NET Institute*

www.NETinst.org

Working Paper #08-19

September 2008

The Diffusion of Fixed Broadband: An Empirical Analysis

Sangwon Lee
Jamestown College

Justin S. Brown
University of Florida

* The Networks, Electronic Commerce, and Telecommunications ("NET") Institute, http://www.NETinst.org, is a non-profit institution devoted to research on network industries, electronic commerce, telecommunications, the Internet, "virtual networks" comprised of computers that share the same technical standard or operating system, and on network issues in general.

The Diffusion of Fixed Broadband: An Empirical Analysis**

By

Sangwon Lee, Ph.D.
Assistant Professor
Communication Department
Jamestown College
6002 College Lane
Jamestown, ND 58405
Tel. 701-252-3467
slee@jc.edu

And

Justin S. Brown, Ph.D.
Assistant Professor
Department of Telecommunication
University of Florida
Gainesville, FL 32611
Tel. 352-846-1428
jsbrown@ufl.edu

NET Institute* Working Paper

September 2008

* The Networks, Electronic Commerce, and Telecommunications ("NET") Institute, http://www.NETinst.org, is a non-profit institution devoted to research on network industries, electronic commerce, telecommunications, the Internet, "virtual networks" comprised of computers that share the same technical standard or operating system, and on network issues in general.

** We thank Sylvia Chan-Olmsted, Sanford Berg, Mark Jamison, David Ostoff, and Mircea Marcu for many helpful comments. We gratefully acknowledge financial support from the NET Institute (www.netinst.org) and the Kauffman Foundation.

Abstract

Broadband infrastructure is a key component of the knowledge economy. Broadband connections on both fixed and mobile networks are becoming an indicator of the knowledge economy. Employing the largest secondary data set, this study examines adoption factors of fixed broadband.

The result of nonlinear and linear regression analysis of fixed broadband deployment suggests local loop unbundling (LLU) policy, platform completion between different broadband technologies and other diverse industry, ICT (Information and Communication Technology) and demographic factors influence fixed broadband diffusion. Specifically, the regression analysis of fixed broadband penetration found different types of LLU policies and previous fixed broadband penetration are significant factors of fixed broadband deployment. Some of the significant factors of fixed broadband deployment are different in developed countries than developing countries. This finding suggests, countries fostering broadband deployment need to adopt LLU policy for broadband, but the costs and benefits of the different LLU policy types should be carefully considered. Interestingly, the result of nonlinear regressions of fixed-broadband penetration suggest high levels of platform competition are related to high levels of fixed-broadband penetration, but the effects of platform competition are not statistically significant in OECD countries. This outcome is consistent with the result of linear regression analysis of developed countries (high income ITU membership countries). Considering OECD countries are composed of 30 developed countries with comparatively high GDP per capita, this result is robust. Taking into account this study's results as well as previous empirical studies on fixed broadband deployment, the effects of platform competition are strong in the initial deployment

of fixed-broadband, but the effects of platform competition are decreasing when the broadband market size is sufficiently large or the broadband market is mature.

Also, as expected, previous fixed- broadband penetration was found to be an influential factor of current fixed-broadband deployment in all ITU membership countries, whether characterized as developed or developing countries. Considering impacts of platform competition in ITU membership countries, currently it appears in many countries that network effects and the effects of platform competition co-exist.

Introduction

Continuous technological innovations in telecommunication industry enable us to enter the era of convergence between broadband Internet, wireless networks, and multimodal content and services. Broadband communications lie at the heart of this trend. Broadband infrastructure is a key component of the knowledge economy and high-speed connections are becoming an important economic indicator (ITU, 2006). Widespread and affordable broadband access encourages innovation and economic growth in an economy, and attracts foreign investment (ITU, 2003a).

Although there exist various definitions of broadband, the International Telecommunication Union (ITU) defines broadband as a network offering a combined speed of equal to, or greater than, 256 kbit/s in one or both directions (ITU, 2005; ITU, 2006).[1] Fixed broadband may be defined as transmission capacity with sufficient bandwidth to permit combined provision of voice, data, and video, with no lower limit through a fixed line (ITU, 2003b). According to the International Telecommunication Union (ITU), as of December 2007, more than 335 million broadband subscribers exist all over the world (ITU, 2007).

Successful diffusion of broadband is necessary for the provision of advanced IP-based services such as VoIP (Voice over Internet Protocol) and IP TV (Internet Protocol Television) (Lee & Brown, 2008). In spite of the steady growth in broadband diffusion, many countries are still in the early stages of fixed-broadband deployment and are assessing policies to promote

[1] Initially broadband was defined as communication technologies that provide high-speed, always-on connections to the Internet for large numbers of residential and small-business subscribers (Crandall, 2005; Fransman, 2006; ITU, 2003b). This definition of broadband focuses on the fixed-broadband technologies such as DSL and cable modem. The definition of broadband by the ITU - network offering a combined speed of equal to, or greater than, 256 kbit/s in one or both directions- may include more diverse broadband technologies such as mobile broadband.

faster adoption. Many countries have considered local loop unbundling (LLU)[2] and facilities-based competition as important policy initiatives to promote rapid, fixed-broadband diffusion. Platform competition (facilities-based competition among several different broadband platforms) is often thought to be crucial for reducing prices, improving the quality of service, increasing the number of customers and promoting investment and innovation (ITU, 2003b; DotEcon and Criterion Economics, 2003).

In spite of a growing body of literature on fixed-broadband diffusion previous studies have following limitations: 1) limited number of independent variables; 2) insufficient number of observations; and 3) lack of refined theoretical explanation; and 4) inconsistent empirical results. These previous empirical studies on fixed-broadband adoption employed only limited number of independent variables with insufficient data. Also, previous studies have not covered some important independent variables such as institutional environment, international telecommunication infrastructure investment, content, and age. Previous studies also do not typically propose refined theoretical frameworks such as network effects and inter-modal competition. Also, the results of these empirical studies are not consistent. For instance, the effects of local loop unbundling (LLU) policy still are not clearly understood through empirical studies. In addition, there is no published empirical study which tests the effectiveness of different types of LLU policies such as full unbundling, line sharing, and bit stream access.

Using 1999-2006 OECD (Organization for Economic Cooperation and Development) data, the longest available panel to date, we estimate a logistic regression to capture the nonlinear nature and examine the influential factors of fixed-broadband diffusion. Also, we examine whether there have been network effects in the diffusion of fixed broadband in OECD countries.

---

[2] Local loop unbundling refers to the process of requiring incumbent operators to open, wholly or in part, the last mile of their telecommunications networks to competitors (ITU, 2003b; OECD, 2003).

In addition, we assess the effects of different types of LLU policies such as full unbundling, line sharing, and bit stream access as well as inter-modal competition.

Literature Review

Current Status of Global Fixed-broadband Diffusion

Many countries are still in the early stages of broadband, as evidenced by the differences in deployment between countries. According to the latest Organization for Economic Co-operation and Development (OECD) penetration data (December 2006), Denmark, Netherlands, Iceland, Korea, and Switzerland are leading broadband economies among OECD countries (see table 1).

Table 1. Fixed-broadband Penetration (Top 20 OECD countries) by Technology, December 2006

	DSL	Cable	Fiber/LAN	Total	Rank	Total Subscribers
Denmark	19.6	9.4	2.8	31.9	1	1,590,539
Netherlands	19.5	12.0	0.4	31.8	2	5,192,200
Iceland	28.8	0	0.2	29.7	3	87,738
Korea	11.4	10.7	7.0	29.1	4	14,042,728
Switzerland	18.8	8.8	0	28.5	5	2,140,309
Norway	21.7	3.8	1.5	27.7	6	1,278,346
Finland	23.5	3.5	0	27.2	7	1,428,000
Sweden	16.0	5.2	0	26.0	8	2,346,300
Canada	11.4	12.3	0	23.8	9	7,675,533
Belgium	14.0	8.4	0	22.5	10	2,353,956
U.K.	16.5	5.1	0	21.6	11	12,993,354
Luxembourg	18.2	2.2	0	20.4	12	93,214
France	19.1	1.1	0	20.3	13	12,699,000
Japan	11.1	2.8	6.2	20.2	14	25,755,080
United States	8.5	10.3	0.3	19.6	15	58,136,577
Australia	15.0	3.3	0	19.2	16	3,939,288
Austria	10.6	6.4	0	17.3	17	1,427,986
Germany	16.4	0.5	0	17.1	18	14,085,232
Spain	12.1	3.1	0	15.3	19	6,654,881
Italy	13.8	0	0.4	14.8	20	8,638,873

Note. Data were derived from Organization for Economic Co-operation and Development (2007a). Source: OECD broadband statistics. Paris: OECD.

For broadband connections fixed, mobile, and portable Internet technologies can be employed. Fixed broadband is mainly implemented through technologies such as digital subscriber line (DSL), cable modem, and fiber- to- the- home (FTTH) (ITU, 2003b). Thus far, for fixed broadband, the dominant platforms are DSL (64.34 %) and cable modem (29.89 %), though other platforms (e.g. FTTH) serve around 6 percent (ITU, 2006).

Previous Studies on Fixed-broadband Diffusion

Policy Factors: LLU, Platform Competition, and Institutional Environments

On the supply side, many countries have considered local loop unbundling regulation as an important policy initiative to promote rapid broadband diffusion. Local loop unbundling (LLU) — which refers to the process by which incumbent carriers lease, wholly or in part, the local segment of their telecommunications network to competitors — has been considered an important policy to stimulate intra-modal competition (OECD, 2003). Implementation of LLU widely differs among countries. Types of LLU – full unbundling[3], line sharing[4] and bit stream access[5] — and LLU prices are different across countries (OECD, 2003). There are arguments for and against local loop unbundling. LLU policy might introduce competition in the DSL markets and prices might fall when incumbent carriers are compelled to open up their networks to competitors (ITU, 2003a). Thus, LLU may generate consumer benefits in the near future through

---

[3] Full unbundling (physical access to raw copper) exists where an incumbent provides full access to its raw copper (OECD, 2003). With full unbundling new entrants take full control of the copper pairs and can provide both voice and DSL services. However, the incumbent still retains ownership of the unbundled loop and is responsible for maintenance (OECD, 2003).

[4] Line sharing (shared access) allows an incumbent to maintain control over copper pairs while new players can lease part of the copper pair spectrum for data services including Integrated Services Digital Network (ISDN) and DSL (OECD, 2003). However, there are some technical concerns such as line noise (OECD, 2003).

[5] Bit stream access (wholesale access) is a type of wholesale arrangement in which new entrants have no managing control over the physical lines and are not allowed to install their own equipment(OECD, 2003). The new entrants generally do not favor this type because, unlike full unbundling and line sharing, they can only provide the services that the incumbent designates (OECD, 2003).

open access to competitors (Frieden, 2005a). However, LLU may confiscate incumbents' property and reduce their incentives to invest in advanced telecommunication technologies (Frieden, 2005a).

There have been a lot of debates on the effects of LLU in the United States. Hausman (2001, 2002) claims LLU regulation in the U.S. has impeded the incumbents' deployment of the network facilities required for DSL, conveying competitive advantages and market share to cable operators providing broadband cable modem services. Through an empirical analysis of CLECs' investment plans and an event study that explores the impact of the Tauzin-Dingell bill on share prices, Glassman and Lehr (2001) found that reduction of network unbundling for broadband deployment places downward pressure on the competitive carriers' equity prices, thereby reducing investment by entrants in network facilities. Employing logit regression analysis from selected ITU countries, Garcia-Murillo (2005) found unbundling an incumbent's infrastructure only results in a substantial improvement in broadband deployment for middle-income countries, but not for their high-income counterparts. Distaso et al. (2006) also found LLU price is an explanatory variable of fixed-broadband adoption. Recently through regression analysis of OECD countries' data, Grosso (2006) found LLU have influenced fixed-broadband deployment. Through their empirical study of 179 observations, Wallsten (2006) found unbundling is a key driver of fixed broadband adoption in OECD countries. In spite of a growing body of literature on the effects of LLU policy on broadband deployment, no empirical study tests the effectiveness of different types of LLU policies such as full unbundling, line sharing, and bit stream access.

Institutional environment might also influence broadband deployment. Using ordinary least-squares hierarchical regression analysis, Andonova (2006) found institutional environment such as political rights and civil liberties are correlated with deployment of the Internet. In spite of these previous studies, there was no empirical study, which tests the influences of institutional environment such as economic and political freedom on fixed-broadband diffusion.

A few studies argue that inter-modal competition (platform competition among different technologies) with other factors in the supply side of the broadband market increase broadband adoption. Aron and Burnstein (2003) suggest that broadband availability in a state is driven by inter-modal competition and cost factors, but not by the raw availability of broadband services. Using U.S. state data in 2000, they found that the independent effect of direct, inter-modal competition is associated with increased household subscription to broadband services (Aron & Burnstein, 2003).

Recently, through two different econometric analyses (time-series analysis and multiple-regression analysis) using data from 50 states, Lee (2006) suggests platform competition and the availability of different broadband platforms have influenced broadband diffusion in the United States. Through panel data analysis, Denni and Gruber (2005) find that inter-platform competition, intra-platform competition in the DSL market, and telecommunication density have a positive impact on broadband diffusion in the United States.

Beyond research that assesses industry factors that contribute U.S. broadband adoption, several studies compare multiple factors of broadband adoption among countries. From the analysis of EU membership countries' data, a report from DotEcon & Criterion Economics shows that inter-modal competition among platforms rather than access-based market entry increases the adoption of broadband. This report suggests broadband penetration tends to be higher in European countries where DSL and non-DSL platforms have similar market share, but the report was not supported by statistical methods (DotEcon & Criterion Economics, 2003). Based upon analysis of data from 14 European countries, Distaso, Lupi and Maneti (2006) demonstrate that inter-platform competition drives broadband adoption, but that competition in the DSL market does not play a significant role.

Industry Factors: Price, Speed, and Telecommunication Infrastructure Investment

Through statistical analysis of approximately 100 countries, Garcia-Murillo (2005) found price, income (GDP per capita), competition have been influential factors of fixed-broadband adoption. Cava-Ferreruela and Alabau-Muňoz (2006) suggest technological competition, low cost of deploying infrastructures, and prediction of the use of new technologies might be key factors for broadband supply and demand, respectively. More recently Fransman (2006) suggested "disruptive competitors" are an important determinant of global broadband performance.[6]

Recently Ridder (2007) found low fixed-broadband price is correlated to the high level of broadband diffusion. Atkinson et al. (2008) also found low level of broadband price is factor of broadband adoption in OECD countries. More recently employing multivariate analysis of 110 country data, Lee and Brown (2008) find broadband speed, platform competition, and content contribute to global broadband adoption.

Telecommunication infrastructure investment from private and public sector is a contributing factor of telecommunication network deployment (ITU, 2003b). Some top

[6] "Disruptive competition" can be defined as existing when competitors to the incumbent in the markets have been so aggressive with their pricing that they even do not cover their marginal costs in the markets and end up making short-run losses (Fransman, 2006). Fransman (2006) argues that a main reason for superior broadband performance of Korea and Japan is results of "disruptive competition."

broadband economies such as Korea and Sweden employed national deployment strategies to promote infrastructure investment from the public and private sectors (ITU, 2003a).

Demographic Factors: Income, Education, Urban Population, Population Density, and Age

Some empirical studies on fixed-broadband deployment suggest demographic factors such as income and population density have influenced fixed-broadband adoption. In addition to the supply-side research, several empirically-driven studies illustrate the demand side of broadband adoption in the U.S. Through data analysis of a national sample of U.S. households, Rappoport, Kridel, Taylor and Alleman (2001) found that price elasticity of demand for broadband service is much greater than narrowband service. Using an estimation of an economic model based on statistical data from 2000 to 2001, Crandall, Sidak and Singer (2002) showed that the decision to use a broadband connection depends on the opportunity cost of time for the user and intensity of Internet use. Kim, Bauer and Wildman (2003) suggest the preparedness of a nation and population density as a cost condition of deploying advanced networks are the most consistent factors explaining broadband uptake in OECD countries.

More recently, through a nationwide U.S. survey, Savage and Waldman (2005) found that preference for high-speed access is apparent among higher income and college-educated households. Through data analysis of U.S. national surveys from 2002 to 2005, Horrigan (2005) claims the intensity of online use is the critical factor in understanding the home broadband adoption decision and suggests the intensity of Internet use is a function of connection speed and years of online experience. Horrigan's more recent survey demonstrates younger age, higher education and income, and urban living share of population may lead to higher level of broadband adoption (Horrigan, 2007). In addition, the United States Government Accountability

Office (2006) found consumers with higher incomes and college degrees are significantly more likely to adopt fixed-broadband.

Chaudhuri, Flamm and Horrigan (2005) found the influences of traditional socio-demographic variables like income and education on broadband deployment are strong in the U.S.. They also find substantial variation observed in access price may largely have a spatial explanation of Internet access (Chaudhuri et al., 2005). Recently, through a household-level analysis, Clements and Abramowitz (2006) found income, age, educational attainment, and the presence of children influence adoption of broadband service in the United States. Using data from 50 states in the United States, Lee (2006) also suggests income have influenced broadband deployment in the United States.

Recently Grosso (2006) found income measured by GDP per capita is related to the broadband penetration among OECD countries. Wallsten (2006) also found income and urbanization are factors of broadband adoption in OECD countries. In his empirical study, Turner (2006) found income and poverty rate are influential factors of broadband deployment. Recently Ridder (2007) and Atkinson (2008)'s empirical study found age is negatively correlated to the broadband adoption in OECD countries. Trkman et al. (2008) found population density and education are influential demographic factors of fixed-broadband deployment in EU countries.

ICT Factors: PC Penetration, Content, and Teledensity

Recent studies on broadband diffusion provide ICT factors such as infrastructure and teledensity have influenced fixed-broadband adoption. Through a comparative study of broadband deployment in Canada, Japan, Korea, and the United States, Frieden (2005) argues the role of government in Information and Communication Technology (ICT) incubation is important for rapid broadband deployment. Kim, Bauer and Wildman (2003) suggest the preparedness of a nation is a factor of broadband deployment. Through a multivariate analysis of ITU membership countries, Lee and Brown (2008) find ICT infrastructure such as PC penetration and content are significant factors of global broadband adoption.

Using panel data analysis of the U.S. states, Denni and Gruber (2005) also find that telecommunication density has been an influential factor of broadband deployment in the United States. Recently Wallsten (2006) also found teledensity is a factor of broadband adoption in OECD countries. More recently, through a factor analysis, Trkman et al. (2008) found that communication technology expenditure, household PC access rate, Internet penetration, and fixed phone penetration are factors of fixed-broadband deployment in EU countries.

Network Effect

Network effect is related to the broadband adoption. Network effect is the circumstance in which the net value of an action is affected by the number of agents taking equivalent actions (Liebowitz and Margolis, 1994). In other words, network effect means the fact that higher usage of certain products or services makes them more valuable. A consequence of network effect is that the purchase of a good by one individual indirectly benefits others who own the good. This type of side-effect in a transaction is known as an externality in economics, and externalities arising from network effects are known as “network externalities” (Church & Gandal, 2005). The resulting “bandwagon effect” is an example of a positive feedback loop (Rohlfs, 2001).

For products characterized by network effects the decision by consumers regarding which network to join will depend not only on relative product characteristics and prices, but also the expected size of the network (Church & Gandal, 2005). The role of the size of the existing installed base in determining the size of the network in the future arises because positive network effects give rise to positive feedback effects (Shapiro, & Varian, 1999). These positive feedback effects create a strong tendency for "the strong grow stronger " in a virtuous cycle—the greater the installed base, the greater network benefits, the more attractive the network to adopters, the greater adoption, the greater the installed base, etc. (Shapiro, & Varian, 1999; Church & Gandal, 2005).

If network effect exists in the use of broadband, new subscribers joining a broadband network might influence the utility of current subscribers (Madden et al., 2004). Network effects might suggest that current subscription is positively correlated to previous subscription (Economides & Himmelberg, 1995). Madden et al. (2004) found that these network effects have influenced mobile telephony subscription. However there is no empirical work to test the existence of network effects on fixed-broadband subscription. Rohlfs (2001) suggested a form of network effects that he calls "bandwagon effects." He suggests that as more and more people subscribe new media technology such as VCRs, personal computer, mobile and broadband Internet, others are attracted to it (Rohlfs, 2001; Haring et al., 2002). Recently Jang et al. (2005) found that the pattern of diffusion of mobile telecommunications for OECD countries is generally characterized by an S-shaped curve; nevertheless, significant differences exist in the spread of the S curve, largely because of differences in the magnitude of the network externality coefficient.

In spite of a growing body of literature that addresses the factors contributing to fixed-broadband diffusion at the national level, the results of empirical studies are not always consistent and insufficient data has prevented previous studies from capturing the nonlinear nature of broadband diffusion. For instance, the influence of important variables on global fixed-broadband adoption across countries — such as platform competition, LLU, population density, urban population, PC penetration, content, and age — have not been clearly understood in a single systematic study (see Table 2). There is no empirical study which tests effects of institutional environments such as economic and political freedom and telecommunication infrastructure investment. Also, there is no empirical study, which tests network effect and impacts of different types of LLU policies such as full unbundling, line sharing, and bit stream access.

Table 2. Cross-National empirical studies on fixed-broadband diffusion

Study	Main independent variables	Significant variables
Kim et al. (2003) **30 countries** 30 observations	Broadband price Dial-up service price Income Preparedness of a nation Competition Population density Policy (unbundling, cross ownership, government funding)	Preparedness of a nation Population density
Garcia-Murillo (2005) **Approximately 100 countries** Observations varies depending on the model (18-92)	Broadband price Income Education Competition Population density Policy (unbundling, cross ownership) Content Personal computers Internet access	Broadband price Income Population density Competition Internet access Unbundling
Distaso et al. (2006) **EU countries** 158 observations (15 time periods)	Intra-modal competition Inter-modal competition Rights of way LLU price Price of leased line Price of ten minutes call	Inter-modal competition LLU price
Cava-Ferreruela and Alabau-Muňoz (2006)	Broadband price Competition Infrastructure investment	Technological competition Cost of deploying infrastructures

30 countries 90 observations (3 years: 2000-2002)	Telecom services penetration Internet indicators Economic indicators Demographic indicators Education indicators Social indicators	Economic indicators Demographic indicators
Grosso (2006) **30 countries** 117 observations (4 years: 2001-2004)	Competition Income Unbundling Fixed Internet penetration	Competition Income Unbundling
Wallsten (2006) **30 countries** 179 observations (5 years: 1999-2003)	Income Unbundling Teledensity Urbanization	Income Unbundling Teledensity Urbanization
Turner (2006) 30 countries 30 observations (2005)	Price Income Population density Education Poverty rate Urbanization	Income Poverty rate
Ridder (2007) 30 countries 30 observations (2005)	Price Income Age Education Saturation Weather Urbanization Competition Policy	Price Age Urbanization Saturation
Atkinson et al. (2008) 30 countries 30 observations (2007)	Market concentration Urbanicity Home ownership Income Temperature Median age Internet users Education Income inequality Price Internet users	Urbanicity Income Internet users Price Median age
Trkman et al. (2008) 25 countries 23 observations (2006)	Electronic purchasing Internet users Information technology expenditures Communication technology expenditures Household Income Household PC access PC users Internet penetration	Communication technology expenditures Household PC access Internet penetration GDP per capita Fixed phone penetration Population density Education

	GDP per capita Price Fixed phone penetration Population density Education	

Empirical Models

To examine determinants of the global fixed-broadband deployment, this study employs both non-linear and linear regression models. This logistic regression model[7] (non-linear regression model) employs 240 observations for broadband services from OECD (Organization for Economic Co-operation and Development) countries. This study also estimates a linear regression model of fixed-broadband penetration. The linear regression model employs approximately 380 observations for fixed-broadband services from the ITU (International Telecommunication Union) membership countries.

Non-linear model of fixed-broadband diffusion

For the estimation of fixed-broadband diffusion, we employed a logistic model of technology diffusion. Gruber and Verboven's (2001b) logistic model of mobile diffusion is applied to the diffusion model for fixed-broadband. The logistic specification is appropriate for capturing the existence of network externalities (Gruber and Verboven, 2001b). With network externality, higher adoption of fixed-broadband services makes subscribers more valuable. In some countries fixed-broadband penetration pattern is nonlinear and standard S-shaped curve.

Letting y_{it} denote the percentage of country *i*'s population that has broadband access to the Internet by time *t*, the standard logistic diffusion equation is:

[7] This logistic regression model is based on the previous study by Lee and Marcu (2007).

$$y_{it} = \frac{y_{it}^*}{1 + \exp(-a_{it} - b_{it}t)} \qquad (1)$$

where a_{it}, b_{it}, and y_{it}^* are parameters, as discussed below.

Not all individuals in a country adopt a new media technology, such as broadband, regardless of how inexpensive the technology may become. This is captured in the model by y_{it}^*, the long run expected fraction of subscribers (the ceiling parameter, or saturation point).[8] The parameter a_{it} in equation (1) is a constant of integration that gives the initial value of fixed-broadband penetration.[9] A positive value shifts the S-shaped function upwards while a negative one shifts it downwards, without modifying the S-shape.

The parameter b_{it} in equation (1) captures the speed of fixed-broadband diffusion. This can be seen by differentiating equation (1) with respect to time:

$$\frac{dy_{it}}{dt}\frac{1}{y_{it}} = b_{it}\frac{{y_{it}}^* - y_{it}}{{y_{it}}^*} \qquad (2)$$

Equation (2) shows that b_{it} is equal to the growth rate in the number of adopters, relative to the fraction of potential subscribers who have not yet adopted the technology.

---

[8] Note that $y_{it} \rightarrow y_{it}^* \quad as \quad t \rightarrow \infty$.

[9] Note that $y_{it} \rightarrow \frac{y_{it}^*}{1+e^{-a_{it}}} \quad as \quad t \rightarrow 0$.

The speed of fixed-broadband diffusion varies with policy variables D_{it}^{j} and country socio-economic characteristics X_{it} in linear fashion. In the previous literatures two broad classes of logistic diffusion models have been proposed: the variable-ceiling logistic and the variable-speed logistic (Fernandez-Cornejo & McBride, 2002). Letting the ceiling vary with country characteristics poses significant estimation problems. There is no guarantee that the parameter will stay at theoretically justifiable levels, or that the model will converge. The variable-speed logistic model is easier to estimate and the speed of adoption can be positive or negative, depending on the movement of exogenous factors.

The logistic regression is symmetric and imposes an inflection point halfway between zero and the saturation point. The inflection point is crucial in determining the saturation point (Bewley and Griffiths, 2003). The saturation point is estimated from the observations of early adopting countries that have passed the midway point, such as Japan and South Korea. To the extent the saturation points of lagging countries differ from those of forerunners, holding the ceiling parameter fixed across countries may bias the expected saturation point for lagging countries. This is somewhat mitigated by the addition of an error term to equation (1) for the purpose of estimation.

$$b_{it} = \beta^{0} + \sum_{j=1}^{J} \beta^{j} D_{it}^{j} + X_{it}\beta \qquad (3)$$

The country characteristics included in X_{it} are variables that may influence the supply and demand for fixed-broadband services. The demand for fixed-broadband services is expected to increase with the higher level of income, education, PC penetration, bandwidth and Internet content. Higher population density and percentage of urban population decrease deployment cost, increasing the supply of broadband. The effects of policy variables on fixed-broadband penetration are main interests of this nonlinear regression. The main policy variables included in this study are dummy variables capturing the effects of different types of LLU such as full bundling, line sharing, bit stream access, LLU price regulation (regulatory approval for line rental charges). Interaction dummy variables of these different types of LLU with LLU price regulation are included in this model with platform competition and institutional environments such as political and economic freedom.

Linear model of fixed-broadband diffusion

To capture more diverse determinants of global broadband deployment, a multiple regression analysis (linear model) is also implemented. To examine the influences of quantifiable variables on the diffusion patterns of fixed-broadband, this study formulates the following linear regression model. Since the distribution of dependent variable and many independent variables in this linear regression model is positively skewed, data transformation with logarithm was employed.

$$\begin{aligned}\text{Ln } Y_t \text{ (BPR)} = {} & \beta_0 + \beta_1(\text{ln Platform Competition}) + \beta_2(\text{ln Previous Penetration}) + \\ & \beta_3(\text{ln Political Freedom}) + \beta_4(\text{ln Economic Freedom}) + \\ & \beta_5(\text{ln Fixed-broadband Price}) + \beta_6(\text{ln Mobile Price}) + \beta_7(\text{ln Speed}) + \\ & \beta_8(\text{ln Bandwidth}) + \beta_9(\text{ln Investment}) + \beta_{10}(\text{ln Income}) + \\ & \beta_{11}(\text{ln Education}) + \beta_{12}(\text{ln Population Density}) + \\ & \beta_{13}(\text{ln Urban Population}) + \beta_{14}(\text{ln Age}) + \\ & \beta_{15}(\text{ln PC Penetration}) + \beta_{16}(\text{ln Content}) + \beta_{17}(\text{ln Internet usage}) + \\ & \beta_{18}(\text{ln Teledensity}) + \varepsilon_t \qquad (4)\end{aligned}$$

The empirical model (4) for multivariate analysis was a composite model from previous empirical studies. In the model, the dependent variable (Y_t) is fixed-broadband diffusion. This study included independent variables such as platform competition, previous penetration, political freedom, economic freedom, fixed-broadband price, speed, bandwidth, telecommunication network investment, income, education, population density, urban population, age, PC penetration, content, Internet usage, and teledensity. To examine whether mobile broadband is a complement to or a substitute for fixed-broadband, mobile price was also included in the linear regression model.

Also, based on the result of regression analysis, significant factors of fixed-broadband diffusion for developed countries (high income countries) and developing countries (medium or low income countries) are compared.

Data and Measurement

Table 3 and 4 shows the variables, their measurement, and the corresponding data sources for fixed-broadband deployment. The dependent variable, fixed-broadband deployment, was measured by the number of broadband subscribers per 100 inhabitants. As detailed in the literature review, there are many potential independent variables involving policy, industry, ICT and demographic factors that may influence fixed-broadband adoption.

Policy Factors

LLU (Local loop unbundling) might be a key driver of the fixed-broadband deployment (ITU, 2003b; Garcia-Murillo, 2005; Distaso et. al., 2006). To capture the effects of different types (full unbundling, line sharing, and bit stream access) of LLU and LLU price regulation (regulatory approval for line rental charges), dummy variables (1 for with full unbundling 0 for otherwise; 1 for with unbundling 0 otherwise; 1 for with bit stream access 0 for otherwise; 1 for with price regulation 0 for no price regulation) are also employed. Some previous studies used dummy variable as a measure of LLU (Garcia-Murillo, 2005; Lee & Brown, 2007). For the actual nonlinear model of regression, interaction variables of these dummy variables are used to prevent multicollinearity issue. Three types of LLU policy were identified from the interactions of these dummy variables- LLU Policy I (full unbundling, line sharing and bit stream access without price regulation), LLU Policy II (full unbundling, line sharing, no bit stream access with price regulation), and LLU Policy III (full unbundling, line sharing and bit stream access with price regulation). For the one-way ANOVA, dummy variable (1 for with LLU, 0 for no LLU) is used. Political freedom is measured by the inverse of the score on civil liberties (originally ranging from 1 to 7) (Andonova, 2006). For the measurement of economic freedom, the index of economic freedom index has been used. The index of economic freedom is defined by multiple rights and liberties such as business freedom, trade freedom, monetary freedom, and freedom from government (Beach & Kane, 2007).

Industry Factors

Platform competition is an important industry variable in which the broadband market is served by competing platforms. In the previous studies platform competition could be measured by HHI (Herfindahl-Hirshman-Index) or dummy variable (0 or 1) (Distaso et. al., 2006; Lee & Marcu, 2007). A report from DotEcon & Criterion Economics (2003) suggested broadband penetration tends to be higher in European countries where DSL and non-DSL platforms have similar market share. This study employs more generalized measures for platform competition by the HHI (Herfindahl-Hirshman-Index) between different fixed-broadband technologies.

Fixed-broadband price arguably has been a key industry factor in promoting broadband demand. Successful broadband economies are characterized by low prices as a result of flourishing competition and innovative pricing schemes to attract a wide variety of customers

(ITU, 2003a). Broadband price is measured by broadband monthly charge (in U.S. Dollars). Broadband speed is also considered important independent variable that might influence global broadband adoption. It is measured by broadband download speed (kilobit per second). As a product differentiation strategy in the broadband access market, broadband speed might influence broadband demand. For the measurement of bandwidth, international Internet bandwidth (bits per inhabitant) is employed. For the measurement of telecommunication infrastructure investment, annual telecommunication investment is employed. For mobile price, per minute charge (in U.S. Dollars) for a local call during peak time is used.

Demographic Factors

Demographic variables such as income, education, population density, urban population and age might influence fixed-broadband deployment. For the measurement of income, GDP per capita is used. Many studies employed GDP per capita for the measurement of income (Kim et al., 2001; Garcia-Murillo, 2005; Grosso, 2006; Ridder, 2007). Level of education is measured by the UNDP education index. The United Nations Development Programme (UNDP) education index measures a country's relative achievement in both adult literacy and combined primary, secondary and tertiary gross enrolment. Initially an index for adult literacy and one for combined gross enrollment are calculated and then these two indices are combined to create the education index, with two-thirds weight given to adult literacy and one-third weight to combined gross enrolment (UNDP, 2005).

Population density is measured by population density per $km.^2$ Urban population is measured by the percentage of urban population. This study has interest in particular segment of age groups, so age is measured by percentage of age between 15 and 34.

ICT Factors

Internet content may be related to the diffusion of broadband. For the proxy measurement of content, Internet hosts per 10000 inhabitants is employed. Internet usage is measured by Internet users per 100 inhabitants. Teledensity is measured by main telephone lines per 100 inhabitants. To measure the PC infrastructure, estimated PCs per 100 inhabitants is used.

Other Factors

This study also examines the independent variable of income and regions using categorical variables. Previous subscription could influence the diffusion of fixed-broadband. To test the influence of network effects on the fixed-broadband deployment, this study includes previous year's fixed-broadband subscribers per 100 inhabitants in the model.

This study employs different samples for non-linear and linear regression model for fixed-broadband deployment. Through employing two different samples, this study can include more independent variable for the model. For non-linear regression model, OECD data from 1999 to 2006 is used, with a total of 240 observations for the non-linear model. For the linear model, ITU data from 2002 to 2006 is employed, providing approximately 380 observationsfor the linear model.

Table 3. Variables, measurement and data sources for fixed-broadband diffusion (Non-linear regression model)

Variables	Measurement	Data Sources
Fixed-broadband deployment	Fixed-broadband subscribers per 100 inhabitants	OECD (1999-2006)
Income	GDP per capita	ITU (1999-2006)
PC Infrastructure	Estimated PCs per 100 inhabitants	ITU (1999-2006)
LLU Policy I	Dummy (1 for with full unbundling, line sharing, bit stream access, no LLU price regulation, 0 for otherwise)	OECD (1999-2006)
LLU-Policy II	Dummy (1 for with full unbundling, line sharing, bit stream access, with LLU	OECD (1999-2006)

	price regulation, 0 for otherwise)	
LLU-Policy III	Dummy (1 for with full unbundling, line sharing, bit stream access, with LLU price regulation, 0 for otherwise)	OECD (1999-2006) OECD (1999-2006)
Population density	Population density (per km^2)	ITU (1999-2006)
Internet content	Internet hosts per 10000 inhabitants	ITU (1999-2006)
Platform Competition	HHI (Herfinall-Hirschman Index) for different fixed-broadband platforms	OECD (1999-2006)
Education	UNDP Education index	UNDP (1998-2007)
Bandwidth	International Internet Bandwidth (Bits per inhabitant)	ITU (1999-2006)
Political freedom	Inverse of the score on civil liberties	Freedom House (1999-2006)
Economic freedom	Index of economic freedom	Heritage Foundation (1999-2006)

Table 4. Variables, measurement and data Sources for fixed-broadband diffusion (Loglinear regression model)

Variables	Measurement	Data Sources
Fixed-broadband deployment	Fixed-broadband subscribers per 100 inhabitants	ITU (2002-2005)
Income	GDP per capita	ITU (2002-2005)
PC Infrastructure	Estimated PCs per 100 inhabitants	ITU (2002-2005)
Platform Competition	HHI (Herfinall-Hirschman Index) for different fixed-broadband platforms	ITU (2002-2005)
Population Density	Population density (per km^2)	ITU (2002-2005)
Internet Usage	Internet user per 100 inhabitants	ITU (2002-2005)
Internet Content	Internet hosts per 100 inhabitants	ITU (2002-2005)
Mobile Price	Per minute local call (USD) peak	ITU (2002-2005)
Speed	charge	ITU (2002-2005)
Education	Broadband speed (Kbit/s) UNDP education index	UNDP (2002-2005)
Urban Population	Percentage of urban population	Euromonitor (2002-2005)
Telecommunication Infrastructure Investment	Annual telecommunication investment (USD)	ITU (2002-2005)
Teledensity	Main telephone lines per 100 inhabitants	ITU (2002-2005)
Previous Penetration	Previous year's fixed-broadband subscribers per 100 inhabitants	ITU (2001-2004)
Bandwidth	International Internet bandwidth (Bits per inhabitant)	ITU (2002-2005)

Age	Percentage of age between 35-44	World Bank (2002-2005)
Political Freedom	Inverse of the score on civil liberties	Freedom House (2002-2005)
Economic Freedom	Index of economic freedom	Heritage Foundation (2002-2005)
Fixed-broadband Price	Lower speed monthly charge (USD)	ITU (2002-2005)

Results and Analysis

Nonlinear Regression Model (OECD Countries)

Data for nonlinear regression model covers all 30 OECD countries from 1999 to 2006. This study estimates the variable-speed logistic model described in equations (1) and (3) by nonlinear least squares, after adding disturbances to equation (1). Table 5 provides the results (see nonlinear model part in table 5).

PC penetration was associated with higher broadband penetration levels. PC penetration was statistically significant at the .01 level. High level of education, population density, and Internet content (the number of Internet hosts per 10000 inhabitants) were statistically significant at the .05 level. The main interest of this nonlinear model of fixed broadband diffusion is the effect of LLU policy. All three types of LLU policy variables are statistically significant at the 1 percent level. This may mean that LLU policy I (with full unbundling, line sharing, bit stream access and without LLU price regulation), LLU policy II (with full unbundling, line sharing, no bit stream access and with LLU price regulation) and LLU policy III (with full unbundling, line sharing, bit stream access and with LLU price regulation) have contributed high level of fixed broadband penetration.[10]

[10] Most of OECD countries have two types of LLU policy. One major type of LLU was LLU policy, which has full unbundling, line sharing, and bit stream access and the other major type of LLU in OECD countries was LLU policy, which has full unbundling and line sharing without bit stream access. With two different types of LLU, for this empirical study, interaction of these two types and LLU price regulation. Only three cases of LLU policies were

Table 5. Results of regressions of fixed broadband diffusion

	Nonlinear Model		Log linear (Extended Model)		Log linear (Reduced Model)	
	Coefficients		Coefficients		Coefficients	
Variable	B	t-stat	B	t-stat	B	t-stat
Constant	-	-	.62	.92	.02	.13
Ceiling	26.14	19.85***	-	-	-	-
Initial level Parameter	-3.52	-13.08***	-	-	-	-
Speed	-	-	.04	.80	-	-
Fixed broadband price	-	-	-.09	-.03*	-.10	-1.9*
Mobile price	-	-	.08	1.8*	.06	1.4
Education	.47	2.11**	-.08	-1.7	-	-
Internet use	-	-	.35	3.98***	.31	4.28***
Population density	B<.001	2.07**	.002	.067	-	-
Bandwidth	1.07E-06	0.30	.13	3.75***	.13	4.15***
Content	B<.001	2.77**	-.05	-1.47	-	-
	-.023	-.40	-.18	-1.85*	-.10	-1.3
Political freedom	-.004	-1.61	-.60	-1.58	-	-
Economic freedom	-	-	.07	.58	-	-
Urban population	-	-	.27	.78	-	-
Age (35-44)	B<-.001	-1.07	-.07	-1.84*	-.08	-2.1**
Platform competition						
Previous penetration	-	-	.65	21.5***	.63	23.01***
Telecom investment	-	-	-.007	-.41	-	-
Teledensity	-	-	-	-	-	-
Income	-1.13E-06	-0.63	-	-	-	-
PC Penetration	.004	3.09***	-	-	-	-
LLU Policy Type I	.21	3.39***				
LLU Policy Type II	.19	2.81***				
LLU Policy Type III	.15	3.00***				
R-Squared	0.93		0.92		0.91	
Number of observations	217		255		282	

* Statistically significant at the 10% level
** Statistically significant at the 5% level
***Statistically significant at the 1% level

High level of platform competition, which is measured by HHI (Herfindall-Hirschman Index) was related to high level of fixed broadband penetration, but it was not statistically significant at the .10 level (p-value:.29). Bandwidth, political freedom, and economic freedom were not significant in the model. To check for multicollinearity in this model, correlation

identified and included in the model after careful check of correlation between these different types of LLU cases, which might not lead to multicollinearity in the model.

analysis was also conducted. Based on the .80 benchmark, there were no highly correlated independent variables in the model. R-squared for this model was .932 and the adjusted R-squared was .930.

Linear Regression model (ITU membership countries)

A total of 380 observations were analyzed employing the multiple regression analysis. Extended and reduced model were identified from the data analysis. Note that dependent variable and independent variables were transformed using logarithmic function since data were positively skewed.

1. Extended model

Initially, all eighteen independent variables were included for the multiple regression analysis. Multicollinearity issue might occur when independent variables are highly correlated, a correlation analysis conducted to check potential multicollinearity problems. To assess the strength of correlations, the .80 Pearson correlation criterion was employed. PC penetration, teledensity, and income were removed from the initial model because of its high correlation with other independent variables. Table 6 shows the ANOVA table of the extended regression model, which illustrates the model's significance at the .01 level (F statistic: 199.15, P <. 001).

Specifically, Internet use, bandwidth, and previous penetration were statistically significant at the .01 level. Other independent variables such as fixed broadband price, political freedom, mobile price, and platform competition were statistically significant at the .1 level. Other variables such as speed, education, population density, content, urban population, age (35-44), and telecommunication investment were not statistically significant. R-squared for the extended model was .926.

2. Reduced model

To check the stability of results in the empirical study, non-significant variables such as speed, education, population density, content, urban population, age (35-44), and telecommunication investment were removed from the reduced model. The reduced model is significant at the .01 level (F statistic: 357.76). In this model, mobile price was positively related to the dependent variable, but it was not statistically significant at the .1 level. Internet use, bandwidth, and previous penetration were statistically significant at the .01 level, and platform competition was significant at the .05 level. Also, lower price of fixed broadband was associated with higher level of fixed broadband penetration. R-squared for the reduced model was .915. Table 5 provides the results of the reduced model from the regression analysis.

Results of Fixed-Broadband Diffusion for Developed and Developing Countries

A total of 132 observations were analyzed employing the multiple regression analysis for developed countries and a total of 148 observations were analyzed for developing countries. R-squared for the model for developed countries was .90, and R-squared for the model for developing countries was .81. Dependent variable and independent variables were transformed using logarithmic function since data were positively skewed.

1. Regression Analysis: Developed Countries

In the initial model, all eighteen independent variables were included for the multiple regression analysis. PC penetration, teledensity, and Internet use were removed from the initial model because of its high correlation with other independent variables. For the extended model, some insignificant variables such as political freedom, economic freedom, urban population, age (35-44), and telecommunication investment were removed from the model. In the reduced model, other insignificant variables such as speed, fixed broadband price, bandwidth, and platform competition were also removed from the model. Table 6 provides the ANOVA table of the reduced regression model, which illustrates the model's significance at the .01 level (P <. 001).

In the reduced model, education and previous penetration were statistically significant at the .01 level. Other independent variables such as income, population density, and content were statistically significant at the .05 level. Mobile price was negatively associated with high level of fixed broadband diffusion at the .1 level in the developed countries. The results of analysis of developed countries were consistent with the results of analysis of OECD countries. In both models, high level of education, population density, and Internet content were statistically significant.

2. Regression Analysis: Developing Countries

Initially, all eighteen independent variables were included for the multiple regression analysis. PC penetration, teledensity, and income were removed from the initial model because of its high correlation with other variables. For the extended model, some insignificant variables such as education, population density, content, economic freedom, urban population, age (35-44), and telecommunication investment were removed from the model. For the reduced model, other insignificant variable such as speed was also removed from the model. Table 6 provides the results of the extended and reduced regression model, which illustrates the model's significance at the .01 level (P <. 001).

The result of analysis for developing countries was very different from the result of developed countries. In the reduced model, bandwidth and previous penetration were statistically significant at the .01 level. Internet use was statistically significant at the .05 level. Mobile price was positively associated with high level of fixed broadband diffusion at the .1 level in the developing countries instead of negative association in the developed countries. Fixed broadband price and HHI was negatively associated with the high level of fixed broadband penetration.

Table 6. Results of regressions of fixed broadband penetration for developed and developing countries

Variable	Developed Countries				Developing Countries			
	Extended model		Reduced model		Extended model		Reduced model	
	Coefficients B	t-stat	Coefficients B	t-stat	Coefficients B	t-stat	Coefficients B	t-stat
Constant	-.17	-.40	-.48	-1.52	-.28	-.66	-.20	-.70
Speed	.04	1.46	-	-	.18	1.35	-	-
Fixed broadband price	-.10	-1.61	-	-	-.14	-1.80*	-.13	-1.67*
Income	.13	1.43	.16	2.13**	-	-	-	-
Mobile price	-.06	-1.79*	-.06	-1.69*	.13	1.75*	.14	1.83*
Education	1.91	2.96***	2.28	3.79***	-	-	-	-
Internet use	-	-	-	-	.19	1.66*	.24	2.14**
Population density	.03	1.68*	.04	2.50**	-	-	-	-
Bandwidth	.03	.90	-	-	.11	1.97*	.15	2.71***
Content	.05	1.90*	.06	2.55**	-	-	-	-
Political freedom	-	-	-	-	-.23	-1.55	-.23	-1.54
Economic freedom	-	-	-	-	-	-	-	-
Urban population	-	-	-	-	-	-	-	-
Age (35-44)	-	-	-	-	-	-	-	-
Platform competition	-.05	-.74	-	-	-.10	-1.90*	-.09	-1.72*
Previous penetration	.62	20.71***	.65	24.27***	.61	13.89***	.61	14.09***
Telecom investment	-	-	-	-	-	-	-	-
Teledensity	-	-	-	-	-	-	-	-
PC Penetration	-	-	-	-	-	-	-	-
R-Squared	0.90		0.90		0.81		0.81	
Number of observations	132		132		148		148	

* Statistically significant at the 10% level. ** Statistically significant at the 5% level. ***Statistically significant at the 1% level

Main Findings

Effects of Policy Factors on Broadband Deployment

This study examined several policy factors of broadband diffusion. For fixed-broadband, the effects of interactions of different types of LLU policies and LLU price regulation on fixed-broadband deployment were examined. Also, the effects of diverse industry, ICT and demographic factors on fixed broadband diffusion were tested.

1. Effects of LLU policy on fixed broadband diffusion

The results of nonlinear regression analysis suggests the effects of interactions of different types of LLU and LLU price regulation were very significant factors of fixed broadband diffusion in OECD countries. Most OECD countries adopted two types of LLU. The first type of LLU in OECD countries is implementation of full unbundling, line sharing, and bit stream access all together. Some OECD countries adopted full unbundling and line sharing only without bit stream access (OECD, 2003). Also, many OECD countries have LLU price regulation such as regulatory approval for line rental charges (OECD, 2003). The result of nonlinear regression study suggests that LLU policy type I (full unbundling, line sharing, and bit stream access without LLU price regulation for line rental charges), LLU policy type II (full unbundling, line sharing, and no bit stream access with LLU price regulation for line rental charges), and LLU policy type III (full unbundling, line sharing, and bit stream access with LLU price regulation for line rental charges) were significant factors of fixed broadband diffusion in OECD countries.

Based on these results, in general, LLU policy can be an effective policy tool for improving broadband diffusion.[11] Considering that DSL is the major source of residential broadband delivery in most countries, intra-modal competition in the DSL market through LLU policy might have contributed to a greater adoption of fixed-broadband (Lee & Brown, 2008). LLU policy might simulate the competitive effect by opening up an incumbent network for competitive access. Effective intra-modal competition through LLU policy may bring real choice

[11] These results are consistent with the results of other previous studies by Ridder (2007), Wallsten (2006), and Grosso (2006).

for customers and reduce DSL prices (Lee, 2006; DotEcon & Criterion Economics, 2003). However, implementation of LLU policy and LLU price widely differs among countries (OECD, 2003). In spite of significance LLU policies' effect on broadband deployment, strong LLU regulation may confiscate incumbents' property and reduce their investment incentives in new telecommunication technologies (Frieden, 2005a). Considering these costs and benefits of LLU policy, more refined LLU policy should be recommended.

Effects of Industry Factors on Broadband Deployment

Platform/network competition is a significant factor of broadband deployment. The result of log linear regression of fixed-broadband diffusion suggests the higher level of platform competition measured by HHI (Herfinall-Hirschman Index) is associated with the higher level of fixed broadband penetration. Though coefficient B of platform competition shows its relationship with fixed-broadband diffusion, it was not a significant factor of fixed-broadband diffusion in developed countries (see Table 6) in the log linear model. This result is consistent with the result of the nonlinear model of fixed broadband diffusion for OECD countries. Considering OECD countries consist of 30 developed countries, this result appears robust (see Table 5 and 6). However, in developing countries, platform competition was an influential factor of fixed-broadband diffusion. With these results, considering most developed countries have higher level of fixed-broadband penetration, it appears platform competition is mainly effective for countries in the initial diffusion stage of fixed-broadband deployment. In the log linear model of fixed-broadband deployment, this study also found fixed broadband price, which is measured by lower speed monthly charge (USD), was negatively associated with the higher level of fixed-broadband diffusion. As Ridder (2007) suggested, many previous empirical studies on fixed broadband couldn't find this negative association between fixed-broadband price and fixed-broadband deployment.[12] Considering the relationship between price and normal goods, negative association between fixed-broadband price and fixed-broadband deployment is an expected result.

The log linear regression of fixed-broadband deployment also suggests that bandwidth, which is measured by bits per inhabitants, is a driver of fixed broadband deployment. Considering bandwidth may determine the quantity of information transmitted and the offering of diverse broadband applications, the positive association between bandwidth and fixed broadband deployment is an expected result.

The effect of mobile price on fixed-broadband deployment is very interesting. In the linear regression analysis for all ITU membership countries, mobile price is not a significant factor of fixed-broadband diffusion. Also, the result of linear regression analysis of mobile broadband suggests fixed-broadband price is not a significant factor of mobile-broadband diffusion. Based on these results, in the linear regression model for all countries, mobile service (and mobile-broadband service) is not a complement or substitute to fixed-broadband services and fixed-broadband service is not a complement or substitute to mobile-broadband service. However, surprisingly, in developed countries, mobile price is negatively associated with the higher level of fixed broadband, but, in developing countries, mobile price is positively associated with the higher level of fixed broadband. This result might suggest that in developed countries mobile service is a complement to fixed-broadband services, but in developing countries mobile service is a substitute to fixed broadband. Considering consumers in low-income countries tend to have a limited budget for media and telecommunication services, this result is plausible.

[12] Garcia-Murillo (2005) found association of fixed broadband price, which is measured by monthly price per megabite, with the number of fixed broadband subscribers. However, in the study, fixed broadband price was positively correlated to the number of subscribers.

Effects of Demographic/ICT Factors on Broadband Deployment

Higher levels of education are associated with higher levels of fixed-broadband deployment in both nonlinear and linear regression models. As Rodgers (2003) suggests, many early adopters tend to have higher socio-economic status (e.g. high level of education).

High level of population density and urbanization are considered as supply factors for broadband diffusion (Ridder, 2007). The results of nonlinear and linear regression analysis of fixed broadband suggests higher levels of population density are associated with higher levels of fixed-broadband deployment. This result may imply more densely populated countries have advantages in the cost conditions for network deployment. The result of nonlinear regression analysis suggests that higher levels of PC penetration are associated with the higher levels of fixed broadband penetration in OECD countries (see Table 5). This result might suggest that an already well-established ICT infrastructure may lead to more rapid fixed-broadband deployment. Also, the result of linear regression for all ITU membership countries suggests high levels of Internet usage in a country is correlated with high levels of fixed broadband diffusion (see Table 5). As Frieden (2005) contends, these results of ICT factors might suggest that ICT incubation, which is supported by ICT infrastructure or ICT use such as PC infrastructure and Internet use, may be key drivers of broadband deployment.

In addition, Internet content, as measured by the number of Internet hosts per 10000 inhabitants, was a significant factor for fixed broadband penetration in OECD countries (see Table 5). This result implies that the amount of compelling content, services and applications within a nation is an important factor of fixed-broadband diffusion (Lee & Brown, 2008). Also, the result of linear regression analysis of fixed-broadband diffusion suggests previous fixed-broadband penetration is positively associated with current fixed-broadband penetration, which may imply the existence of network effects. As Economides and Himmelberg (1995) suggest, if there are network effects, current subscription of new media is positively correlated with previous subscription of new media. Based on the result of log linear regression study of fixed-broadband deployment, this study at least suggests that between 2002 and 2005, new fixed-broadband subscribers influenced the utility of current fixed-broadband subscribers.[13]

Discussion and Conclusion

One of the main goals of this study is to examine the effects of platform competition on broadband deployment. Platform competition occurs when different technologies (platforms) compete to provide similar or differentiated telecommunication services to end-users (Church & Gandal, 2005). Platform competition in network industry involves competition between technologies that are not only differentiated, but also involve competing networks (Church & Gandal, 2005). Using ITU membership countries data, this study tested the impacts of platform competition between cable modem, DSL and other platforms on fixed-broadband penetration. The result provides competition between different fixed-broadband platforms is an influential factor of fixed-broadband deployment in ITU membership countries.[14] Interestingly, the result of nonlinear regressions of fixed-broadband penetration suggest high levels of platform competition are related to high levels of fixed-broadband penetration, but the effects of platform competition are not statistically significant in OECD countries. This result is consistent with the result of linear regression analysis of developed countries (high income ITU membership countries). Considering OECD countries are composed of 30 developed countries with comparatively high GDPs per capita, it seems this result is robust.

---

[13] If more broadband penetration data, which covers more periods, are available, using different nonlinear model, more refined research to test the impact of network effect on broadband deployment will be possible.

[14] It appears this result was similar in developing countries (see Table 6).

Upon examination of this study's results of and previous empirical studies on fixed broadband deployment, it appears the effects of platform competition are strong in the initial deployment (e.g. a developing country with low level of fixed broadband penetration) of fixed-broadband, but the effects of platform competition are decreasing when the broadband market size is sufficiently large or broadband market is mature.[15] Strong platform competition among different technologies may lead to lower prices, increased feature offerings, and more extensive broadband networks (ITU, 2003a), but, it seems, after the initial deployment of fixed-broadband, these effects of platform competition decrease. In the future, with larger numbers of data and observation periods, the effects of platform competition should be continuously examined.[16]

This study also examined whether network effects are involved in the diffusion of broadband. For the test of network effect, a long period of observations with sufficient number of data is necessary. For the nonlinear model of fixed broadband, this study employs Gruber and Verboven (2001)'s model. Since nonlinear model of fixed- broadband diffusion already assume network externality, this study tested whether previous subscription of fixed-broadband is a significant factor of current subscription in the log linear regression model of fixed broadband. As expected, previous fixed- broadband penetration was an influential factor of current fixed-broadband deployment in all ITU membership countries, whether characterized as developed or developing countries. Considering impacts of platform competition in ITU membership countries, it appears that network effects and the effects of platform competition co-exist. The result of log linear regression analysis suggests, for fixed broadband, new subscribers joining a

[15] In some OECD countries such as Korea and Japan, the diffusion pattern of fixed broadband already shows s-shape curve, as Rodgers (2003) suggested in the diffusion of innovations theoretical framework.
[16] Hőffler (2007) found negative side of platform/network competition. He suggested that comparing additional social surplus attributable to cable competition with the cable investments, without significant positive externality, infrastructure competition has probably not been welfare enhancing (Hőffler, 2007).

broadband network might influence the utility of current subscribers. This network effect in fixed-broadband markets might become significant after a certain broadband subscription percentage has achieved critical mass. This study has not examined the critical mass point for fixed-broadband deployment; however, network effect and critical mass point may be captured in fixed-broadband deployment pattern in some countries like Korea, Japan and UK (Lee & Marcu, 2007). Research should continue to examine network effects and the effects of platform competition, thereby capturing how broadband diffusion patterns change over time.

Also, the result of this empirical study suggests that an established infrastructure (e.g. PC penetration, ICT use, previous fixed broadband penetration) for relevant information and communication technologies is an influential factor for fixed-broadband diffusion (Lee et al., 2007). This result may imply the phenomenon of leapfrogging in developing countries cannot be easily applied to the diffusion of fixed-broadband. More refined studies about the applicability of leapfrogging theory to broadband diffusion are necessary in the future.

Relating to policy implications, this study examined the effects of LLU policy on fixed-broadband diffusion. There have been a lot of debates on the effects of LLU policy, but the type of LLU policy and LLU price are very different across countries. The result of nonlinear regression study suggests that LLU policy type I (full unbundling, line sharing, and bit stream access without LLU price regulation for line rental charges), LLU policy type II (full unbundling, line sharing, and no bit stream access with LLU price regulation for line rental charges), and LLU policy type III (full unbundling, line sharing, and bit stream access with LLU price regulation for line rental charges) were all significant explanatory variables of fixed broadband diffusion in OECD countries. Apparently it seems this result supports the effectiveness of LLU on fixed broadband in many countries. Effective LLU policy may generate consumer benefits in the near future through open access to competitors (Frieden, 2005a). Considering the result of this study, countries fostering broadband deployment need consider adopting LLU policy for the fixed-broadband market. However, LLU might reduce incumbent's incentives to invest in new telecommunication technologies (Frieden, 2005a). Considering these costs and benefits of LLU policy, it may be better if countries might pursue light-touch regulation such as line-sharing and/or bit stream access instead of full unbundling at a reasonable LLU price. A previous study suggests the uptake of these light forms of LLU has been relatively successful (de Bijl & Peitz, 2005).

This study also found significant effects of platform competition on fixed-broadband diffusion in the initial deployment of fixed broadband. This result implies, at least in the initial broadband markets, regulation across different platforms should be as competitively neutral as possible for sustaining strong platform competition. Considering positive effects of network externality and the possibility of decreasing effects of platform/network competition on broadband diffusion in the long term, it is still important to note that concepts of efficiency and ease of integration are critical for future broadband markets.

Also, this study has different policy implications for developed and developing countries. The results of fixed broadband deployment study suggest that mobile service could be a substitute for fixed broadband service in developing countries, but it could be a complement for fixed broadband service in developed countries. This result may imply, in the long term, when mobile broadband services are mature in many countries, deployment of fixed (mobile) broadband might positively influenced mobile (fixed) broadband in developed countries. Considering leapfrogging theory cannot easily applied to broadband deployment in the developing countries, this result of statistical analysis for developing countries may suggest without sufficient previous ICT experiences and better economic status,[17] it is not easy to deploy fixed and mobile broadband at the same time.

This study does possess some limitations. For the fixed-broadband diffusion model, because of data availability, more diverse independent variables were not included for the nonlinear regression model. Also, since the nonlinear model already assumes network externality, the impacts of network effects on fixed broadband could not be tested in the model. When more data and observations over a longer period are available, and, with different nonlinear model such as Gompaz model, more refined analysis on the effects of platform competition and network effects will be possible. Also, for the analysis of the effects of LLU policy, if diverse data about the effects of line sharing and bit stream access are available with sufficient observations, more refined comparison of the effects of different type of LLU policies are possible.

[17] It appears that insufficient income and limited budget for mobile and fixed broadband services are reasons of substitute relationship between mobile service and fixed broadband services in developing countries.

References

Andonova, V. (2006). Mobile phones: the Internet and the institutional environment. *Telecommunications Policy*, *30*, 29-45.

Aron, D. J. & Burnstein, D. E (2003), "Broadband adoption in the United States: An empirical analysis", in Shampine, A.L. (Ed.), *Down to the wire: Studies in the diffusion and regulation of telecommunications technologies*, Nova Science Publishers, Haupaugge, NY, pp.119 -138.

Atkinson, R.D., Correa, D.K. & Hedlund, J.A. (2008). Explaining international broadband leadership. Washington, DC: The Information Technology and Innovation Foundation.

Bewley, R. & Griffiths, W.E., (2003). The penetration of CDs in the sound recording market: issues in specification, model selection and forecasting. *International Journal of Forecasting*, 19, 111-121.

Cava-Ferreruela, I. & Alabau- Muňoz, A. (2006). Broadband policy assessment: A cross-national empirical analysis. *Telecommunications Policy*, *30*, 445-463.

Church, J. & Gandal, N. (2005). Platform competition in telecommunications. In Cave, M., Majumdar, S. & Vogelsang I. (ed.), *The handbook of telecommunications vol. 2.: Technology evolution and the Internet*.

Clements, M & Abramowitz, A. (2006, September). The development and adoption of broadband service: A household level analysis. Paper presented *35th Research Conference on Communication, Information and Internet Policy*, Arlington, VA.

Chaudhuri, A., Flamm, K.S. and Horrigan J. (2005). An analysis of the determinants of internet access. *Telecommunications Policy*. 29 (9-10), pp. 731-755.

Crandall, R. W., Sidak, J.G. & Singer, H.J. (2002). The empirical case against the regulation of broadband access. *Berkeley Technology Law Journal*, *17*(3), pp. 953-87.

Crandall, R. W. (2005), "Broadband Communications", in Cave, M., Majumdar, S. and Vogelsang, I. (Eds.), *Handbook of telecommunications economics, Volume 2: Technology evolution and the Internet*, North-Holland, Amsterdam, Netherlands, pp.156 -191.

De Bijl, P.W.J. & Peitz, M. (2005). Local loop unbundling in Europe: Experience, prospects and policy challenges. *Communications & Strategies*, *57*, 33-57.

Denni, M. & Gruber, H. (2005). The diffusion of broadband telecommunications: The role of competition. Paper presented at International Telecommunication Conference, Pontevedra.

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

DotEcon & Criterion Economics (2003). Competition in broadband provision and its implication for regulatory policy: A report for the Brussels Round Table. London: DotEcon & Criterion Economics. Retrieved July 7, 2006, from http://www.dotecon.com/publications/BRTfull15-10-03.pdf

Economides, N. & Himmelberg, C. (1995). Critical mass and network size with application to the US fax market. Discussion paper EC-95-11, Stern School of Business, New York University.

Fernandez-Cornejo, J & McBride, W. D., (2002). Adoption of bioengineered crops. US Department of Agriculture Agricultural Economics Report, 810.

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

Freedom House (2007). Freedom in the world country ranking. Retrieved May 10 from http://www.freedomhouse.org/template.cfm?page=15.

Frieden, R. (2005a). Unbundling the local loop: A cost/benefit analysis for developing nations. *Info*, *7*(6), pp. 3-15.

Frieden, R. (2005b). Lessons from broadband development in Canada, Japan, Korea and the United States, *Telecommunications Policy*, *29*(8), pp. 595-613.

Garcia-Murillo, M. (2005). International broadband deployment: The impact of unbundling. *Communications & Strategies*, *57*. 83-108.

Glassman, J. & Lehr, W. (2001), "The economics of Tauzin-Dingell: Theory and evidence," Retrieved December 3 from http://ebusiness.mit.edu/research/papers/128%20Lehr,%20Tauzin-Dingell.pdf.

Grosso, M. (2006). Determinants of broadband penetration in OECD nations. Paper presented to the Australian Communications Policy and Research Forum.

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

Haring, J., Rohlfs, J.H. & Shooshan, H.M. (2002). Propelling the broadband bandwagon. Bethesda, MA; Strategic Policy Institute.

Heritage Foundation (2008). 2008 Index of economic freedom. Retrieved May 10, 2008 from http://www.heritage.org/research/features/index/downloads.cfm

Hausman, J. A. (2001), "Regulation by TSLRIC: Economic effects on investment and innovation", in Sidak, J., Engel, C. and Knieps, G. (Eds.), *Competition and Regulation in Telecommunications: Examining Germany and America,* Kluwer Academic, Boston, MA, pp. 51-68.

Hausman, J. A. (2002). Internet related services: The results of asymmetric regulation, in Crandall, R.W. and Alleman, J.H. (Eds.), *Broadband: Should we regulate High-Speed Internet*, AEI-Brookings Joint Center for Regulatory Studies, Washington, DC, pp.129-56.

Hőffler, F. (2007). Cost and benefits from infrastructure competition: Estimating welfare effects from broadband access competition. *Telecommunications Policy*, *31*, pp. 401-418.

Horrigan, J.B. (2005). Broadband adoption at home in the United States: Growing but slowing", Paper presented at 33rd Research Conference on Communication, Information and Internet Policy, Arlington.

Horrigan, J.B. (2007). Home broadband adoption 2007, Retrieved November 26, 2007 from http://www.pewinternet.org/pdfs/PIP_Broadband%202007.pdf

International Telecommunication Union (2003a). Promoting broadband: Background paper for workshop on promoting broadband. Retrieved November 11, 2005 from http://www.itu.int/osg/spu/ni/promotebroadband/PB03-PromotingBroadband.pdf

International Telecommunication Union (2003b). *Birth of broadband*. Geneva: ITU.

International Telecommunication Union (2004). *The portable Internet*. Geneva: ITU.

International Telecommunication Union (2005). *The Internet of Things*. Geneva: International Telecommunication Union.

International Telecommunication Union (2006). *Digital.life*. Geneva: International Telecommunication Union.

International Telecommunication Union (2007). ITU ICT Statistics Database. Retrieved May 24, 2008 from http://www.itu.int/ITU-D/icteye/Indicators/Indicators.aspx#.

Jang, S., Dai, S. & Sung, S. (2005). The pattern and externality effect of diffusion of mobile telecommunications: The case of OECD and Taiwan. *Information Economics and Policy 17*, 133-148.

Kim, J. H., Bauer, J.M. & Wildman, S.S. (2003). Broadband uptake in OECD countries: Policy lessons from comparative statistical analysis. Paper presented at the 31st Research Conference on Communication, Information and Internet policy. Arlington: Virginia.

Lee, C. & Chan-Olmsted, S.M. (2004), Competitive advantage of broadband Internet: A comparative study between South Korea and the United States, *Telecommunications Policy*, *28* (9-10), 649-677

Lee, S. (2006). Broadband deployment in the United States: Examining the impacts of the platform competition. *The International Journal on Media Management,* Vol. 8, No. 4, pp. 173-181.

Lee, S., Brown, J. S. (2008). Examining Broadband Adoption Factors: An Empirical Analysis between Countries. Info, *10* (1), pp.25-39.

Lee, S., & Marcu, I. M. (2007, August). Fixed and mobile broadband deployment: An empirical analysis of adoption factors. Paper presented *to the 35th Research Conference on Communication, Information and Internet Policy*, Arlington, VA.

Lehr, W., Osorio, C., Gillett, S. & Sirbu, M. (2005), "Measuring broadband's economic impact", Paper presented at 33rd Research Conference on Communication, Information and Internet Policy, Arlington, VA.

Liebowitz, S.J. & Margolis, S. (1994). Network externality: An uncommon tragedy. *Journal of Economic Perspective*, *8* (2). 133-150.

Madden, G., Coble-Neal, G. & Dalzell, B. (2004). A dynamic model of mobile telephony subscription incorporating a network effect. *Telecommunications Policy*, *28*, 133-144.

Organization for Economic Co-operation and Development (2001). *The development of broadband access in OECD countries*. Paris: OECD.

Organization for Economic Co-operation and Development (2003). *Development in local loop unbundling*. Paris: OECD.

Organization for Economic Co-operation and Development (2005). *Communications outlook 2005*. Paris: OECD.

Organization for Economic Co-operation and Development (2006). OECD broadband statistics. Paris: OECD. Retrieved July 5, 2006 from http://www.oecd.org/document.

Organization for Economic Co-operation and Development (2007a). OECD broadband statistics. Paris: OECD. Retrieved July 26, 2007 from http://www.oecd.org/document

Organization for Economic Co-operation and Development (2007b). *Communications outlook 2007*. Paris: OECD.

Organization for Economic Co-operation and Development (2007c). Catching-up in broadband: What will it take?. Paris: OECD. Retrieved October 2, 2007 from http://www.oecd.org/dataoecd

Rappoport, P. N., Kridel, D. J., Taylor, L. D. and Alleman, J. (2001), "Residential demand for Access to the Internet" in Madden, G. (Ed.), *Emerging telecommunications networks: The international handbook of telecommunications economics, Volume II.*, Edward Elgar Publishers, Cheltenham, UK, pp.1-20.

Ridder, J. D. (2007, August). Catching-up in broadband: What will it take?. Paper presented *to the 35th Research Conference on Communication, Information and Internet Policy*, Arlington, VA.

Rohlfs, J.H. (2001). *Bandwagon Effects in High-Technology Industries*. Cambridge, MA: The MIT Press.

Savage, S. J. & Waldman, D. (2005). Broadband Internet access, awareness, and use: Analysis of United States household data. *Telecommunications Policy*, *29* (8), 615-633.

Shapiro, C. & Varian, H. R. (1999). *Information Rules*. Boston, MA: Harvard Business School Press.

Turner, S.D. (2006). Broadband reality check II: The truth behind America's digital decline. Washington, DC: The Free Press.

Trkman, P., Blazic, B., J. & Turk, T. (2008). Factors of broadband development and the design of a strategic policy framework. *Telecommunications Policy*, *32*, pp.101-115.

Wallsten, S. (2006). Broadband and unbundling regulations in OECD countries. Working paper 06-16, AEI-Brookings Joint Center for Regulatory Studies.