigation. LECG Ltd Retrieved from https://pdfs.semanticscholar.org/2691/18253c680cd301df879ebee9556b59f768b1.pdf

Wooldridge J.M., (2002). Econometric Analysis of Cross Section and Panel Data. Cambridge, MIT Press.

Zhang X., (2017). Exploring the patterns and determinants of the global mobile divide. *Telematics and Informatics*, 34, pp. 438-449.

Zenhäusern P., Telser H., Vaterlaus S., & Mahler P.. 2007. Plaut Economics Regulation Index, Regulatory density index in telecommunications with particular consideration of investment incentives. Plaut Economics. Retrieved from: http://www.econ.uzh.ch/staff/telser/publications/Regulatory-Index.pdf>.