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Determinants of Mobile Broadband Penetration: An Empirical International Study

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Determinants of Mobile Broadband Penetration: An Empirical International Study.

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Abstract.

This study examines relevant factors that determine mobile broadband penetration for a large set of international countries, using instrumental variables econometric techniques. Furthermore it tests for stationarity of the variables using appropriate tests when cross sectional dependence is present. In respect to our main findings we conclude that lower cost of mobile services internet content facilitates mobile broadband diffusion. Moreover we highlight the importance of developing e-services in promoting mobile broadband. In addition we find that mobile and fixed broadband are complements signifying that they are beneficial spillover effects in promoting either of them. Concerning socioeconomic factors we find that factors such as education, income, percentage of urban population and percentage of population between 15-64 years old incite mobile broadband proliferation. Finally countries with multiple mobile standards have significantly higher mobile broadband penetration.

1. Introduction.

The proliferation of digital technologies have radically transform organizations, as well as individual's lifestyles. Digital 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 stimulates innovation, promotes growth in an economy, and entices 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).

The development of the mobile phone as a communication device has been rapid over the last two decades. Initially the main factor inhibiting the spread of the mobile internet was its' disadvantage in terms of speed, in contrast to fixed broadband (Westlund and Bohlin, 2008). However recent technology advancements has 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 today (Kongaut and Bohlin, 2016). Initially, mobile cellular technology could not compete with fixed-line networks in terms of speed of access. However 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 have come to rival fixed-line broadband services. Even at the later years of the last decade, mobile subscribers have come to surpass fixed line subscribers worldwide (OECD, 2007). The above discussion serves to highlight the importance of mobile broadband in the development of societies and the importance of identifying the factors that contribute to its' proliferation.

The remaining portion of this study is organized as follows. Section 2 investigates the relevant literature of mobile broadband adoption. Section 3 discusses the empirical model and relevant variables, section 4 presents the results of the regression analysis, and finally section 5 provides a discussion and conclusions.

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 it was no accident that 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, rather than studies that examine mobile diffusion in a specific country.

Early literature on the subject of 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 particular 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 at a later time showed a significant but slow catching effect, and the introduction of competition, during both the analogue and digital periods, had a significant positive effect. Finally they conclude that the fixed network is a substitute to the 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. Moreover 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 the fixed network has a positive relationship to mobile diffusion, suggesting a complementary 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 diffusion. 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 of the studies that focused on the determinants of mobile diffusion using a worldwide sample of international countries is that of Rouvinen (2006). The author employed a panel data set of 165 countries from 1993 to 2000 in order to examine any differences in the determinants of digital mobile telephony diffusion between developed and developing countries. He argues that multiple standards hinder diffusion and market competition promotes it for both developed

and developing countries. Moreover 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 and also that surprisingly more democratic regimes actually inhibit 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) used a panel of 62 international countries for a period from 2002 to 2007. They 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 most studies find 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 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 compliments, 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 factors examined, at least in part, 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). Using 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. (2011) exploring 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 find that mobile broadband services are complement to fixed broadband services as they conclude that fixed broadband price is positively 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 launch of Android smartphones, competition among telecommunication carriers, education 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 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. Moreover they find a significant network effect.

In regards to the literature of mobile broadband penetration the factors that they examined are similar to the studies of mobile telephony, as well as their findings. 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 (Shinohara et al., 2014; 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., 2011) and fixed and mobile broadband are complements (Lee et al., 2011).

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 (Gruben and Verboven, 2001a; Rouvinen P., 2006; Yates et al., 2013). Including in the analysis a large number of countries allows for more robust results in order to identify the determinants of mobile broadband penetration worldwide.

3. Empirical Model and Data.

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 (1) 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. Furthermore to prevent problems of positive skewness that may affect the analysis, most variables¹ were transformed to their natural logarithms.

$$\begin{aligned} \ln(\text{Mobile Broadband penetration})_{it} = & b_0 + b_1(\ln \text{Mobile Price})_{it} + b_2(\ln \text{Fixed Broadband price})_{it} \\ & + b_3(\text{Market Liberalization})_{it} + b_4(\text{Education})_{it} + b_5(\text{Economic Freedom})_{it} \\ & + b_6(\ln \text{Income})_{it} + b_7(\ln \text{Content})_{it} + b_8(\text{Urban Population})_{it} \\ & + b_9(\ln \text{E-Services})_{it} + b_{10}(\text{Standardization Policy})_{it} + b_{11}(\text{Age})_{it} + \alpha_{it} + \varepsilon_{it} \end{aligned} \quad (1)$$

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 eleven 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) urban population, ix) e-services and x) standardization policy and xi) age, which are further elaborated below.

3.2 The Data and Variables.

Table 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 2015². Although the specific sample was selected due to reasons of data availability³, there are still missing observations and the

¹ With the exception of 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.

² See Table A.2 in Appendix A, for a list of countries included in this study.

³ The ITU database includes over 200 countries, however for some countries there were too few observations for the dependent variable (mobile broadband penetration), while for some other countries there were no or too little observations for some independent variables to be included in the analysis.

panel data set is unbalanced⁴. The majority 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 use mobile broadband services to access the internet in a pay-per-use basis, subscriptions with prepaid broadband plans⁵, as well as mobile broadband subscriptions with a monthly data plan for internet access with a recurring subscribers' fee.

3.2.1 Mobile Price.

Mobile price is defined as the mobile-cellular sub-basket in US dollars (adjusted for PPP) as published by the International Telecommunications Union⁶. The sub-basket refers to the price of a mobile standard monthly usage of 30 outgoing calls plus 100 SMS messages per month. Although sufficient data on mobile broadband price were not available to us, mobile price is expected to be correlated to the price that subscribers have to 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.

3.2.2 Fixed Broadband Price.

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 broadband 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. This is not surprising. Mobile and fixed line networks are both substitutes and complements (OECD, 2012). 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).

3.2.3 Market Liberalization.

Market liberalization refers to the degree that the regulator restricts the number of licenses in the mobile telephony service market. Specifically "monopoly" refers to if the service is restricted exclusively to one operator, "partial competition" refers to when the regulatory framework limits the number of

⁴ For the dependent variable Mobile Broadband penetration there are missing observations for 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, Honduras for 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.

⁵ It includes only subscriptions where the users have actually access the internet in the previous three months.

⁶ See ITU (2015).

licensees and “full competition” when any company can be licensed to provide the service (there is no limit on number of licensees). *Market liberalization* can be considered 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 services⁷. Competitive markets produce benefits in allocative and dynamic efficiency and thus are expected to facilitate mobile broadband diffusion. For instance, 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 adoption of mobile telecommunications”.

3.2.4 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 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 a population [25 years and older]. People who are more educated, are more likely to demand that more services are to be made available through the internet (van Dijk, J., 2005).

3.2.5 Income.

Income is measured as GDP per capita in constant 2010 prices in US dollars (adjusted for PPP). As the level of income constraints consumption of mobile broadband services of potential subscribers, it is expected that higher income shifts upwards the demand curve for mobile broadband services and thus facilitates mobile broadband diffusion.

3.2.6 Economic Freedom.

The variable *Economic Freedom* is measured by the economic freedom index published its year by the Heritage Foundation. The index is consisted by four sub-indexes which are i) rule of law, ii) government size, iv) regulation efficiency and v) open markets⁸. It is a measure of several distinct freedoms such as property rights, judicial effectiveness, government spending, business freedom, labor freedom and investment freedom among others. Lee S. (2008) explored the relationship between mobile broadband and economic freedom but he did not find it to be significantly associated.

3.2.7 Content.

The main motivation for adopting broadband services is access to internet content. Therefore, internet content may be related to the diffusion of broadband. In this study *Content* 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 etc . Although each internet user

⁷ 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 allowance of additional entry in the mobile market with the potential granting of additional licenses, does not necessarily mean that entry will occur, or signifies the degree that will occur.

⁸ The Heritage Foundation, (2018).

Table 1 Variables, Measurement and data sources.

Variable	Measurement	Source
Mobile Broadband penetration	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.
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 ⁹ .
Age	Percentage of population between 15-64 years old.	The World Bank World Development Indicators database.

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, more internet content is expected to increase subscribers' willingness to pay.

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

⁹Information on mobile 3G standards come from websites <http://www.cdg.org/index.asp>, <http://www.spectrummonitoring.com/>, www.gsmarena.com, https://en.wikipedia.org/wiki/List_of_CDMA2000_networks.

or e-banking in a country. Better development of e-services enhance the utility of potential and existing subscribers for broadband services and thus are expected to promote mobile broadband penetration.

3.2.9 Urban Population.

Urban population is defined as the percentage of the total population in a country that resides in an urban environment. 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”. Thus urban population is expected to have a positive relationship to mobile broadband diffusion.

3.2.10 Standardization Policy.

Standardization policy measurement is 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 3G standards coexist or not 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 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”.

3.2.11 Age.

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 for job related purposes and to have the necessary e-skills required. Thus it is expected that this percentage of the population is more willing to pay for the consumption of mobile services.

4. Results and Analysis.

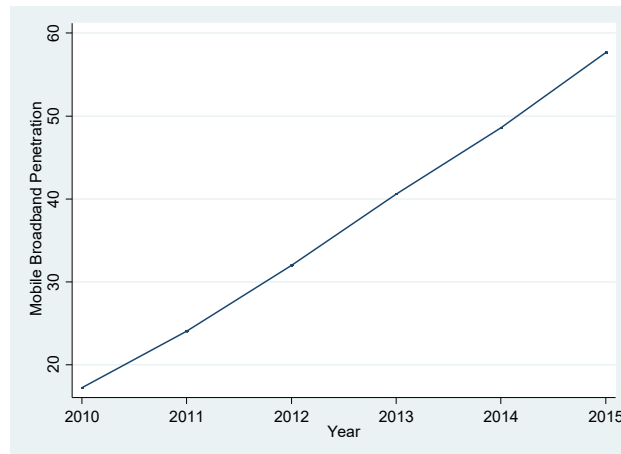
Table 2 presents the descriptive statistics of the untransformed variables. Graph 1 below presents graphically the development of Mobile Broadband penetration over the sample period. It is evident that mobile broadband exhibits a substantial, near linear upward trend and it has not yet reached saturation levels. Following the rest of Section 4, Section 4.1 tests for cross sectional dependence. Section 4.2 discusses the test for unit roots, section 4.3 provides a discussion and test for multi-collinearity and finally section 4.4 presents the results.

Table 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
E-services	744	0.0354571	0.0646492	0.0000125	.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

Graph 1. Mobile Broadband penetration through the sample period.



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

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 panels¹⁰ (Halkos and Polemis, 2017). Early literature on unit root tests assumed that no cross sectional dependence was present, whereas when

¹⁰ However cross sectional dependence is more of a problem in macro panels and less so in micro panels with large number of cases and few years. (Baltagi, 2013).

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 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 *Standardization policy* and *Age*.

Table 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
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 $\sim N(0,1)$. ***, significant at 1%.

4.2 Unit Roots.

A novelty of this study, comparing to the literature of mobile diffusion 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. The presence of a unit root in the dependent and independent variables in the model can result in the problem of spurious regression where statistical significant relationships are inferred where in actuality they do not exist (due, to for example a third unaccounted factor influencing 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 type test as proposed by Maddala and Wu (1999). This test does not require a balanced panel data set and also 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 4 shows the results of the test. The Fisher 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 large panels, as is the case in this study, the P_m statistic is preferred (Choi, 2001). Therefore we can conclude that all variables in the sample are stationary¹¹.

Table 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)
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.

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 in the model can increase the value of standard errors and thus can reduce the efficiency of the model. Moreover estimates of the coefficients of the model tend to be sensitive to alternation on the data or specification of the model¹². VIF does not have critical values where results can be compared but 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 5 presents the results. 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. Therefore the model does not seem to suffer from severe multi-collinearity. However taking a more conservative approach we test if the coefficients and significance levels of the regression analysis change considerably when each three variables with the highest VIF are excluded. Table A.1 in the

¹¹ The variables market liberalization and standardization policy are not included since they are binary.

¹² Although multi-collinearity is less likely to be a factor in panel data (Hsiao C., 2003).

Appendix presents these results. The coefficients and significant levels do not change considerably and therefore we can conclude that are results are robust.

Table 5 Multi-collinearity Diagnostics.

Variables	VIF	VIF-Squared	Tolerance	R-Squared
Mobile Price	1.20	1.10	0.8334	0.1666
Fixed Broadband Price	1.44	1.20	0.6932	0.3068
Market Liberalization	1.15	1.07	0.8685	0.1315
Education	5.06	2.26	0.1977	0.8023
Income	8.76	2.96	0.1142	0.8858
Economic Freedom	1.66	1.29	0.6019	0.3981
Content	3.63	1.91	0.2755	0.7245
E-services	6.89	2.63	0.1450	0.8550
Urban Population	3.18	1.78	0.3147	0.6853
Standardization Policy	1.08	1.04	0.9275	0.0725
Age	2.79	1.67	0.3590	0.6410
Mean VIF	3.35			

4.4 Empirical Results.

Table 6 presents the results of the regression model using the Fixed Effects Instrumental variables General Method of Moments two stage (FEIV-GMM2s) estimator. Moreover the results of plain Fixed Effects estimator are presented for comparison reasons. We apply in our analysis the FEIV-GMM2s estimator since when the model is over-identified and in the presence of heteroscedasticity the GMM estimator is more efficient than the 2SLS estimator (Baum, 2014). A robust Hausman test is conducted 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. In the instrumental variables estimation one of the endogenous variables is mobile price because 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. For instance, the level of income is expected to influence the adoption of mobile services, however the proliferation of telecommunications infrastructure has been also shown to impact the growth of an economy (Roeller and Waverman, 2001; Koutroumbis, 2009, for example) in turn. The same applies for industry factors such as internet content and e-services. While these factors may impact mobile broadband adoption, they also in turn are affected by the level of broadband adoption, presenting 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 are governments or businesses to offer such services as there is a larger customer base to consume them. Therefore, all these factors ar

Table 6 Results of Regression Analysis for the determinants of Mobile Broadband Penetration

Dependent Variable Mobile Broadband Penetration.		
Independent Variables	FE	FEIV-GMM2s
Mobile Price	-0.208 (-1.59)	-0.206** (-1.98)
Fixed Broadband price	-0.258 (-1.62)	-0.239** (-2.04)
Market Liberalization	-0.008 (-0.04)	0.033 (0.23)
Education	0.114*** (2.99)	0.099*** (3.42)
Income	2.486** (2.36)	1.341* (1.67)
Economic Freedom	-0.004 (-1.12)	-0.004 (-1.23)
Content	0.240** (2.41)	0.464*** (3.30)
E-Services	0.618** (3.85)	0.746*** (4.39)
Urban Population	0.392*** (3.92)	0.393*** (5.59)
Standardization Policy	0.427* (1.66)	0.456** (2.21)
Age	0.246*** (3.78)	0.253*** (5.21)
Hausman test robust (P-value)	203.316 (0.0000)	
Sargan-Hansen test (P-value)		2.075 (0.3544)
Difference-in-J Endogeneity test (P-Value)		13.192 (0.0104)
F test (P- value)	30.24 (0.0000)	48.72 (0.0000)
R ²	0.6350	0.6259
Numb. of observations	686	686

(1) *, ** and *** denote significance at the 10%, 5% and 1%, respectively.

(2) t-statistic is denoted in parenthesis.

(3) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

consider endogenous in this study. Considering our findings in table 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. Finally, the Difference-in-J endogeneity test confirms that the endogenous regressors are correlated with the error term, justifying our choice to use instrumental variables methods.

The *Mobile Price* variable has the expected negative sign and is significant, signifying that lower cost of mobile services incite the proliferation of mobile broadband. This finding corresponds to studies of mobile diffusion such as Koski and Kretschmer (2002), Madden et al. (2004), Shinohara et al. (2014) Sagbansua et al. (2015), where they too found a negative correlation between mobile prices and mobile

broadband diffusion. The *Fixed Broadband price* variable is significant and negative, suggesting that mobile and fixed broadband are complements. This finding corresponds to studies such as Ahn and Lee, (1999), Gruber H., (2001), and Lee et al., (2011), where they also found fixed and mobile broadband to be complements. The *Income* variable is positive and significant suggesting that GDP per capita is an important driver of mobile broadband. As stated previously, several studies have reached a similar conclusion (Ahn and Lee, 1999; Gruben and Verboven, 2001a; Madden et al, 2004; Bohlin et al 2010; Lee S., 2008; Sagbansua et al., 2015). *Education* is as expected positive and significant, suggesting that education plays an important role in inciting mobile broadband diffusion. Studies that support this conclusion are for instance, Srinuan et al. (2012) and Sagbansua et al. (2015). The variable *content* is significant and positive indicating that the amount of local 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). The *e-services* variable is positive and significant. This highlights the importance of e-services in promoting mobile broadband, as it increases the willingness of subscribers to adopt mobile broadband services. *Urban population* is positive and significant reflecting that lower deployment costs per potential subscriber in urbanized countries positively affects mobile broadband proliferation. Similarly to Lee, (2008), Lee et al. (2011) and Koski and Kretschmer, (2002) we find that *Standardization policy* is positive and significant, signifying that multiple standards incite mobile broadband proliferation. Finally, the *Age* covariate as expected is positive and significant, suggesting that countries that have a larger population between 15-64 years old have higher mobile broadband penetration.

5. Discussion and Conclusions.

This study attempts to identify relevant factors that determine mobile broadband penetration for a large set of international countries.

This study highlights 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. It is important for policymakers to encourage the development of e-services in general and specifically for governments to promote e-services such as e-government or e-health for their citizens as it increases the value of broadband services for subscribers. Moreover relevant internet content is an important driver of mobile broadband diffusion indicating the importance of the development of the ICT industry in a country. The role of education, among other benefits in society, in inciting mobile broadband diffusion, gives another important reason for policymakers to invest in it. The complementarity between mobile and fixed broadband indicates that promoting one of them will result in beneficial spillover effects for the other. Finally multiple standards competition facilitates mobile broadband adoption. This finding has important implications for policymakers especially in the light of the emergence of new mobile standards such as for 5G mobile telephony. Competition between standards may be the best guarantee that the best standards are selected by market forces and innovation is stimulated.

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 were unavailable to the authors and a proxy variable was used instead. Similarly competitive forces in the market would be more accurately measured if detailed data were available to the authors on market shares of each mobile carrier. Market liberalization may not be a sufficient indicator of competition in

the market as other factors determine entry except the allowance of competition by governments. Finally standardization policy refers to only 3G networks standards as insufficient data were available for 4G mobile standards, although most mobile carriers have already implemented 4G networks.

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Appendix A.

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

Dependent Variable				
Mobile Broadband Penetration.				
Independent Variables	(1)	(2)	(3)	(4)
Mobile Price	-0.206** (-1.98)	-0.238** (-2.22)	-0.206** (-1.96)	-0.225** (-2.10)
Fixed Broadband price	-0.239** (-2.04)	-0.309*** (-2.68)	-0.258** (-2.15)	-0.269** (-2.25)
Market Liberalization	0.033 (0.23)	0.138 (0.93)	0.100 (0.68)	0.0102 (0.07)
Education	0.099*** (3.42)	0.128*** (4.35)	-	0.116*** (3.93)
Income	1.341* (1.67)	2.726*** (3.22)	1.911** (2.40)	-
Economic Freedom	-0.004 (-1.23)	0.00006 (0.02)	-0.00499 (-1.53)	-0.00363 (-1.09)
Content	0.464*** (3.30)	0.591*** (3.87)	0.495*** (3.69)	0.391*** (3.26)
E-Services	0.746*** (4.39)	-	0.766*** (4.41)	0.809*** (4.72)
Urban Population	0.393*** (5.59)	0.468*** (6.75)	0.468*** (6.57)	0.421*** (6.28)
Standardization Policy	0.456** (2.21)	0.483*** (2.68)	0.398* (1.83)	0.420** (2.00)
Age	0.253*** (5.21)	0.221*** (4.62)	0.217*** (4.61)	0.248*** (4.74)
Sargan-Hansen test (P-value)	2.075 (0.3544)	0.077 0.7814	1.028 (0.5980)	0.019 (0.8895)
F test (P- value)	48.72 (0.0000)	43.70 (0.0000)	50.57 (0.0000)	45.12 (0.0000)
R ²	0.6259	0.6001	0.6152	0.6226
Numb. of observations	686	686	686	686

(1) *, ** and *** denote significance at the 10%, 5% and 1%, respectively.

(2) t-statistic is denoted in parenthesis.

(3) Robust standard errors to arbitrary heteroscedasticity and autocorrelation.

(4) 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.

(5) All specifications are inferred using the FEIV-GMM2s estimator.

Table A.2**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.				

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