An empirical analysis of fixed and mobile broadband diffusion*

Sangwon Lee[a**], Mircea Marcu[b], Seonmi Lee[c]

May 2011

* We thank Sanford Berg, Justin Brown, David Sappington, Sylvia Chan-Olmsted, Mark Jamison, and anonymous referees for their very valuable insights. This paper was revised from an earlier version dated August 2007.

[a] *School of Broadcast and Cinematic Arts, Central Michigan University, Moore Hall 351, Mount Pleasant, MI 48859, USA*

[b] *College of Medicine, University of Florida, Gainesville, FL 32611, USA*

[c] *IT Policy Research Department, Economics & Management Research Lab, KT Corporation, 206 Jeongjadong, Bundanggu, Gyeonggido, Republic of Korea*

** Corresponding author. Tel.: +1-989-774-2819; fax: +1-989-774-2426.
E-mail address: lee10s@cmich.edu

Abstract

Broadband communications lie at the heart of the developing information society. Employing a logistic diffusion model, we analyze the factors that influence the diffusion of fixed and mobile broadband. For fixed broadband diffusion, we find that local loop unbundling, income, population density, education, and price are significant factors of fixed broadband diffusion. For mobile broadband, multiple standardization policy and population density are the main factors of the initial diffusion of mobile broadband services. The results of the mobile broadband model also suggest that in many OECD countries, mobile broadband service is a complement to fixed broadband service in the initial deployment of broadband.

JEL Classification: O2; O3; O5

Keywords: Broadband diffusion; fixed broadband; mobile broadband; local loop unbundling; multiple standardization policy

1. Introduction

Broadband communications lie at the heart of the developing information society. Widespread broadband diffusion encourages innovation, contributes to productivity and growth, and attracts foreign investment (ITU, 2003a). The International Telecommunication Union (ITU) defines broadband as a network offering a combined speed equal to, or greater than, 256 kbit/s in one or both directions (ITU, 2005; ITU, 2006). In terms of the broadband penetration rate, there were 24.4 subscribers per 100 inhabitants at the end of June 2010 in the Organization for Economic Co-operation and Development (OECD) countries (OECD, 2010). Fixed broadband may be defined as transmission capacity with sufficient bandwidth to permit combined provision of voice, data, and video through a fixed line such as DSL and cable modem (ITU, 2003b). Mobile broadband systems support data transport rates of at least 256 kbit/s for all radio environments, which exceed the rates under second generation wireless networks (ITU, 2006; ITU, 2003b; Shelanski, 2003). Mobile broadband systems enable many advanced video applications such as mobile videoconferencing, video phone/mail, mobile TV/video player, and digital audio/video delivery (ITU, 2001).

In spite of the overall rapid growth in broadband diffusion, many countries are still in the early stages of broadband deployment and are assessing policy strategies to promote faster broadband adoption. Many countries have considered local loop unbundling (LLU)[1] 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;

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

DotEcon and Criterion Economics, 2003). Experts differ on whether single or multiple standards promote faster diffusion of mobile communications.

There is a growing body of literature on fixed broadband diffusion examining the important influential factors of global broadband diffusion. The results are not always consistent, and insufficient data has prevented previous studies from capturing the nonlinear nature of broadband diffusion. In addition, in spite of its significance and implications, there are few empirical studies about influential factors of mobile broadband diffusion. For the same reason, there are few studies that investigate whether mobile broadband is a complement or a substitute for fixed broadband in a nonlinear diffusion model.

Using OECD data, we estimate a logistic regression to capture the nonlinear nature and examine the influential factors of fixed and mobile broadband diffusion. We find that local loop unbundling, income, population density, education, and fixed broadband price are significant factors of fixed broadband diffusion. For mobile broadband, we find that multiple standardization policy and population density are the main factors of initial diffusion of mobile broadband services. The result of data analysis also suggests that in many OECD countries mobile broadband service is a complement to fixed broadband service in the initial deployment of broadband.

The paper is organized as follows: Section 2 summarizes the existing literature on fixed and mobile diffusion; Section 3 presents the model, method, and data; Section 4 presents the empirical results; and Section 5 concludes.

2. Literature review

There has been a steady growth of broadband adoption throughout the world. There were over 555 million fixed broadband subscribers and 940 million mobile broadband subscribers at the end of 2010 (ITU, 2010). In OECD countries dominant fixed broadband access platforms are DSL (Digital Subscriber Line) (with 58 % of the fixed broadband market) and cable modem (29 %) (OECD, 2010). For mobile broadband markets, standard mobile (with 73% of the mobile broadband markets) is a dominant access platform (OECD, 2010). As of June 2010, the Netherlands, Denmark, Switzerland, and South Korea had the highest fixed broadband penetration rates among OECD countries (OECD, 2010). The extent of mobile broadband diffusion varies widely across countries. As of June 2010, South Korea, Sweden, Japan, and Norway were leading mobile broadband economies in terms of the mobile broadband penetration rate (OECD, 2010). WCDMA and CDMA 2000 are the two main standards for 3G wireless technologies (Gandal et al., 2003). Most of the European Community adopted WCDMA for 3G wireless services (ITU, 2006). On the other hand, many countries in the Americas, Asia, and Africa adopted CDMA 2000 or both CDMA 2000 and WCDMA in their 3G markets (ITU, 2006).

2.1. Empirical studies on global fixed broadband diffusion

There is a growing body of empirical research about fixed broadband diffusion. Some empirical studies found that inter-modal competition, local loop unbundling (LLU), and demographic variables such as income and population density increase fixed broadband diffusion (Garcia-Murillo, 2005; Grosso, 2006; Lee, 2006). Analyzing data from 14 European countries, Distaso et al. (2006) argued that inter-platform competition drives broadband diffusion, but that competition in the DSL market does not play a significant role. Also, some previous empirical studies on initial fixed broadband diffusion in the United States found inter-modal competition is a driver of fixed broadband diffusion in the United States (Burnstein and Aron, 2003; Denni and Gruber, 2005).

In their study of 30 OECD countries, Cava-Ferreruela and Alabau-Muňoz (2006) found that technological competition, low costs of deploying infrastructures, and predilection to use new technologies are key factors for broadband supply and demand. Using logit regression, Garcia-Murillo (2005) found that unbundling an incumbent's infrastructure only results in a substantial increase in broadband deployment for middle-income countries but not for their high-income counterparts. Kim et al. (2003) suggested the attitude toward information and technology and the cost conditions of deploying advanced networks are the most consistent factors explaining broadband uptake in OECD countries.

Broadband infrastructure is increasingly recognized as fundamental for economic growth in many countries (OECD, 2009). Recent empirical studies measured the economic impacts of the broadband infrastructure on growth (Lehr et al., 2006; Koutroumpis, 2009). By incorporating a simultaneous approach methodology that endogenises supply, demand and output, Koutroumpis (2009) estimated the economic impact of broadband infrastructure on growth in OECD countries. Koutroumpis (2009) found that there are increasing returns to broadband telecommunications investments, which are consistent with the persistence of network effects. Koutroumpis' (2009) study indicated there is evidence of a critical mass phenomenon in broadband infrastructure investments. Employing multivariate regression modeling, Lehr et al. (2006) also found broadband diffusion enhances economic growth and performance, and that the economic impact of broadband is measurable.

2.2. Empirical studies on global mobile diffusion

Previous empirical studies on global mobile diffusion found that standardization policy, competition, and low user cost are influential factors of global mobile diffusion (Gruber, 2001; Gruber and Verboven, 2001; Liikanen et. al., 2001; Koski and Kretschmer 2005; Rouvinen, 2006). Studies in the economics of standards have focused on the private and social incentives for standardization (Gandal, 2002; David and Greenstein, 1990). There are both advantages and disadvantages to market-mediated multiple standards relative to a government-mandated single standard. Although market-mediated standards may lead to limited network externalities and economies of scale, multiple wireless standards and different types of services across technologies enable the existence of diverse competing systems which may lead to more and better mobile services (Gruber and Verboven, 2001). Gruber and Verboven (2001) found that the early diffusion of digital technologies in mobile markets was faster in Europe, where most countries had adopted a single standard. Koski and Kretschmer (2005) concluded that standardization has a positive but insignificant effect on the timing of initial entry of 2G services but can also lead to higher prices by dampening competition. Cabral and Kretschmer (2007) examined the effectiveness of public policy in the context of competing standards with network externalities and concluded that current mobile diffusion levels are quite similar between the United States (multiple standards) and Europe (mostly single standard). More recently, Rouvinen (2006) found that standards competition hinders, and market competition promotes diffusion in both developed and developing countries.

In spite of a growing body of literature that addresses the factors contributing to fixed broadband diffusion at the national level, the results of empirical studies are not always consistent, and insufficient data has prevented previous studies from capturing the nonlinear nature of broadband diffusion. In particular, the results concerning the effects of income, broadband price, and competition on broadband diffusion are mixed (OECD, 2007). Also, in spite of rapid diffusion of mobile broadband technology, few empirical studies have focused on the factors that affect mobile broadband diffusion globally. We are not aware of any study that examines whether mobile broadband is a complement or a substitute for fixed broadband in a nonlinear diffusion model. If mobile broadband is a complement, it may offer the potential to increase aggregate broadband penetration. If mobile broadband is a substitute, its impact on aggregate broadband penetration is ambiguous. It may help accelerate penetration through platform competition, but it could also undermine investment in sunk, fixed-line broadband. For examining whether mobile broadband is a complement or a substitute for fixed broadband, we include fixed broadband price as an independent variable in the mobile broadband diffusion model.

Employing the logistic model of broadband diffusion, this study examines whether diverse policy, industry, and demographic factors have influenced fixed and mobile broadband diffusion in OECD countries.

3. The model, method, and data

3.1. The logistic 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 an S-shaped curve. There are different functional forms that can describe an S-shaped curve such as the logistic, Gompertz, log reciprocal, and simple modified exponential (Gruber, 2001; Gruber and Verboven, 2001; Singh, 2008; Trappey & Wu, 2008). Among these different functional forms, the logistic diffusion model is one of the most commonly used models for the estimation of new communication technologies (Geroski, 2000; Singh, 2008). Also, the logistic diffusion model can capture the existence of network externalities (Gruber and Verboven, 2001). For these reasons, this paper adopts the logistic diffusion model to estimate the diffusion of broadband technologies. In the beginning of the diffusion process, few people have broadband access. Because people value the opportunity to interact with and to access content provided by other people, more people adopt the technology as the stock of broadband subscribers increases, leading to an exponential increase in the number of broadband users. However, the flow of broadband subscribers declines as the stock approaches the total number of potential adopters in the market, perhaps due to congestion or low valuation for broadband services among the remaining non-subscribers. In many OECD countries, the S-shaped time profile of the logistic curve appears to approximate well the diffusion of broadband. We estimate diffusion of fixed and mobile broadband employing two separate equations.

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

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

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

Not all individuals in a country adopt a new technology, such as fixed and mobile broadband, regardless of how inexpensive the technology may be. This is captured in the model by y_{it}^{*}, which is the long run expected fraction of subscribers (the ceiling parameter, or saturation point).[2] The parameter a_{it} in equation (1) is a constant of integration that gives the initial value of

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

In principle, the ceiling parameter can be estimated as fixed effects for each country. However, many countries are still in their early stages of broadband adoption. Therefore, there are insufficient observations to estimate consistently the potential number of broadband adopters in each country. The logistic regression is symmetric and imposes an inflection point halfway between zero and the saturation point. The inflection point is crucial in determining the saturation point (Bewley and Griffiths, 2003). The saturation point is estimated from the observations of early adopting countries that have passed the midway point, such as South Korea and Japan in our case. However, to the extent that the saturation points of lagging countries differ from those of forerunners, holding the ceiling parameter fixed across countries may bias the expected saturation point for lagging countries. This is somewhat mitigated by the addition of an error term to equation (1) for the purpose of estimation.

broadband penetration.[3] A positive value shifts the S-shaped function upward, while a negative one shifts it downward without modifying the S-shape.

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

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

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

We allow the speed of diffusion to vary with policy variables D_{it}^{j} and country socio-economic characteristics X_{it} in linear fashion:[4]

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

The country characteristics included in X_{it} are variables that are likely to influence the supply of, and the demand for, broadband. We expect that average disposable income (measured by GDP per capita [purchasing power parity]), education (measured by the UNDP education index)[5], broadband price (measured by monthly fixed and mobile broadband price [mega bit/s] as a percentage of monthly income [USD]) are likely to influence the demand for broadband

---

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

[4] Two broad classes of logistic diffusion models have been proposed: the variable-ceiling logistic and the variable-speed logistic (Fernandez-Cornejo and McBride, 2002). Letting the ceiling vary by country characteristics poses significant estimation problems. There is no guarantee that the parameter will stay at theoretically justifiable levels, or that the model will converge. The variable-speed logistic model is easier to estimate, and the speed of adoption can be positive or negative, depending on the movement of exogenous factors.

[5] 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 enrolment 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).

services.

To examine whether mobile broadband is a complement or a substitute for fixed broadband, we include fixed broadband price as an independent variable in the mobile broadband diffusion model. If mobile broadband is a complement for fixed broadband, the demand for mobile broadband is increased when the price of fixed broadband is decreased, and the demand for mobile broadband is decreased when the price of fixed broadband is increased. We also expect higher population density to reduce deployment cost, which increases the supply of broadband. We are mainly interested in the impact of policy variables on broadband penetration. For the fixed broadband model, policy variables included in our study are the local loop unbundling policy and platform competition. LLU policy may introduce intra-modal competition in the DSL markets, and prices might fall when incumbent carriers are compelled to open their networks to competitors (ITU, 2003a). For the measurement of LLU policy, we use the number of unbundled local loop as a percentage of main lines. Some previous empirical studies estimated impacts of LLU price and intra-modal competition on broadband diffusion. Distaso et al. (2006) found that lower unbundling prices stimulate broadband uptake. Grosso (2006) found that intra-modal competition is an influential factor of fixed broadband deployment (Grosso, 2006). Another important policy variable is platform competition. Platform competition occurs when different technologies compete to provide telecommunication services to end-users (Church and Gandal, 2005). Platform competition in the broadband industry involves competition among different broadband technologies (such as DSL, cable modem, and fiber-to-the-home) that are not only differentiated, but also are competing networks. Platform competition among different broadband technologies may lead to lower prices, increased feature offerings, and more extensive broadband networks (ITU, 2003a). For the measurement of platform competition, we utilize the Herfindahl-Hirschman Index (HHI) for different fixed broadband platforms. The HHI has been used in previous studies to measure platform competition (Denni and Gruber, 2005; Distaso et al., 2006; Koutroumpis, 2009; Bohlin et al., 2010). For the measurement of platform competition, fixed broadband platforms taken into account are DSL, cable modem, fiber-to-the-home (FTTH) and other broadband technologies. Platform competition is calculated by the sum of the squared technology shares of each fixed broadband platform. Regarding mobile broadband, platform competition is related to the market-mediated multiple standards. Therefore, for the mobile broadband, we included standardization policy variable (measured by a dummy variable, 1 for with multiple standards, 0 for single standard) in the empirical model. In the empirical model, the platform competition variable for fixed broadband plays a similar role to the standardization policy variable for mobile broadband. Table 1 shows the variables in our regression analysis and measurement of variables.

3.2. Data description

This study utilizes annual data for 30 OECD countries for the fixed broadband diffusion model and annual data for 26 OECD countries for the mobile broadband diffusion model. The data for the estimation of fixed broadband diffusion cover the years from 2000 to 2008. For the mobile broadband, the data cover from 2003 to 2008. The data employed have been collected by different sources depending on variables. Fixed and mobile broadband penetration, LLU policy, standardization policy, competition, and broadband price data are collected from the OECD. Income and population density data have been collected from the ITU. Education data are collected from the UNDP. Table 1 provides descriptive statistics of variables.

Table 1 Variables, measurement and descriptive statistics

Variables (fixed broadband)	Measurement	Mean	St. Dev.	Min	Max
Fixed Broadband Deployment	Fixed broadband subscribers per 100 inhabitants	11.24	10.18	0	36.80
Income	GDP per capita (Purchasing Power Parity)	28991.74	11612.41	8615	84713
LLU Policy	Number of unbundled local loop as a percentage of main lines	2.70	4.95	0	26.60
Population Density	Population density (per km^2)	132.40	122	2	491
Platform Competition	HHI (Herfindahl-Hirschman Index) for different fixed-broadband platforms	6288.72	2238.50	593.86	10000
Education	UNDP Education index	0.95	0.04	0.77	0.99
Fixed Broadband Price	Monthly fixed broadband price (mega bit/s) as a percentage of monthly income (USD)	0.04	0.19	0.0001	2.61
Variables (mobile broadband)	**Measurement**				
Mobile broadband deployment	3G Mobile subscribers per 100 inhabitants	14.40	19.38	0.001	95.02
Income	GDP per capita (Purchasing Power Parity)	32670.60	11523.06	11983	84713
Population Density	Population density (per km^2)	143.75	127.59	3	491
Education	UNDP Education index	0.96	0.03	0.82	0.99
Fixed Broadband Price	Monthly fixed broadband price (mega bit/s) as a percentage of monthly income (USD)	0.01	0.03	0.0001	0.30
Standardization Policy	Dummy (1 for with multiple standards, 0 for single standard)	0.28	0.45	0	1
Mobile Broadband Price	Monthly mobile broadband price (mega bit/s) as a percentage of monthly income (USD)	0.01	0.007	0.0001	0.10

4. Empirical results

4.1. Fixed broadband diffusion

We estimate the variable-speed logistic model described in equations (1) and (3) by nonlinear least squares after adding disturbances to equation (1).[6] We employ the country fixed effects model for the estimation of fixed broadband diffusion. The results are presented in Table 2. One of the main interests of this study is to examine whether LLU policy has been effective in promoting fixed broadband diffusion. LLU policy variable is statistically significant at the .05

[6] In principle, the fraction of adopters is bounded between 0 and 1, and the error term should be truncated to ensure that the fitted values are within the feasible region. While this is a concern when analyzing mature markets, it is less of an issue for the relatively immature broadband market.

percent level. LLU policy appears to have increased the speed of broadband diffusion significantly. LLU policy encourages competition by reducing economic barriers to entry, thereby allowing new entrants to build some components of their networks and obtain other components from the incumbent DSL operator (OECD, 2001). Intra-modal competition in DSL markets through LLU policy may reduce DSL prices (Lee, 2006; DotEcon and Criterion Economics, 2003). Presumably, cable providers would have to reduce prices as well to avoid losing customers. Through lower prices, LLU could lead to an increased rate of growth of both DSL and cable penetration. However, LLU may reduce incentives for incumbents to invest in telecommunications infrastructure and retard broadband deployment (Spulber and Yoo, 2003). Considering these benefits and the costs of LLU policy, more refined LLU policy is necessary.

The result of the data analysis also provides some demographic variables such as income, education, and population density, which were statistically significant. This result implies that higher levels of income and education are important drivers of fixed broadband diffusion in many OECD countries. This result also suggests that higher population density increases the speed of broadband penetration. Theoretically, the significance of the population density variable suggests that better cost condition is a driver of fixed broadband diffusion.

In the fixed broadband diffusion model, we also tested whether industry factors such as fixed broadband price and platform competition were influential factors of fixed broadband diffusion. The result of the data analysis indicates that lower price and higher level of platform competition is associated with a high level of broadband penetration. However, only the fixed broadband price variable was statistically significant. As an OECD report suggested, many previous empirical studies about fixed broadband could not find this negative association between fixed broadband price and fixed broadband deployment (OECD, 2007). Considering the relationship between price and normal goods, negative association between fixed broadband price and fixed broadband deployment is an expected result.

Table 2 Logistic regressions of fixed and mobile broadband penetration

	Fixed broadband penetration		Mobile broadband penetration	
Variable	Coefficients	t	Coefficients	t
Ceiling	53.3583	4.91***	151.6584	1.45
Initial Level Parameter	-306.4712	-3.61***	-314.5587	-0.98
Natural Speed	0.1467	3.49**	0.1563	0.98
Income	5.91E-09	2.34**	-1.14E-08	-1.40
LLU Policy	1.26E-05	2.14**	--	--
Population Density	6.14E-07	2.42**	2.38E-06	2.37**
Platform Competition	-2.91E-08	-1.45	--	--
Education	0.0059	3.66***	-0.0007	-0.21
Fixed Broadband Price	-0.0158	-5.74***	-0.0592	-1.73*
Standardization Policy	--	--	0.00058	2.34**
Mobile Broadband Price	--	--	-0.0278	-1.07
Country fixed effects	Yes		Yes	
R-Squared	0.9406		0.8340	
Number of observations	231		124	

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

4.2. Mobile broadband diffusion

The country fixed effects model is employed for the estimation of mobile broadband diffusion. The results of the mobile broadband diffusion study are presented in Table 2. The results of the data analysis suggest that multiple standardization policy, population density, and fixed broadband price are statistically significant. The significance of the multiple standardization policy dummy implies the importance of market-mediated, multiple standards when a new technology evolves into a different stage of development characterized by more advanced, differentiable features. The result of the data analysis also suggests that higher population density contributes to mobile broadband deployment. In light of the recent debates and allegations that some countries have fallen behind, while others are ahead in the broadband adoption race, our results suggest that larger, less densely populated countries are indeed at a disadvantage when it comes to the deployment of mobile broadband communications. Also, the significance of the fixed broadband price variable suggests that in many OECD countries, mobile service is a complement to fixed broadband services.[7] Other variables such as income, education, and price are not statistically significant.

5. Conclusions

In this study, we analyzed the factors that influence the diffusion of fixed and mobile broadband. One of the main goals of this study was to examine whether LLU policy was successful in promoting fixed broadband diffusion in many OECD countries. LLU policy is a statistically significant variable in our estimations. In spite of this result, our finding of a positive effect of LLU policy on the speed of diffusion does not necessarily mean that all countries should pursue such a strategy. Effective LLU policy may generate consumer benefits in the near future through open access to competitors. However, unbundling the local loop favors short-term speed over the long-term incentives to invest. Ideally, governments would like to achieve the highest level of penetration as rapidly as possible at a reasonable cost. If these alternatives are jointly too expensive and thus to some extent mutually exclusive, governments face a choice between policies that favor speed of diffusion and those that promote the highest eventual penetration. Our logistic regression model allows us to capture the effect of policy variables on the speed of diffusion but not the effect on the long-term expected number of subscribers. The results of the data analysis may mean that unbundling is not necessarily suboptimal and, thus,

[7] However, this result of the data analysis should be considered as a preliminary result, since it is possible that the complete set of variables may not be taken into account in the mobile broadband diffusion model. More precise results could be obtained, if a simultaneous estimation model, which examines broadband adoption factors considering both fixed and mobile broadband technology jointly, is employed. Therefore, in future research, the relationship between fixed and mobile broadband service in broadband markets could be tested again, employing a simultaneous approach.

may be worth pursuing. If unbundling had no effect on the speed of diffusion, then unbundling should not be mandated in light of its possible negative impact on investment incentives. However, short-term gains in the speed of diffusion appear to exist. Therefore, further analysis of the effect of unbundling on investment incentives and eventual penetration levels is necessary to be able to decide in favor or against unbundling. Also, the type of LLU policy and LLU price are very different between countries. For instance, there is great variation in the ways local loop unbundling has been implemented in different countries. Types of LLU – full unbundling, line sharing, and bit stream access — and LLU prices differ between countries (OECD, 2003). If diverse data about the different types and prices of LLU are available with sufficient observations, more refined analysis of LLU policies is possible.

In this study, we found that multiple standardization policy is associated with a high level of mobile broadband penetration. Our findings support the assertion of Cabral and Kretschmer (2007). That is, as mobile technology becomes more mature, standardization and its scale and efficiency benefits seem to become less relevant. In this context, technological competition in mobile broadband markets is likely to foster innovative applications. Also, this study has policy implications for the initial diffusion of 4G mobile technologies. Considering 4G mobile technology is a type of mobile broadband technology, the result of this mobile broadband diffusion study implies that, in the initial 4G mobile markets, governments need to be open to diverse standards for competition instead of government-mandated standards.

The result of the mobile broadband diffusion study also suggests that in many OECD countries mobile service is a complement to fixed broadband services. Considering that most OECD countries have high income, this result seems possible. The result may imply the mobile service's potential to increase aggregate broadband penetration. Future studies may examine how this result is different in low income countries. Also, the result indicates that market situations in both fixed and mobile broadband should be considered for promoting 4G mobile technologies.

This study was limited by the relatively small number of observations in our sample, particularly regarding the mobile broadband diffusion model. Furthermore, because of data availability, more diverse independent variables cannot be included in the empirical models. In addition, since the logistic regression model already assumes network externality, the impacts of network effects on broadband diffusion could not be tested in the model. When more data and observations over a longer period are available, more refined analysis of the impacts of network effects on broadband diffusion will be possible. Finally, this study utilizes OECD countries' data samples. Since most of the OECD countries are relatively high income countries, the results of this empirical study have limitations in application to developing countries.

References

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

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

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

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

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

Church, J. & Gandal, N., 2005. Platform competition in telecommunications, in Cave, M., Majumdar, S., Vogelsang I. (Eds.), The handbook of telecommunications vol. 2.: Technology evolution and the Internet. Elsevier, Amsterdam, The Netherlands, pp. 118-154.

David, P., Greenstein, S., 1990. The economics of compatibility standards: An introduction of recent research. Economics of Innovation and New Technology 1, 3-41.

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

Distaso, W., Lupi, P., Maneti, F.M., 2006. Platform competition and broadband uptake: Theory and empirical evidence from the European Union. Information Economics and Policy 18, 87-106.

DotEcon and Criterion Economics, 2003. Competition in broadband provision and its implication for regulatory policy: A report for the Brussels Round Table. Electronic document at http://www.dotecon.com, DotEcon and Criterion Economics.

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

Gandal, N., 2002. Compatibility, Standardization, and network effects: Some policy implications. Oxford Review of Economic Policy 18, 80-91.

Gandal, N., Salant, D., Waverman, L., 2003. Standards in wireless telephone networks. Telecommunications Policy 27, 325–332.

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

Geroski, P.A., 2000. Models of technology diffusion. Research Policy 29 (4-5), 603-625.

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

Gruber, H., 2001. Competition and innovation: The diffusion of mobile telecommunications in Central and Eastern Europe. Information Economics and Policy 13, 19-34.

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

ITU, 2001. 3G mobile licensing policy: From GSM to IMT-2000- a comparative analysis. ITU Workshop on Licensing 3G Mobile, September 19-21, ITU, Geneva.

ITU, 2003a. Promoting broadband: Background paper for workshop on promoting broadband. Electronic document at http://www.itu.int.

ITU, 2003b. Birth of Broadband. ITU, Geneva.

ITU, 2004. The Portable Internet. ITU, Geneva.

ITU, 2005. The Internet of Things. ITU, Geneva.

ITU, 2006. Digital.life. ITU, Geneva.

ITU, 2010. ICT Statistics. ITU, Geneva.

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

Koski, H., Kretschmer, T., 2005. Entry, standards and competition: Firm strategies and the diffusion of mobile telephony. Review of Industrial Organization 26(1), 89-113.

Koutroumpis, P., 2009. The economic impact of broadband on growth: A simultaneous approach. Telecommunications Policy 33, 471-485.

Lee, S., 2006. Broadband deployment in the United States: Examining the impacts of the platform competition. The International Journal on Media Management 8, 173-181.

Lehr, W., Gillett, S., Osorio, C., Sirbu, M., 2006. Measuring broadband's economic impact. Broadband Properties, 12-24.

OECD, 2001. The development of broadband access in OECD countries. OECD, Paris.

OECD, 2003. Development in local loop unbundling. OECD, Paris.

OECD, 2005. Communications outlook 2005. OECD, Paris.

OECD, 2007. Catching-up in broadband: What will it take?. OECD, Paris.

OECD, 2009. Communications outlook 2009. OECD, Paris.

OECD, 2009. The role of communication infrastructure investment in economic recovery. OECD, Paris.

OECD, 2010. OECD broadband statistics. OECD, Paris.

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

Shelanski, H., 2003. Competition policy for 3G wireless services, in: Noam E.M., Steinbock D. (Eds.), Competition for the Mobile Internet. Kluwer Academic Publishers, Norwell, pp. 39-54.

Singh, S. K., 2008. The diffusion of mobile phone in India. Telecommunications Policy 32, 642-651.

Spulber, D. F., Yoo, C. 2003. Access to networks: Economic and constitutional connections. Cornell Law Review 88, 885-1024.

Trappey, C. V., Wu, H., 2008. An evaluation of the time-varying extended logistic, simple logistic, and Gompertz models for forecasting short product lifecycles. Advanced Engineering Informatics 22, 421-430.

UNDP, 2004. Human development report 2005. UNDP, New York.

UNDP, 2005. Human development report 2006. UNDP, New York.