The Determinants of the Global Broadband Deployment: An Empirical Analysis

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Abstract

The world of telecommunications has changed rapidly as we enter the era of convergence between broadband Internet, wireless networks, and the content sector. The provision of advanced video services via the broadband platform will be impossible without the successful diffusion of broadband services. The current deployment of such services is significantly more advanced in some countries than others. Through two different econometric analyses, this study examines the factors affecting such differences.

Based on the Gruber and Verboven (2001)'s model, this study estimates a logistic model of broadband penetration. This logistic regression model employs 240 observations for broadband services from OECD (Organization for Economic Co-operation and Development) countries. The logistic regression model covers all 30 OECD countries from 1999 to 2006. This study also estimates a linear regression model of broadband penetration. The linear regression model employs approximately 220 observations for broadband services from ITU (International Telecommunication Union) membership countries. The linear regression model covers 56 countries from 2003 to 2006. The results of this empirical study might show that platform competition, Local Loop Unbundling Policy (LLU), broadband speed, information and communication technology (ICT) infrastructure, Internet use, population density, international Internet bandwidth, content, and Institutional environment contribute to the global broadband adoption. The impacts of platform competition might be strong when market share of dominant technology and non-dominant technology is similar. This study also may find that mobile broadband is neither a complement nor a substitute for fixed broadband yet. Main findings of this study suggest policy and strategy implications.

Introduction

The world of telecommunications has changed rapidly as we enter the era of convergence between broadband Internet, wireless networks, and the content sector. Broadband infrastructure is a key component of the knowledge economy. Communication technologies that provide high-speed, always-on connections to the Internet for large numbers of residential and small-business subscribers are commonly referred to as "broadband" (Crandall, 2005). Widespread and affordable broadband access encourages innovation, contributes to productivity and growth in an economy, and attracts foreign investment (ITU, 2003a). The provision of advanced IP-based services such as IP telephony and IP video will be impossible without the successful diffusion of broadband.

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 adoption. The provision of advanced video services via the broadband platform will be impossible without the successful diffusion of broadband services. The current deployment of broadband Internet is significantly more advanced in some countries than others. According to the latest Organization for Economic Co-operation and Development (OECD) penetration data (December 2006), Denmark, Netherlands, Iceland, Korea, and Switzerland are leading broadband economies among OECD countries (see Table 1, pg. 3).

On the supply side, many countries have considered local loop unbundling regulation and facilities-based competition as important policy initiatives to promote rapid broadband diffusion. Local loop unbundling (LLU) — which refers to the process by which incumbent carriers lease, wholly or in part, the local segment of their telecommunications network to competitors — has been considered an important policy to stimulate intra-modal competition (OECD, 2003). It is also widely held that platform, inter-modal competition (facilities-based competition among several different broadband platforms) is crucial for reducing prices, improving quality of service, increasing

customers and promoting investment and innovation (DotEcon & Criterion Economics, 2003). In spite of a growing body of literature about broadband adoption, only a few cross-cultural empirical studies about the important factors of global broadband adoption exist.

Through two different econometric analyses, this study examines the factors affecting global broadband deployment. Using non-linear and linear regression, this study assesses whether or not platform competition, LLU policy, broadband speed, Information and Communication Technology (ICT) infrastructure, Internet use, income, education, population density, fixed broadband price, content, international Internet bandwidth, mobile broadband price, teledensity, and institutional environment are drivers of global fixed broadband deployment. Based upon the results of this empirical research, this paper suggests policy and strategy implications to policy-makers and broadband service providers.

Literature Review

Broadband adoption has been steadily growing throughout the world. According to the International Telecommunication (ITU), there were about 215.5 million total broadband subscribers and 3.3 subscribers per 100 inhabitants in the world in 2005 (ITU, 2006). Broadband adoption rates over the first 10 years is faster than other offerings like cellular and dial-up services across OECD countries (OECD, 2006). Internationally, the dominant broadband access platforms are DSL (64.34 %) and cable modem (29.89 %), though other platforms, such as fiber-to-the-home and wireless broadband access serve around 6 % (ITU, 2006).

As of December 2006, Denmark, the Netherlands, Iceland, Korea, and Switzerland were the top five OECD countries in terms of broadband penetration rates (OECD, 2007; Table 1). Despite the recent growth of broadband access and the largest raw number of broadband subscribers, with a 19.6 percent national broadband penetration rate per 100 inhabitants, the United States ranks only 15th among 30 OECD countries (OECD, 2007).

Table1. Fixed Broadband Penetration (Top OECD countries) by Technology, December 2006

	DSL	Cable	Fibre/LAN	Total	Rank	Total Subscribers
Denmark	19.6	9.4	2.8	31.9	1	1,590,539
Netherlands	19.5	12.0	0.4	31.8	2	5,192,200
Iceland	28.8	0	0.2	29.7	3	87,738
Korea	11.4	10.7	7.0	29.1	4	14,042,728
Switzerland	18.8	8.8	0	28.5	5	2,140,309

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

In terms of overall global broadband market share by subscribers, the United States leads the group, garnering about 22.9 percent of the global broadband subscribers. Nevertheless, the region of Asia trumped all others in broadband adoption with 38.47 percent of the world broadband market share (ITU, 2006). Evidently significant regional differences exist in the number of broadband subscribers.

There is a growing body of empirical research about fixed broadband deployment. Some empirical studies find that inter-modal competition, local loop unbundling (LLU), demographic variables in the supply-side and demand side variables such as income and broadband price increase the fixed broadband adoption. Through an empirical analysis of 30 OECD countries, Cava-Ferreruela and Alabau-Muñoz (2006) suggest technological competition, low cost of deploying infrastructures, and prediction to use new technologies might be key factors for broadband supply and demand, respectively. In addition, using statistical analysis of data from 14 European countries, Distaso and others (2006) argue that inter-platform competition drives broadband adoption, but that competition in the DSL market does not play a significant role. Using logit regression analysis Garcia-Murillo (2005) finds that 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.

Kim and others (2003) suggest the preparedness of a nation and the cost conditions of deploying advanced networks are the most consistent factors explaining broadband uptake in OECD

countries. Using generalized least squares multiple regression analysis, Grosso (2006) also finds that competition, income, and unbundling have a positive impact on broadband diffusion (see Table 2).

Table2. International empirical studies examining broadband adoption factors

Study	Indepentdent variables	Countries	Number of Observations	Significant Findings
Kim et. al. (2003)	Broadband price Dial-up service price Income Preparedness of a nation Competition Population density Policy (unbundling, cross ownership, government funding)	OECD 30 countries	30	Preparedness of a nation Population density
Garcia-Murillo (2005)	Broadband price Income Education Competition Population density Policy (unbundling, cross ownership) Content Personal computers Internet access	ITU approximately 100 countries	Observations varies depending on the model (18-92)	Broadband price Income Population density Competition Internet access Unbundling
Distaso et. al. (2006)	Intra-modal competition Inter-modal competition Rights of way LLU price Price of leased line Price of ten minutes call	EU 14 countries	158 (15 time periods)	Inter-modal competition LLU price
Cava-Ferreruela and Alabau-Muňoz (2006)	Broadband price Competition Infrastructure investment Telecom services penetration Internet indicators Economic indicators Demographic indicators Education indicators Social indicators	OECD 30 countries	90 (3 years: 2000-2002)	Technological competition Cost of deploying infrastructures Economic indicators Demographic indicators
Grosso (2006)	Competition Income Unbundling Fixed Internet penetration	OECD 30 countries	117 (4 years: 2001-2004)	Competition Income Unbundling

Despite existing research efforts to better understand broadband adoption, the influence of important variables on global broadband adoption across countries — such as platform competition, LLU, population density, ICT infrastructure, fixed broadband price, Internet use, content, and broadband speed — have not been clearly understood in a single systematic study (see Table 2). There is no empirical study whether institutional environment and international Internet bandwidth influenced the global broadband deployment.

Also, no published empirical study examines whether mobile broadband is a complement to or a substitute for fixed broadband. Based upon research that suggest cell phones serve as a substitute for wired-line phone service (e.g., ITU, 2003c), one might expect a similar relationship between broadband wireless services and fixed broadband.

Table 2 illustrates the variables and findings of empirical, international broadband deployment studies. Accordingly, based on the literature reviewed, this study proposes the following research questions (RQs):

RQ1: Does platform competition and LLU policy influence global broadband deployment?

RQ2: Do other factors such as income, population density, fixed broadband price, broadband speed, Information Communication Technology (ICT) infrastructure, education, international Internet bandwidth, Internet use, content, teledensity, and institutional environment significantly influence global broadband adoption?

RQ3: Is mobile broadband a complement to or a substitute for fixed broadband?

The Model, Method and Data

To examine determinants of the global broadband deployment, this study employs both non-linear and linear regression analysis. 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 broadband penetration. The linear regression model employs approximately 220 observations for

broadband services from ITU (International Telecommunication Union) membership countries.

1. Non-linear Model of Broadband Diffusion

The diffusion of new technologies is usually nonlinear. This study follow Gruber and Verboven (2001) and estimate a logistic model of broadband penetration. In many countries fixed broadband penetration is nonlinear, and that it resembles the standard S-shaped pattern of the logistic curve. Letting y_{it} denote the percentage of country *i*'s population that has broadband access to the Internet by time *t*, the standard logistic diffusion equation is:

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

where a_{it} and b_{it} are parameters, as discussed below, and y_{it}^* is the penetration ceiling or percentage of potential adopters.

The parameter a_{it} in equation (1) is a constant of integration that gives the initial value of broadband penetration.[1] A positive value shifts the S shaped function upwards while a negative one shifts it downwards, without modifying the S-shape. Not all individuals in a country adopt a new technology, such as broadband, regardless of how inexpensive broadband may become. This is captured in the model by the ceiling parameter y_{it}^*. Finally, the parameter b_{it} in equation (1) captures the speed of adoption. This can be seen by differentiating equation (1) with respect to time.

The parameters in equation (1) can vary with characteristics such as income, prices, population density, and other country characteristics. Two broad classes of logistic diffusion models have been proposed: the variable-ceiling logistic and the variable-speed logistic. Letting the ceiling vary with country characteristics poses significant estimation problems. There is no guarantee that the

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

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. Therefore this study allows the speed of diffusion to vary with policy variables D_{it}^{j} and country socio-economic characteristics X_{it} as follows:

$$b_{it} = \beta^{0} + \sum_{j=1}^{J} \beta^{j} D_{it}^{j} + X_{it}\beta \,. \qquad (2)$$

The parameter β^{0} represents the natural speed of adoption. The country characteristics included in X_{it} are supply and demand shifters suggested by previous empirical research on the determinants of fixed broadband adoption. They are: real GDP per capita expressed in constant 2000 US Dollars as a measure of income, the number of computers per 100 inhabitants as a measure of ICT infrastructure, population density as determinants of deployment cost, Internet usage, and the number of Internet hosts per 100 inhabitants as a proxy for Internet content.

The policy variables included in our study are dummy variables capturing the unbundling of the local loop and the existence of platform competition. Our measure of platform competition equals one for years in which both cable and DSL subscriber existed in the country. The local loop unbundling dummy equals one for years when unbundling was in effect and zero otherwise. The dummy variables thus change over time, depending on the timing of the introduction of competition and the year when unbundling began. Some of the previous studies have found that inter-modal competition and local loop unbundling are important determinants of broadband penetration (Cava-Ferreruela & Alabau-Muňoz, 2006). Table3 shows the variables, their measures, and the data sources.

Table 3 about here

2. Linear Model of Broadband Diffusion

To capture more diverse determinants of global broadband deployment, a multiple regression analysis (linear model) is implemented. To examine the influences of quantifiable variables on the diffusion patterns of fixed broadband, this paper formulated the following multiple regression model.

$$\begin{aligned} Y_t\,(BPR) = {} & \beta_0 + \beta_1(\text{Platform Competition}) + \beta_2(\text{Fixed Broadband Price}) + \beta_3(\text{Speed}) + \\ & \beta_4(\text{Income}) + \beta_5(\text{ICT Infrastructure}) + \beta_6(\text{Education}) + \beta_7(\text{Population Density}) + \\ & \beta_8(\text{Price of Mobile Broadband}) + \beta_9(\text{Content}) + \beta_{10}(\text{Internet Usage}) + \\ & \beta_{11}(\text{Teledensity}) + \beta_{12}(\text{International Internet Bandwidth}) + \\ & \beta_{13}(\text{Institutional Environment}) + \varepsilon_t \qquad (1) \end{aligned}$$

The empirical model (1) for multivariate analysis was a composite model from previous empirical studies. In the empirical model, the dependent variable (Y_t) is broadband penetration rate (approximately 220 observations). From the previous studies of broadband adoption, some of independent variables were identified. Platform competition, fixed broadband price, broadband speed, income, ICT infrastructure, education, population density, and content are important quantifiable variables included in the multiple regression analysis. This study also adds independent variables such as Internet usage, teledensity, international Internet bandwidth, and institutional environment. To examine whether mobile broadband is a complement to or a substitute for fixed broadband, mobile price was also included in the regression model.

Broadband penetration rate (BPR: dependent variable) was measured by the number of broadband subscribers per 100 inhabitants. Platform competition (PLATFORM) is an important variable in which the broadband market is served by competing platforms. PLATFORM is measured by (100 – market share of dominant technology – market share of non-dominant technology). In the previous literature, a report from DotEcon & Criterion Economics (2003) suggested broadband penetration tends to be higher in European countries where DSL and non-DSL platforms have similar

market share. Broadband price arguably has been a key 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 (PRICE) was measured by broadband monthly charge (in U.S. Dollars). Broadband speed (SPEED) was also considered important independent variable that might influence global broadband adoption. SPEED was measured by broadband download speed (kilobit per second). As a product differentiation strategy in the broadband access market broadband speed might influence broadband demand.

Table 4 about here

Level of information/communication technology infrastructure is closely related to broadband demand. To reflect the level of information and communication technology infrastructure, ICT infrastructure (ICT) was measured by personal computer penetration per 100 inhabitants. Level of education (EDU) was measured by the United Nations Development Program (UNDP) Education Index, and population density (P-DENSITY) was measured by population density per km^2. For the measurement of income (INCOME), GDP per capita was used. For mobile price (MPRICE), per minute charge (in U.S. Dollars) for a local call during peak time was used. Internet content (CONTENT) may be related to the diffusion of broadband. For the proxy measurement of content, Internet hosts per 100 inhabitants was employed. Internet usage (INTERNET-USAGE) was measured by Internet users per 100 inhabitants. International Internet bandwidth (I-BANDWIDTH) was measured by bits per capita. Institutional environment was measured by the inverse of the score on civil liberties (originally ranging from 1 to 7; Andonova, 2006). Table 4 shows variables, measurement and data sources of the multiple regression analysis. Data were collected primarily

from the ITU (2003b, 2004, 2005b, 2006), and the UNDP (2003, 2004, 2005).

Conclusion and Discussion

This study adds to the existing research that has employed a macro-level, international approach to empirically understanding broadband adoption. This study contains important policy and research implications that are discussed below.

The impacts of platform competition might be strong when market share of dominant technology and non-dominant technology is similar. Intra and Inter-modal competition may bring real choice for customers and downward pressure on costs in the broadband access market (Lee, 2006; DotEcon & Criterion Economics, 2003). In this context, in the broadband access market, regulation across platforms should be as competitively neutral as possible for sustaining strong platform competition and LLU should be made available at cost-based prices. With these significant variables, this study also might suggest that various demand and supply side variables such as broadband speed, information and communication technology (ICT) infrastructure, Internet use, population density, international Internet bandwidth, content, and Institutional environment contribute to the global broadband adoption.

This study also may find that mobile broadband is neither a complement nor a substitute for fixed broadband yet.

In addition, since fixed broadband is still relatively new in many countries, this might prevent more extensive empirical analyses. Further empirical research including more variables with multiple measurements might be helpful for future research.

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Table 3. Variables, Measurement and Data Sources for Non-linear Model

Variables	Measurement	Data Sources
Fixed broadband deployment	Fixed broadband subscribers per 100 inhabitants	OECD (1999-2006)
Cable modem deployment	Cable modem subscribers per 100 inhabitants	OECD (1999-2006)
DSL deployment	DSL subscribers per 100 inhabitants	OECD (1999-2006)
Income	GDP per capita	UN (1999-2006)
ICT Infrastructure	Estimated PCs per 100 inhabitants	ITU (1999-2006)
LLU	Dummy (1 for with LLU, 0 for no LLU)	OECD (1999-2006)
Population density	Population density (per km^2)	ITU (1999-2006)
Internet use	Internet user per 100 inhabitants	OECD, ITU (1999-2006)
Broadband content	Internet hosts per 100 inhabitants	ITU (1999-2006)
Platform Competition	Dummy (1 for with DSL and cable modem, 0 for only DSL or cable modem)	OECD (1999-2006)

Table 4. Variables, Measurement and Data Sources for Linear Model

Variables	Measurement	Data Sources
Broadband Penetration (BPR)	Broadband subscribers per 100 inhabitants	ITU (2003-2006)
Platform Competition (PLATFORM)	100 – market share of dominant technology – market share of non-dominant technology	ITU (2003-2006)
Price of Broadband (PRICE)	Broadband monthly charge (USD)	ITU (2003-2006)
Broadband Speed (SPEED)	Broadband download speed (kbit/s)	ITU (2003-2006)
Income (INCOME)	GDP per capita	ITU (2003-2006)
ICT Use (ICT)	Estimated PCs per 100 inhabitants	ITU (2003-2006)
Education (EDU)	UNDP Education Index	ITU (2003-2006)
Population Density (P-DENSITY)	Population density (per km^2)	ITU (2003-2006)
Price of mobile (MPRICE)	Per minute local call (USD) peak	ITU (2003-2006)
Content (CONTENT)	Internet hosts per 100 inhabitants	ITU (2003-2006)
Internet Usage (INTERNET-USAGE)	Internet users per 100 inhabitants	ITU (2003-2006)
International Internet bandwidth (I-BANDWIDTH)	Internet users per 100 inhabitants	ITU (2003-2006)
Teledensity (TELEDENSITY)	Main Telephone lines per 100 inhabitants	ITU (2003-2006)
Institutional environment (INSTITUTION)	Inverse of the score on civil liberties	Freedom House (2001)