A Cross-Country Analysis of Fixed Broadband Deployment: Examination of Adoption Factors and Network Effect*

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Abstract

Broadband infrastructure is a key component 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 suggests local loop unbundling policy, platform competition among various broadband technologies, and other diverse industry, ICT, and demographic factors influence fixed broadband diffusion. This empirical study also suggests that network effects and the effects of platform competition co-exist in many countries.

Continuous technological innovations in the telecommunication industry enable us to enter the era of convergence of 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). 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).

Even though there's been steady growth in broadband diffusion, many countries are still in the early stages of fixed-broadband deployment and are assessing policies to promote faster adoption. Many countries have considered local loop unbundling (LLU) 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 the following limitations: 1) limited number of independent variables; 2) insufficient

number of observations; 3) lack of refined theoretical explanation; and 4) inconsistent empirical results. These previous empirical studies on fixed-broadband adoption employed only a limited number of independent variables with insufficient data. Also, previous research has not covered some important independent variables such as institutional environment, bandwidth, telecommunication infrastructure investment, content, and age. In addition, studies do not typically propose refined theoretical concepts such as network effects and platform competition. Also, the results of these empirical studies are not consistent. For instance, the effects of local loop unbundling (LLU) policy are still not clearly understood through empirical studies.

Using 1999-2006 OECD (Organization for Economic Cooperation and Development) data, the longest available panel to date, we examine the influential factors of fixed-broadband diffusion using both nonlinear and linear regression models. Also, we examine whether there have been network effects in the diffusion of fixed broadband in many countries. 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 platform competition.

Literature Review

Current Status of Global Fixed-Broadband Deployment

Many countries are still in the early stages of broadband, as evidenced by the differences in deployment among countries. According to the latest Organization for Economic Co-operation and Development (OECD) penetration data (June 2008), Denmark, Netherlands, Norway, and Switzerland are leading broadband economies among OECD countries (OECD, 2008). 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). However, the upgrade to fiber-based connections continues in some countries, like Korea and Japan, where fiber is the leading platform over DSL and cable modems (OECD, 2008).

Network Effect and Platform Competition

Network effect is a theoretical concept that may inform 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 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.

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 (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 — like 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.

Platform competition is an important theoretical basis of this study. Platform competition occurs when different technologies compete to provide telecommunication services to end-users (Church & Gandal, 2005). Platform competition in network industry involves competition among technologies that are not only differentiated, but also are competing networks (Church & Gandal, 2005). Strong platform competition among different technologies may lead to lower prices, increased feature offerings, and more extensive broadband networks (ITU, 2003a).

With other dimensions of competition, such as intra-modal competition and market competition (market concentration), platform competition might be a key driver of broadband adoption in many countries. 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 inter-modal competition is associated with increased household subscription to fixed-broadband services (Aron & Burnstein, 2003).

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.

Beyond research that assesses policy factors that contribute U.S. broadband adoption, several studies compare policy 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.

Policy Factors: LLU Policy and Institutional Environments

Many countries have employed local loop unbundling (LLU) regulation as an important policy initiative to promote fixed-broadband deployment. Local loop unbundling (LLU) refer to the process by which incumbent carriers lease, wholly or in part, the local segment of their telecommunications network to competitors (OECD, 2003). Implementation of LLU policy

widely differs among countries. Types of LLU – full unbundling[1], line sharing[2] and bit stream access[3] — and LLU prices are different across countries (OECD, 2003). There might costs and benefits of local loop unbundling. LLU might introduce intra-modal 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 bring consumer benefits in the near future through open access to competitors (Frieden, 2005a). However, LLU may confiscate incumbents' property and reduce their incentives to invest in advanced telecommunication technologies (Frieden, 2005a).

Many debates have taken place on the effects of LLU policy. 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. 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

[1] 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).

[2] 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).

[3] 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).

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 published 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 that encompasses political rights and civil liberties is correlated with deployment of the Internet. In spite of this research, no empirical study tests the influences of institutional environment, like economic and political freedom, specific to fixed-broadband diffusion.

Industry Factors: Price, Speed, Bandwidth, and Telecommunication Infrastructure Investment

Industry factors like fixed-broadband price, speed, bandwidth, and telecommunication infrastructure might influence fixed-broadband penetration. Through statistical analysis of approximately 100 countries, Garcia-Murillo (2005) found price, income (GDP per capita), and competition have been influential factors in 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. Fransman (2006) suggested "disruptive competitors" that may build market share through below-cost pricing are an important determinant of global broadband performance. 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) found broadband speed, platform competition, and content contribute to global broadband adoption.

Higher bandwidth also might be correlated with the broadband adoption. Growth in demand for higher capacity is a key driver of broadband diffusion (ITU, 2006). Fansman (2006) suggests capacity of broadband is a measure of national performance in broadband. In spite of importance of bandwidth, there is no empirical work that tests correlations between bandwidth and broadband deployment.

Telecommunication infrastructure investment from private and public sectors is a contributing factor of telecommunication network deployment (ITU, 2003b). Some top 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, education, and population density, have influenced fixed-broadband adoption. 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 United States. Their empirical analysis suggests substantial variation in 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, Lee (2006) also suggests income has influenced broadband deployment.

In examining demographic factors among different countries, Grosso (2006) found income measured by GDP per capita is related to broadband penetration among OECD countries. Wallsten (2006) found income and urbanization are factors of broadband adoption in OECD countries. Turner (2006) found income and poverty rate are influential factors of broadband deployment among nations. Through recent empirical work, Ridder (2007) and Atkinson (2008) found age is negatively correlated to 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

Previous studies on broadband diffusion contend information and communication technology (ICT) factors like PC 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 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 in 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. 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.

Although there is a emerging body of scholarship that addresses 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. No empirical study tests the effects of institutional environments, such as economic and political freedom and telecommunication infrastructure investment. Also, no empirical study tests network effect and impacts of various types of LLU policies, such as full unbundling, line sharing and bit stream access.

Based on the literature reviewed, the following research questions (RQs) are proposed:

RQ1: Have policy factors, specifically Local Loop Unbundling (LLU), and institutional environment, such as political and economic freedom, contributed to the adoption of fixed-broadband services?

RQ2: Have industry factors — specifically fixed-broadband price, broadband speed, bandwidth, telecommunication infrastructure investment, and mobile service price — influenced the adoption of fixed-broadband services?

RQ3: Have demographic factors — specifically income, education, urban population share, population density and age — influenced the deployment of fixed-broadband services?

RQ4: Have ICT factors — specifically PC penetration, content, Internet usage, and teledensity — influenced the deployment of fixed-broadband services?

RQ5: Have platform competition and network effects influenced the deployment of fixed-broadband services?

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 (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. We applied Gruber and Verboven's (2001b) logistic model of mobile diffusion to the diffusion model for fixed-broadband. Gruber and Verboven's 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. Based on Gruber and Verboven's model, the following logistic diffusion equation was proposed:

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

Here, y_{it} is the percentage of country *i*'s population that has broadband access by time *t*, where a_{it}, b_{it}, and y_{it}^* are parameters.

In equation (1), y_{it}^* is 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] 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:

$$\frac{dy_{it}}{dt}\frac{1}{y_{it}} = b_{it}\,\frac{y_{it}^* - y_{it}}{y_{it}^*} \tag{2}$$

In equation (2) 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 fixed broadband technology.

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

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

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

In equation (3), the speed of fixed-broadband diffusion varies with policy variables D_{it}^{j} and country socio-economic characteristics X_{it} in linear fashion:

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, and 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.

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

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.

Data and Measurement

Tables 1 and 2 show 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, many potential independent variables involving policy, industry, ICT and demographic factors may influence fixed-broadband adoption.

Table 1-2 about here

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). 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, 2008).

Platform Competition, Network Effect and Industry Factors

Platform competition is an important variable in which the broadband market is served by competing platforms. In 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 a similar market share. This study employs more generalized measures for platform competition by the HHI (Herfindahl-Hirshman-Index) among different fixed-broadband technologies.

By using a log linear regression model, this study also tests whether previous broadband subscription has influenced current broadband subscription. If network effect exists, current subscription might be positively correlated with the previous subscription of new media (Economides & Himmelberg, 1995).

Fixed-broadband price might be 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 an important independent variable that might influence fixed-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 an interest in a particular age group, so age is measured by the percentage of population between the ages of 35 and 44.

ICT Factors

Internet content may be related to the diffusion of broadband. For the proxy measurement of content, Internet hosts per 10,000 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.

For a 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 observations for the linear model.

Results and Analysis

Nonlinear Regression Model (OECD Countries)

Data for nonlinear regression model covers all 30 OECD countries from 1999 to 2006. Table 3 provides the results. 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 all types of LLU policy (LLU policy type I, II and III) have contributed high level of fixed broadband penetration.[4] 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 analysis was also conducted. Based on the .80 benchmark, no highly correlated independent variables were in the model. R-squared for this model was .932 and the adjusted R-squared was .930.

Table 3-4 about here

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 the dependent variable and independent variables were transformed using logarithmic function since data were positively skewed.

[4] 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 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.

Initially, all eighteen independent variables were included for the multiple regression analysis. Multicollinearity issues might occur when independent variables are highly correlated; thus a correlation analysis was 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 their high correlation with other independent variables (extended model). Table 3 shows the ANOVA table of the extended and reduced regression model, which illustrates the model's significance at the .01 level. 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. In the reduced 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 a higher level of fixed broadband penetration. R-squared for the reduced model was .915. Table 3 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, as data were positively skewed.

1. Regression Analysis: Developed Countries

Table 4 provides the ANOVA table of the extended and 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 a 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

Table 4 provides the ANOVA table of the extended and reduced regression model for developing countries, 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 a 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.

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 among

technologies that are not only differentiated, but also involve competing networks (Church & Gandal, 2005). Using ITU country-level data, this study tested the impacts of platform competition between cable modem, DSL and other platforms on fixed-broadband penetration. The result provides competition among different fixed-broadband platforms is an influential factor of fixed-broadband deployment in ITU membership countries.[5] 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 comprise 30 developed countries with comparatively high GDPs per capita, it seems this result is robust.

Upon examination of this study's results and previous empirical studies on fixed broadband deployment, it appears the effects of platform competition are strong in the initial deployment (e.g., a 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. 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.[6]

[5] It appears this result was similar in developing countries (see Table 4).
[6] 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).

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. Because the nonlinear model of fixed-broadband diffusion already assumes network externality, this study tested whether previous subscription of fixed-broadband is a significant factor contributing to current subscription in the log linear regression model of fixed broadband. As expected, previous fixed-broadband penetration was an influential factor in current fixed-broadband deployment in all ITU membership countries, whether characterized as developed or developing. 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 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 points may be captured in fixed-broadband deployment patterns in some countries like Korea, Japan and the 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 ICT infrastructure (e.g., PC penetration, ICT use, previous fixed broadband penetration) is an influential factor for fixed-broadband diffusion (Lee et al, 2007). This result may imply that 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.

In terms of policy implications, this study examined the effects of LLU policy on fixed-broadband diffusion. Many debate the effects of LLU policy, but the type of LLU policy and LLU price are very different across countries. The result of nonlinear regression in this study suggests that LLU policy type I, II, and III 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 to 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 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 suggest that while mobile service could be a substitute for fixed broadband service in developing countries, it may 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 influence mobile (fixed) broadband in developed countries. Considering leapfrogging theory cannot easily be applied to broadband deployment in developing countries, this result of statistical analysis for developing countries may suggest that without sufficient previous ICT experiences and better economic status,[7] it is not easy to deploy fixed and mobile broadband simultaneously.

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, because the nonlinear model already assumes network externality, the impact of network effects on fixed broadband could not be tested in the nonlinear regression model. When more data and observations over a longer period are available, and with different nonlinear model like the 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 will be possible.

[7] 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.

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Appendix

Table 1. 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 price regulation, 0 for otherwise)	OECD (1999-2006)
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 2. 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 charge	ITU (2002-2005)
Speed	Broadband speed (Kbit/s)	ITU (2002-2005)
Education	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)

Table 3. 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	-	-
Political freedom		-.40	-.18	-1.85*	-.10	-1.3
Economic freedom	-.023	-1.61	-.60	-1.58	-	-
Urban population	-.004	-	.07	.58	-	-
Age (35-44)	-	-	.27	.78	-	-
Platform competition	-	-1.07	-.07	-1.84*	-.08	-2.1**
	B<-.001					
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

Table 4. Results of regressions of fixed broadband penetration for developed and developing countries

	Developed Countries				Developing Countries			
	Extended model		Reduced model		Extended model		Reduced model	
	Coefficients		Coefficients		Coefficients		Coefficients	
Variable	B	t-stat	B	t-stat	B	t-stat	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