An empirical study of broadband diffusion and bandwidth capacity in OECD countries

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Abstract
Well established broadband infrastructure and large bandwidth capacity are essential to deliver converged broadband services. Employing the Gompertz model, we examined influential factors of broadband diffusion. Utilizing the regression model, we also examined determinants of bandwidth capacity, which implies a network upgrade to support convergence. The results of data analysis suggest network competition between fixed and mobile broadband and network effects are significant factors of broadband deployment in OECD countries. It appears network effects and the effects of network competition co-exist in many OECD countries. For bandwidth capacity, the results of regression analysis suggest content, established broadband infrastructure, urban population, and a high level of innovation in the telecommunications industry are main determinants of bandwidth capacity.

Keywords: broadband deployment, network competition, network effects, bandwidth, convergence

Innovation of broadband technologies in the telecommunications industry enables society to enter the era of media convergence. Specifically broadband infrastructure with higher bandwidth, on both fixed and mobile networks, is a key driver of media convergence among telecommunications, broadcasting, and data services. The rapid expansion in the availability and penetration of converged broadband services holds the promise of revolutionizing the way in which societies communicate, work, learn, and play (Wirth, 2006). Affordable broadband access to diverse broadband contents encourages innovation and growth in an economy and also attracts foreign investment (ITU, 2003a).

In the environment of the Next Generation Networks (NGNs) which will be achieved after fixed and mobile networks are converged, ubiquitous broadband access, which means broadband access anytime, anywhere, by anyone and anything through both fixed and mobile broadband, will be possible (ITU, 2006). Successful diffusion of fixed and mobile broadband is necessary for the provision of advanced IP-based services such as Voice over Internet Protocol (VoIP), Internet Protocol Television (IP TV), mobile television, and fourth generation (4G) applications (Lee, 2008).

Currently broadband is defined as a network offering a combined speed of equal to, or greater than, 256kbit/s in one or both directions, which may include more diverse broadband technologies such as mobile broadband and portable Internet (ITU, 2005; ITU, 2006). Though this definition of broadband technology embraces both fixed and mobile technologies, many previous studies on broadband tend to

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focus on only fixed broadband technology while they have not paid much attention to mobile broadband technology. In the near future fixed and mobile broadband technologies will be converged in the Next Generation Networks (NGN) to offer 4G services (OECD, 2007). Considering this situation, it is logical to examine adoption factors of “extended definition of broadband.” In addition, existing research have made efforts to better understand broadband diffusion and convergence, but they have not considered the macro-level factors of broadband bandwidth expansion to support broadband network upgrade, convergence, and new services. Also, the impacts of network effects and network competition between fixed and mobile broadband networks on broadband diffusion have not been clearly analyzed in the previous research.

Employing the secondary dataset from the Organization for Economic Co-operation and Development (OECD), the International Telecommunication Union (ITU), and other international organizations from 2000 to 2007, this study analyzes the determinants of ubiquitous broadband deployment including both fixed and mobile broadband technology and the influential factors of broadband bandwidth expansion and network upgrade. Employing the Gompertz model of ubiquitous broadband diffusion, this study examines whether network effects and network competition between fixed and mobile broadband have influenced ubiquitous broadband diffusion at the same time. Also, using the regression model of bandwidth, this study examines factors contributing to broadband bandwidth expansion in OECD countries.

**Literature Review**

**Broadband Diffusion and Concept of Ubiquitous Broadband**

International organizations such as International Telecommunication Union (ITU) and Organization for Economic Co-operation and Development (OECD) have reported fixed and mobile broadband deployment for their membership countries. In terms of total broadband penetration rates that include both fixed and mobile broadband subscribers, Korea, Japan, Italy, Sweden and Switzerland were the top five broadband economies in terms of the total broadband penetration rates as of December 2007 (OECD 2009a; OECD, 2009b).

With the development of mobile broadband technologies, the concept of ubiquitous computing\(^1\) can be applied to the ubiquitous broadband access, which means an individual may use multiple forms of broadband access through a number of different devices (Lee, 2008). Under the ubiquitous broadband environment, broadband access anytime, anywhere, by anyone and anything through both fixed and mobile technologies are possible (Lee, 2008). In this concept of ubiquitous broadband, network competition between fixed and mobile networks with other modes of competition (e.g. intra and inter-modal competition) is a driver of ubiquitous broadband diffusion. Considering the fact that the environment of the Next Generation Networks (NGNs) will be achieved after fixed and mobile networks are converged in the near future, this notion of “ubiquitous broadband” is useful in explaining broadband diffusion. As technology continues to evolve, it is necessary to extend the definition to ubiquitous broadband—the total network offering across various types of platforms—including the simultaneous access of fixed and mobile services (ITU, 2006).

**Bandwidth and Convergence**

Many telecommunications service providers have moved towards a converged business model for delivering a wide range of services (OECD, 2009b). These converged broadband services require a high

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1) Marc Weiser (1991) coined the term, “ubiquitous computing” in his article. Weiser (1991) pointed to the “invisibility” of technology through the transformation of everyday items into small computers. In the first paradigm of computing, mainframes were shared by many people (one computer for many people) (ITU, 2006). Now we are moving from the personal computer era (one computer per person) to the phase of the ubiquitous computing era (many computers per person) (ITU, 2006).
level of bandwidth and broadband infrastructure. In the environment of the NGNs which will be achieved after fixed and mobile networks are converged by fully IP (Internet Protocol)-based integrated system, the notion of “ubiquitous broadband” could be replaced by “ubiquitous (converged ubiquitous) broadband” over a network (Lee, 2008). Thus, there is growth in demand for higher capacity and the necessity of converged business models based on a converged broadband network in the broadband industries. These trends in the broadband industries require more bandwidth per user and network upgrade to support convergence and new services (OECD, 2009b). As Fransman (2006) suggested, bandwidth capacity of broadband is a measure of national performance in broadband. Bandwidth is a measure of how fast data flows on a given transmission path, and determines the quantity and the speed of information transmitted (ITU, 2003b). There has been a steady growth of broadband bandwidth in many OECD countries. Figure 1 provides the status of broadband bandwidth (Kbit/s) of subscriber line in selected OECD countries. Korea and Japan were leading countries in terms of broadband bandwidth as of 2007. As suggested, it is important to examine influential factors of network upgrade because network upgrade is a key in supporting convergence and new services. To do so, it is necessary to examine determinants of broadband bandwidth performance in a country. However, currently there has been no empirical study on this topic, which examines factors of broadband bandwidth performance in a country. This study will examine the relevant factors contributing to broadband bandwidth.

Figure 1. Broadband Bandwidth (Kbit/s) in selected OECD countries

![Bandwidth Diagram](source: OECD (2007))

**Network Effects**

Network effect is a theoretical concept that may inform ubiquitous broadband diffusion. Network effects exist when the value of joining a network by buying compatible products increases the number of other adopters who join the network (Church & Gandal, 2005). In other words, network effects suggest that higher usage of certain products or services makes them more valuable. A consequence of network effects 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).

If network effects exist 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). Madden et al. (2004) found that these network effects have influenced mobile telephony subscription. However, there has been no empirical work conducted to test the existence of network effects on ubiquitous broadband adoption.

**Platform/Network/Intra-modal Competition**

Different forms of competition such as platform competition (inter-modal competition), network competition, and intra-modal competition are useful in explaining broadband diffusion and level of bandwidth. Platform competition occurs when different technologies compete to provide telecommunications services to end-users (Church & Gandal, 2005). Platform competition in the network industry involves competition between 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). Some empirical studies found that platform competition is a driver of broadband adoption (Burnstein & Aron, 2003; Distaso et al., 2006; Denni & Gruber, 2007; Lee & Brown, 2008).

With respect to ubiquitous broadband, which includes both fixed and mobile broadband, platform competition may imply competition between fixed and mobile networks. This competition between networks might lead to lower prices, improving the quality of service, increasing the number of customers and promoting investment and innovation (ITU, 2003b; DotEcon & Criterion Economics, 2003).

In addition, intra-modal competition might be a key driver of broadband adoption besides other modes of competition in many countries. For promoting intra-modal competition, many OECD countries adopted the Local Loop Unbundling (LLU) policy in DSL markets. Though the LLU policy may reduce an incumbent provider’s incentive to invest in advanced telecommunications technologies (Frieden, 2005), some previous empirical studies suggest LLU policy might be positively associated with fixed broadband deployment (Grosso, 2006; Garcia-Murillo, 2005; Distaso et al., 2006, Lee and Brown, 2008). Also, along with platform competition, intra-modal competition through LLU policy might influence the level of broadband bandwidth in a country.

**Industry Factors: Price, Speed, and Innovation**

Previous studies show that industry factors such as price and speed influence broadband diffusion. Some empirical studies find low fixed-broadband price is correlated with a higher level of broadband diffusion (Ridder, 2007; Atkinson et al., 2008; Lee & Brown, 2009). Ridder (2007) found that low fixed-broadband price is correlated with the high level of broadband diffusion. Atkinson et al. (2008) also found a low level of broadband price is the factor of broadband adoption in OECD countries. More recently, employing multivariate analysis of 110 country data, Lee and Brown (2008) found that high broadband speed with other factors such as platform competition and content promote broadband diffusion in the ITU membership countries.

Also, innovation in the telecommunications industry is a determinant of level of broadband bandwidth. A fertile environment that fosters innovation might promote broadband demand and high bandwidth (ITU, 2003a). For this innovative environment, thoughtful intellectual property protection and adequate government funding for Internet research are necessary (ITU, 2003a).

**Demographic/Economic Factors**

Previous studies on broadband diffusion find that
higher levels of income, education, urban population share, and population density are correlated with the higher levels of broadband diffusion. Recently, Grosso (2006) find income measured by GDP per capita is related to broadband penetration among OECD countries. Turner (2006) contends income and poverty rate are the influential factors of broadband deployment among nations. Previous empirical studies on broadband deployment suggest that high levels of education are positively correlated with broadband penetration (Horrigan, 2005; Chaudhuri et al., 2005; Clements & Abramowitz, 2006; Trkman et al., 2008). 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. Horrigan’s recent survey (2007) demonstrates younger age, higher education and income, and urban living share of population may lead to greater broadband adoption. Chaudhuri et al. (2005) found that the traditional socio-demographic variables such as income and education impacted strongly on broadband deployment 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).

Some empirical studies on broadband diffusion find a high level of population density is related to rapid fixed-broadband deployment (Kim et al., 2003; Garcia-Murillo, 2005; Lee & Brown, 2008). Through data analysis of approximately 100 countries, Garcia-Murillo (2005) revealed that population density has positive effects on the number of broadband subscribers. Kim et al. (2003) also suggest that population density should be considered as cost conditions of deploying advanced networks, and that it is one of the influential factors in explaining broadband uptake. Recently Trkman et al. (2008) found population density and education are the influential demographic factors of fixed-broadband deployment in EU countries.

Information and Communication Technology (ICT) Infrastructure Factors

Previous empirical studies on fixed broadband deployment demonstrate that Information and Communication Technology (ICT) infrastructure factors such as PC infrastructure and teledensity have influenced broadband penetration (Wallsten, 2006; Lee & Brown, 2008). 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. 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 (2007) also find that telecommunication density has been an influential factor of broadband deployment in the United States. Employing a factor analysis, Trkman et al. (2008) found communication technology expenditures, household PC access rate, Internet penetration, and fixed phone penetration are the factors of fixed-broadband deployment in EU countries.

In spite of an emerging body of scholarship that addresses factors contributing to fixed-broadband diffusion, there has been a limited number of empirical studies to test the adoption factors of broadband including both fixed and mobile broadband technologies. Also, no empirical study has tested the influence of network effect on broadband diffusion. In addition, in spite of the importance of factors of bandwidth, which implies network upgrades to support new services and revenue streams, there has been no empirical study to examine the determinants of broadband bandwidth in a country. Using OECD dataset between 1999 and 2007, this study examines adoption factors of ubiquitous broadband diffusion and determinants of broadband bandwidth in OECD countries. Based on the above literature review, this study proposes the following research questions (RQs):

RQ1: Has network effect affected the deployment of ubiquitous broadband?

RQ2: Has network competition between fixed and mobile broadband influenced the deployment
of ubiquitous broadband?

RQ3: Have industry, demographic, and ICT infrastructure factors contributed to the deployment of ubiquitous broadband?

RQ4: Have platform competition and other industry, demographic, and ICT infrastructure factors influenced broadband bandwidth?

The Empirical Model

The Gompertz Model of Broadband Diffusion

In many OECD countries, the pattern of broadband technology diffusion was similar to the patterns of other new communication technologies based on S-shaped curve (Lee & Marcu, 2007). There are different functional forms that can describe S-shaped curve such as the Gompertz, logistic (epidemic diffusion model), and log reciprocal (Gruber, 2001; Singh, 2008; Trappey & Wu, 2008). Among these different functional forms, the Gompertz and logistic models (epidemic diffusion model) are the two most widely used models. One of the important purposes of this study is to test network effects. Between the two widely used models, since the logistic model (epidemic diffusion model) assumes network externality, to estimate broadband diffusion, this study applies the Gompertz model of technology diffusion. The Gompertz model is widely utilized to estimate technology diffusion in the previous studies on new communication technologies. Specifically, the Gompertz model of technology diffusion has been employed to estimate diffusion of the Internet, computer, and mobile, where costs were initially high, followed by a period of rapid growth, followed by a slowing of uptake as saturation was reached (Kiiski & Pohjola, 2002; Singh, 2009; Trappey & Wu, 2008). Therefore, this study also uses the Gompertz model to estimate ubiquitous broadband. The model is as follows.

Let \( y_i \) denote the total number of broadband subscribers including fixed and mobile broadband per 100 inhabitants in country \( i \) in year \( t \) and let \( y_i' \) be its post diffusion or equilibrium level. In the Gompertz model of ubiquitous broadband, it is assumed that \( y_i \) tends to \( y_i' \) over time following an S-shaped curve. The Gompertz model of ubiquitous broadband diffusion specifies the rate of change in the total number of broadband lines as:

\[
\ln y_i - \ln y_{i-1} = \alpha_y (\ln y_i' - \ln y_{i-1})
\]  

where \( \alpha_y \) is the speed of adjustment taken to be constant in the analysis. The post diffusion or equilibrium level of total number of broadband subscribers per 100 inhabitants is a function of the basic demand-side variables (e.g. the level of income \( I_i \) and price of broadband service \( P_i \) in country \( i \)). Given that income and broadband prices change over time, we may assume that \( y_i' \) is time-dependent. It can be expressed as:

\[
\ln y_i' = \beta_{i0} + \beta_{i1} \ln I_i + \beta_{i2} \ln P_i + \gamma Z_i
\]

where \( Z_i \) is the vector of other possible explanatory variables describing the demand and supply conditions or information and communication technology infrastructure in country \( i \). The estimation equation is obtained by inserting (2) into (1):

\[
\ln y_i - \ln y_{i-1} = \alpha_y + \alpha_y \ln I_i + \alpha_y \ln P_i + \alpha_y \gamma Z_i - \alpha_y \ln y_{i-1}
\]

Specifically, in the empirical model, the dependent variable \( (y_i) \) is broadband diffusion that accounts for both fixed and mobile broadband services. For independent variables, the competition variable such as fixed and mobile broadband network competition, industry factor such as broadband speed, demographic factors such as education, population density, urban population, and ICT factors such as PC penetration, Internet usage, content, and teledensity were included in the empirical model. Previous broadband diffusion (previous year’s broadband penetration) in a country was also included in the model to test network effect.

The Model of Broadband Bandwidth

To examine determinants of broadband bandwidth, this study employs the linear regression model. The
linear regression model employs approximately 170 observations of broadband services from the OECD member countries. To examine the determinants of broadband bandwidth, this study formulates the following regression model. Since the distribution of dependent variable in this linear regression model is positively skewed, data transformation with logarithm was utilized.

\[
\ln Y_t (\text{Bandwidth}) = \beta_0 + \beta_1 (\text{Platform Competition}) + \\
\beta_2 (\text{Income}) + \beta_3 (\text{PC Penetration}) + \beta_4 (\text{Population Density}) + \\
\beta_5 (\text{Contents}) + \beta_6 (\text{Education}) + \\
\beta_7 (\text{Tele-density}) + \beta_8 (\text{Urban Population}) + \\
\beta_9 (\text{Internet Use}) + \beta_{10} (\text{Previous Broadband Penetration}) + \\
\beta_{11} (\text{Broadband Price}) + \beta_{12} (\text{LLU}) + \beta_{13} (\text{Innovation}) + \gamma_1 \omega_t + \delta_0 \alpha_t + \epsilon_t
\]  

In the empirical model, the dependent variable \( Y_t \) is broadband bandwidth of subscriber line in a country. For independent variables, competition and policy factors such as platform competition and Local Loop Unbundling policy are examined in the model. The model also incorporates industry factors such as broadband price and innovation in telecommunication industry. In addition, demographic factors such as income, education, population density, and urban population as well as ICT factors such as PC penetration, Internet usage, content, tele-density and previous broadband penetration are included in the model. In the empirical model \( \beta_0 \) is constant, \( \gamma_1 \alpha_t \) represents time-dummies, and \( \delta_0 \alpha_t \) represents country-dummies.

Data and Measurement

Tables 1 and Table 2 show the variables, their measures, and the corresponding data sources used to analyze ubiquitous broadband diffusion and determinants of bandwidth. In the ubiquitous broadband diffusion model, broadband services can be deployed through DSL, cable modem, and mobile platforms. Therefore the model of broadband diffusion estimates factors of broadband diffusion (including both fixed and mobile). Ubiquitous broadband diffusion is measured by the total number of broadband subscribers per 100 inhabitants (ITU, 2006). The model of broadband bandwidth examines determinants of bandwidth capacity in a country. Bandwidth was measured by the broadband bandwidth (Kbit/s) of subscriber line. The data for the Gompertz model of ubiquitous broadband diffusion covers the period from 2000 to 2007. A total 198 observations were available for the Gompertz model of ubiquitous broadband diffusion. For broadband bandwidth model, the data covers the period from 2000 to 2006. A total of 170 observations were available for the broadband bandwidth model. The data sources here are international organizations such as the ITU, OECD, and World Bank.

Network Effects

With network effect, new broadband subscribers joining a broadband network increase the utility of current broadband subscribers. This process may lead to self-propelling or endogenous network growth, which may suggest that current broadband subscription is positively influenced by previous broadband subscription (Economides & Himmelberg, 1995; Madden et al., 2004).

By employing the Gompertz model of broadband diffusion, this study tests whether the previous year’s broadband subscription has influenced current broadband subscription. To test the influence of network effects on the ubiquitous broadband deployment, this study includes the previous year’s broadband penetration in the empirical model.

Platform/Network/Intra-modal Competition

Network competition between fixed and mobile
broadband might be an influential factor of ubiquitous broadband diffusion. In the empirical model, network competition is measured a dummy variable (1 for fixed and mobile broadband is available in a country, 0 otherwise). For the model of broadband bandwidth, platform competition was included in the model. Platform competition may bring inter-modal competition, innovation, and diverse choices for customers. 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 & Brown, 2009). This study employs more generalized measures for platform competition by the HHI (Herfindahl-Hirshman-Index) for the broadband bandwidth model. Since DSL is a dominant fixed-broadband technology in most countries, LLU policy could be a driver of intra-modal competition in broadband markets (ITU, 2003b). For the measurement of LLU policy, dummy variable (1 for LLU policy is available in a country, 0 otherwise) was used.

**Price, Speed, and Innovation**

For the diffusion of ubiquitous broadband model, independent variables like broadband price and speed were included in the model. Broadband price is measured by monthly broadband price (per mega bit/s) as percentage of monthly income (in U.S. dollars). For the measurement of broadband speed, Kbit per second is utilized. Innovation in telecommunications industry could be a driver of a high level of bandwidth. Innovation was measured by number of patent applications in previous studies (Aschhoff & Sofka, 2009; Hipp & Grupp, 2005). Thus innovation is measured by number of telecommunication patent applications filed at the European patent office in this study.

**Demographic/Economic Variables**

For demographic variables, this study employs the United Nations Development Program (UNDP) education index as the measurement of education. The UNDP education index measures a country’s relative achievement in both adult literacy and combined primary, secondary and tertiary gross enrollment (UNDP, 2005). A share of urban population is employed to measure the demographic aspect of population density (Gruber, 2001; Liikanen et. al, 2004; Kioski & Kretschmer, 2002). In this study, population density is measured by population per km². For the measurement of income, the GDP per capita is employed.

**Information and Communication Technology Infrastructure Variables**

Information and communication technology infrastructure could be a driver of broadband technology diffusion and network upgrade. To measure the PC infrastructure, estimated PCs per 100 inhabitants are used. Teledensity is measured by main telephone

<table>
<thead>
<tr>
<th>Variables</th>
<th>Measurement</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total broadband deployment</td>
<td>Total number of broadband subscribers per 100 inhabitants</td>
<td>OECD (2000-2007)</td>
</tr>
<tr>
<td>Broadband Price</td>
<td>Monthly broadband price (mega bit/s) as percentage of monthly income (USD)</td>
<td>OECD (2000-2007)</td>
</tr>
<tr>
<td>Fixed-mobile Network Competition</td>
<td>Dummy (1 for both fixed and mobile broadband are available, 0 for otherwise)</td>
<td>OECD (2000-2007)</td>
</tr>
<tr>
<td>Income Speed</td>
<td>GDP per capita (USD)</td>
<td>ITU (2000-2007)</td>
</tr>
<tr>
<td></td>
<td>Broadband speed (Kbit/s)</td>
<td>OECD (2000-2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ITU (2000-2006)</td>
</tr>
</tbody>
</table>
lines per 100 inhabitants. For the measurement of broadband content, Internet hosts per 100000 inhabitants are employed. Internet usage is measured by Internet users per 100 inhabitants. For the measurement of broadband infrastructure, to evade an endogeneity issue, previous year’s broadband penetration data was used for the broadband bandwidth model.

### Results

#### The Gompertz Model of Ubiquitous Broadband Diffusion

A total of 198 observations were analyzed to estimate the Gompertz model. This study assumes
that all OECD countries have similar diffusion patterns. To control for possible endogeneity or heteroscedasticity problems, we employed the fixed effect model for the estimation of broadband diffusion using both country and time factors. Explanatory variables describing the demand and supply conditions or information and communication technology infrastructure in country \(i\) were transformed using a logarithmic function. From the data analysis, extended and reduced models were identified.

Table 3 shows the result of estimation of the Gompertz model (3) controlling for the time and country impact. In the extended model, this study removed PC penetration and speed due to the potential multicollinearity problem based on the .70 Pearson correlation criterion. These variables were highly correlated with other explanatory variables. In this model, fixed and mobile network competition, Internet usage, previous broadband penetration, and speed of diffusion \(\alpha\) were statistically significant at the 5 percent level. Other variables such as income, price, population density, education, teledensity, and content were not statistically significant. R squared for the extended model was 0.6522.

To check the stability of results in the extended model, this study ran another regression by excluding insignificant variables such as population density, and content. In this reduced model, fixed and mobile network competition was statistically significant at the 1 percent level. Internet usage and previous broadband penetration were statistically significant at the 5 percent level. R squared for the extended model was .6520. This result suggests network competition between fixed and mobile broadband network and high level of Internet usage are drivers of diffusion of broadband. Also, this result suggests network effects exist in the diffusion of broadband.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Extended Model</th>
<th>Reduced Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed of diffusion (\alpha)</td>
<td>0.7038 4.12***</td>
<td>0.6967 4.15***</td>
</tr>
<tr>
<td>constant (\alpha_0)</td>
<td>-0.7411 -0.19</td>
<td>-0.8798 -0.25</td>
</tr>
<tr>
<td>Income (\alpha_1)</td>
<td>-0.0351 -0.12</td>
<td>-0.0361 -0.13</td>
</tr>
<tr>
<td>Price (\alpha_2)</td>
<td>0.0449 1.09</td>
<td>0.0430 1.06</td>
</tr>
<tr>
<td>Fixed and mobile network competition</td>
<td>0.2387 2.61**</td>
<td>0.2382 2.65***</td>
</tr>
<tr>
<td>Population density</td>
<td>-0.2040 -0.13</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>2.6192 1.49</td>
<td>2.6720 1.54</td>
</tr>
<tr>
<td>Teledensity</td>
<td>0.1706 0.35</td>
<td>0.1751 0.37</td>
</tr>
<tr>
<td>Internet usage</td>
<td>0.4596 2.30**</td>
<td>0.4682 2.39**</td>
</tr>
<tr>
<td>Content</td>
<td>0.0169 0.27</td>
<td>-</td>
</tr>
<tr>
<td>Previous broadband penetration</td>
<td>0.3097 2.12**</td>
<td>0.3033 2.13**</td>
</tr>
<tr>
<td><strong>R squared</strong></td>
<td>0.6522</td>
<td>0.6520</td>
</tr>
<tr>
<td>Number of observations</td>
<td>198</td>
<td>198</td>
</tr>
<tr>
<td>Time impact controlled</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Country impact controlled</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Statistically significant at the 5% level. ***Statistically significant at the 1% level.
Table 4. Results of regressions of broadband bandwidth

<table>
<thead>
<tr>
<th>Variable</th>
<th>Extended Model</th>
<th>Reduced Model</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient B</td>
<td>t statistics</td>
<td>Coefficient B</td>
<td>t statistics</td>
</tr>
<tr>
<td>Platform competition</td>
<td>B &lt; -0.0001</td>
<td>-0.73</td>
<td>B &lt; -0.001</td>
<td>-0.72</td>
</tr>
<tr>
<td>Income</td>
<td>B &lt; -0.0001</td>
<td>-0.38</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PC penetration</td>
<td>0.0016</td>
<td>0.19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Population density</td>
<td>-0.0364</td>
<td>-1.32</td>
<td>-0.039</td>
<td>-1.49</td>
</tr>
<tr>
<td>Content</td>
<td>0.0003</td>
<td>2.72***</td>
<td>0.0003</td>
<td>2.83***</td>
</tr>
<tr>
<td>Education</td>
<td>-2.4083</td>
<td>-0.63</td>
<td>-2.6806</td>
<td>-0.73</td>
</tr>
<tr>
<td>Urban population</td>
<td>0.0669</td>
<td>2.26**</td>
<td>0.0687</td>
<td>2.38**</td>
</tr>
<tr>
<td>Broadband infrastructure</td>
<td>0.0272</td>
<td>3.72***</td>
<td>0.0275</td>
<td>3.93***</td>
</tr>
<tr>
<td>Price</td>
<td>-2.380</td>
<td>-0.81</td>
<td>-0.271</td>
<td>-1.02</td>
</tr>
<tr>
<td>LLU</td>
<td>-0.2574</td>
<td>-1.34</td>
<td>-2.450</td>
<td>-1.30</td>
</tr>
<tr>
<td>Innovation</td>
<td>8.0454</td>
<td>3.61</td>
<td>7.7524</td>
<td>3.75***</td>
</tr>
<tr>
<td>Constant</td>
<td>0.9075</td>
<td>0.20</td>
<td>1.7783</td>
<td>0.42</td>
</tr>
</tbody>
</table>

R squared 0.8988 0.8984
Number of observations 170 170
Time impact controlled Yes Yes
Country impact controlled Yes Yes

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

The Model of Broadband Bandwidth

A total of 170 observations were analyzed employing multiple regression analysis. To control for endogeneity or heteroscedasticity issues, fixed effect model was employed for the estimation of broadband bandwidth. Dependent variable was transformed using a logarithmic function since data were positively skewed. In the initial model, all 13 independent variables were included in multiple regression analysis. The independent variable Internet use was removed from the initial model because of its high correlation with other independent variables. Also, for the extended model, insignificant variables such as teledensity and Internet use were removed from the model. In the reduced model, other insignificant variables such as income and PC penetration were also removed from the model. Table 4 provides the results of the extended and reduced regression model, which illustrates the model’s significance at the 1 percent level (p < .001). In the reduced model, content, broadband infrastructure, and innovation were statistically significant at the 1 percent level. Urban population variable was statistically significant at the 5 percent level.

Discussion and Conclusion

This empirical study examined adoption factors of broadband services and determinants of broadband bandwidth in OECD countries. We examined whether network effects are involved in the diffusion of ubiquitous broadband. Employing the Gompertz model,
this study tested whether previous subscription of broadband is a significant factor contributing to current subscription in the empirical model of broadband diffusion. As we expected, previous broadband penetration positively correlated with current broadband diffusion in OECD countries. This result suggests that higher usage of broadband services makes them more valuable. Also, this result suggests that the decision by broadband consumers regarding which network to join will depend not only on relative broadband prices, but also the expected size of the broadband network (Church & Gandal, 2005). This finding may suggest that it is important to note that concepts of efficiency and ease of integration are important for future broadband markets (Lee & Brown, 2009).

The results of regression analysis suggest that there are positive effects of network competition between fixed and mobile broadband on ubiquitous broadband deployment. Strong network (or platform) competition among different broadband technologies may lead to lower prices, innovations and more extensive broadband networks (ITU, 2003a). This result may imply public policy across different networks (or platforms) should be as competitively neutral as possible in the broadband markets (Lee & Brown, 2009). In spite of this finding, there is negative side of network (or platform) competition. As Höffler (2007) suggested, without significant positive externality, infrastructure competition among different broadband networks has not been welfare enhancing. However, our findings suggest that network effects and the effects of network competition co-exist in many OECD countries. Therefore, in future studies, along with examination of more observation periods, the effects of network competition and network externality should be examined.

The results of regressions of broadband diffusion suggest a higher level of Internet usage is correlated with a higher level of broadband penetration. This finding may point to the importance of emerging, diverse Internet use and applications through both fixed and mobile platforms.

For bandwidth, the result of the regression analysis suggests an innovation in the telecommunications industry is an influential factor of high-bandwidth and network upgrade to support convergence and new services. This finding may suggest policies and incentives to promote for innovative technologies, applications, and contents in the telecommunications industry are necessary. For network upgrade to support convergence, it is proposed that the government plays a role in promoting sufficient intellectual property protection and adequate R &D funding for broadband research (ITU, 2003a).

Also, significance of some ICT infrastructure variables such as established broadband infrastructure and contents imply that established ICT infrastructure leads to growth in demand for high-bandwidth capacity of broadband networks. This finding also suggests the phenomenon of leapfrogging, which bypassing stages in capacity building or investment through which countries were previously required to pass during the process of economic development, cannot be easily applied to the broadband network upgrade.

In addition, for bandwidth, the result of the regression analysis suggests a high level of urban population share is correlated with a high level of bandwidth in OECD countries. This finding implies that high level of urbanization provides better cost condition for network upgrade and investment.

This empirical study has limitations. The data employed in this study contained a comparatively small number of observations with a relatively short period. When more data become available, better research on diffusion of ubiquitous broadband and broadband bandwidth, which has greater implications for 4G mobile deployment, will be possible. Also, this study used OECD countries’ data samples. Since most of OECD countries are relatively high income countries, the results of this empirical study might have limitations in application to developing countries.

References


Organization and Internet policy. Arlington: Virginia.