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**Migration Factors among Broadband Services: Panel Data
Analysis**

By

Sobee Shinohar, Yuji Akematsu, Masatsugu Tsuji

Migration Factors among Broadband Services: Panel Data Analysis

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ABSTRACT

Providing nationwide deployment of broadband services has become an important national agenda. The U.S. announced a National Broadband Plan and EU a Digital Agenda for Europe, both of which aim at providing access to 100 Mbps broadband services by 2020 to substantial numbers of households. The purpose of this paper is to analyze the migration factors among broadband services, namely CATV (BB), DSL and FTTx, in OECD 30 countries. In so doing, we focus especially on migration from CATV (BB) and DSL to FTTx in OECD 30 countries. Since FTTx is not independent of other two competing broadband services, not only FTTx but also CATV (BB) and DSL are analyzed. The results obtained by empirical panel data analysis, which covers the data from the year 2000 to 2010, revealed that (1) each three broadband services are substitutes, (2) faster connection speed promotes each broadband services adoption, (3) initial conditions of Cable TV in 2000 promote CATV (BB) diffusion, (4) unbundling of dry copper promotes DSL diffusion, (5) unbundling of fiber local loop restricts FTTx diffusion, and (6) investment decision on FTTx by carriers affects FTTx diffusion. This analysis will provide an important basis for national broadband policy in each country.

1. INTRODUCTION

Broadband, which enables a rapid transmission of bulk information, has developed greatly. It is used not only in the information communication industry but also in every corner of our lives, including economy and business management, medicine and education. There are a number applications such as e-commerce (electronic commerce), e-government (digital government), e-Health (telemedicine) and e-books (digital books), as well as new systems, including cloud computing. These ICT applications are made possible by broadband as a communication infrastructure. In this way, broadband constitutes as the communication infrastructure of an economy and society. This paper analyzes the factors contributing to the diffusion of these three types of technology in 30 OECD member countries during the period from its dawning, 2002, until the second quarter of 2010. Each country has different economic and social organizations, cultural backgrounds and histories of broadband diffusion, and using panel data analysis, this paper will extract the factors that the countries share in common and show discrepant. Such factors may include features of the three technologies in each country, the initial conditions at the dawn of broadband, regulations and policies in the field of telecommunications, competition in the market, the management strategy of telecommunications carriers, and even properties such as population, income and educational standards. We also analyze the competition among these three technologies, i.e. the migration from old to new technology.

Promoting rapid nationwide deployment or migration of broadband services including Cable modem, which is referred to as CATV (BB) in this paper, DSL¹ and FTTx² has become an important national agenda for many countries Japan has implemented a scheme aimed at providing broadband connections to every household by 2015, while the U.S. is pressing

¹ A type of DSL whose downstream speed is faster than its upstream speed is called ADSL (Asymmetric DSL).

² Usually, optical fiber is called FTTx (Fiber To The Home). In FTTC (Fiber To The Curb), optical fiber is laid up to the side of the road. In this paper, FTTx is used to include these different types.

ahead with a National Broadband Plan, the objective of which is to provide 100Mbps broadband services to 100 million households by 2020. A Digital Agenda for Europe promotes 30Mbps broadband access in whole EU population and 100Mbps broadband access in 50% population in EU by 2020. Smooth and effective diffusion and migration of broadband can be vital to a nation's economic revitalization and growth. In advanced countries in broadband deployment, new phenomena of migration has been occurring, and services with low speed and small capacity have been taken over by those with high or ultra-high speed. At present, the household penetration rate is 60% on average in 30 OECD countries, and further diffusion is being called for. Accordingly, deployment and migration of broadband have become policy issues in all OECD countries.

Regarding migration, how new products expand their diffusion into markets and replace the old have been extensively studied by Bass [1969], Vijay, Eitan and Bass [1990], and Atkinson, Bob, Noam, and Schultz [2010], and the patterns of diffusion and migration have been found to be affected by factors such as initial conditions, demand-pull, supply-push, types of technologies, government policies, etc. In OECD 30 member countries, the diffusion curves have different shapes, indicating that they are influenced by different factors. This paper, therefore, attempts to identify factors affecting broadband diffusion and migration in OECD countries, that is, to answer how and why the diffusion or migration patterns are different among these countries. In so doing, it categorizes these countries into three types and analyzes the influencing factors by comparing these types.

The methodology of analysis of this paper is as follows: OECD countries are classified into three categories: CATV (BB), DSL and FTTx type. For each type, hypotheses on diffusion factors are postulated based on international comparison of data. Thus this paper aims to prove hypotheses by a rigorous empirical method such as panel data with instrumental variables. Thus the diffusion and migration processes for these three broadband technologies are empirically analyzed separately by using panel data tracing back over time to the dawn of the broadband age, around 2000.

As the diffusion rate of fixed broadband increased, it is said that investment in broadband has already passed its peak³. Still, the migration toward FTTx seems to be continuing. Thus, clarifying what develops broadband adoption will provide useful suggestions upon the policies of countries seeking to spread broadband. In addition, the most of OECD countries have been experiencing the migration toward FTTx, but the speed and scale of the migration are not the same in OECD countries, this paper also aims to explain how this difference comes out. As explain previously, broadband has been developed in the framework of market competition, and in this competitive environment, the decision-making of carriers on which broadband technologies they invest plays an important role. In addition, public policy influences which particular broadband technology to be natured, although policy is required to be technological neutrality. If ICT use in medicine or business is targeted by government, then FTTx would be promoted.

The structure of this paper is as follows. Section 2 provides an overview of previous studies. In Section 3, types of broadband are classified based on the situation regarding broadband diffusion in 30 OECD countries and hypotheses regarding the factors that contribute to the diffusion of each technology are listed. In Section 4, estimated results of panel data are presented and the proposed hypotheses are verified. Section 5 provides a discussion. The conclusion is provided in Section 6.

2. PREVIOUS STUDIES

There has been a wide variety of empirical analyses of broadband deployment that have employed various analytical methods, ranging from a questionnaire analysis based on individual data to analyses based on macro data of the whole market. These differ in their object of analysis, in whether they address single or multiple markets, as well as in the

³ Atkinson, Noam and Shultz [2010] point out that, in the US, 92% of households can connect to the fixed internet as of 2010, 65% of which are actually subscribing to a fixed internet service, while only 1.9% are expected to newly subscribe to a fixed internet service in 2012.

number of the countries involved and whether the studies undertake a domestic analysis or an international comparison. Since this paper employs panel data analysis for its method and has for its object 30 OECD countries, in the following overview of previous studies, we will be concentrating on those studies that use this method in a multi-country analysis.

2.1. INTERNATIONAL COMPARISONS

The factors contributing to broadband diffusion may include prices for the three technologies, access speed, regulations and policies, competition in the market, the management strategy of telecommunications carriers, and the properties of each country, such as population, income and educational standards.

When looking at the factors contributing to the diffusion, the analyses conducted centered on economic variables, such as prices for broadband and users' income, competition within a single platform (*intra*-platform competition), *inter*-platform competition between different technologies (markets), deregulation, such as unbundling and collocation, as well as the properties of each country, such as educational standards and population. One focus is on the Herfindahl-Hirschman Index (HHI) and whether competition in terms of the market share of each carrier facilitates diffusion. All analyses obtained the same result that *inter*-platform competition is more significant for diffusion than *intra*-platform competition (especially in the case of DSL).

2.2. FACTORS CONTRIBUTING TO FTTx DIFFUSION AND MIGRATION

In analyzing these factors, only a few of the previous studies focused on FTTx. Each paper has its merits as well as shortcomings. Distaso, Lupi and Manenti [2005] take up only 14 European countries, so they do not include Japan and Korea, the advanced FTTx countries. Furthermore, the period of analysis ends at 2004, which makes it inadequate as an analysis of FTTx at present. Wallsten [2006] and Lee [2010] do not distinguish between the different prices and access speeds of the three technologies, only categorizing them into three different speeds, that is, low-speed, middle-speed and high-speed. For this reason, these studies do not allow us to conduct verification on important points, such as competition and migration between the three different technologies.

In contrast, this paper focuses on the factors contributing to the diffusion of the three broadband technologies, particularly FTTx, which has not yet been fully analyzed. As explained above, these technologies do not necessarily exist independently but can substitute for each other and there is also migration between them. Therefore, it is necessary to analyze CATV (BB), DSL and FTTx comprehensively. Moreover, compared with preceding studies, the data used in this paper covers a broader area and a longer period. The data encompasses the number of lines, speeds and prices for each of the three technologies, CATV (BB), DSL and FTTx, in 30 OECD countries at quarterly intervals during the period from around 2002, when broadband started, to 2010. This allows us to analyze the factors contributing to the diffusion of FTTx, which became conspicuous around 2001 in Korea and around 2004 in Japan, as well as the accompanying migration. Moreover, since we use quarterly data, the number of samples for panel data analysis is sufficient.

3. HYPOTHESES REGARDING CONTRIBUTING FACTORS

In order to postulate hypotheses by examining three technologies and OECD 30 member countries with different backgrounds together, we begin with the classification of broadband diffusion, according to which our hypotheses are constructed regarding the factors contributing to the diffusion of the three technologies.

3.1. TYPES OF BROADBAND DIFFUSION IN THE CURRENT TIME

Figure 1 shows the ratio of the three technologies in 30 OECD countries in 2010. Since the countries differ significantly with regard to which technology is prevalent, the countries were classified into (i) CATV (BB) type, (ii) DSL type, and (iii) FTTx type. We compared the market shares of the three technologies in each country with averages for the 30 OECD countries and classified a country by the category in which the country holds a higher market share than the average. Table 1 shows the countries classified by each type of technology.

Many European countries are categorized into the DSL type, while the United States, the Netherlands, Canada, Hungary, etc., are categorized into the CATV (BB) type. Japan, Korea, and Northern and Central European countries are categorized into the FTTx type⁴. Based on this classification, this paper examines the factors that promoted the three broadband technologies and migration among them.

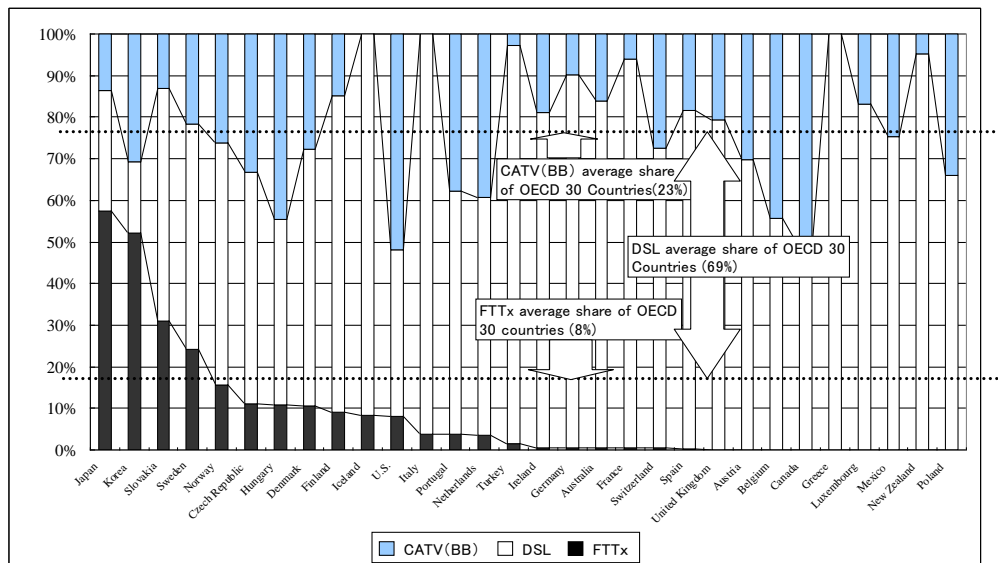


Figure 1 International comparison of broadband services
(Share of the three technologies in 30 OECD countries)
Source: National Regulatory Authorities and operators, Informa, UNSTAT

Table 1 Classification of the types of broadband diffusion

CATV (BB) type	DSL type	FTTx type
United States	Iceland	South Korea
Austria	Ireland	Sweden
Netherlands	Britain	Slovakia
Canada	Italy	Czech Republic
South Korea	Australia	Denmark
Switzerland	Austria	Japan
Czech Republic	Greece	Norway
Denmark	Switzerland	Hungary
Norway	Spain	Finland
Hungary	German	
Belgium	Turkey	
Poland	New Zealand	
Portugal	Finland	
Mexico	France	
	Mexico	
	Luxembourg	

3.2 DYNAMIC PROCESS OF MIGRATION

Figure 1 shows the current share of three broadband technologies, but prior to arriving current market share, each OECD country had experienced different time path. Figures from 2-1 to 2-6 show examples of time paths of six representative countries. It is quite difficult theoretically

⁴ Some countries were categorized into two types. Since this paper focuses on the history of each country, we did not force them into a single category.

to explain how each country had different migration process or trajectories to the present. So far, an analysis initiated by Bass is a rare example of this kind. How new products expand their diffusion into markets and replace the old have been extensively studied by Bass [1969], Vijay, Eitan and Bass [1990], and Atkinson, Bob, Noam, and Schultz [2010]. On the other hand, empirical analysis using time series data can partly examine this, and this is a reason for this paper use panel data analysis. In empirical analysis, the patterns of diffusion and migration are determined by factors such as initial conditions, demand-pull, supply-push, types of technologies, government policies, etc. The diffusion patterns of OECD 30 member countries seem to be different. This paper, therefore, attempts to identify factors affecting broadband diffusion and migration in OECD countries, that is, to answer how and why the diffusion patterns are different among these countries.

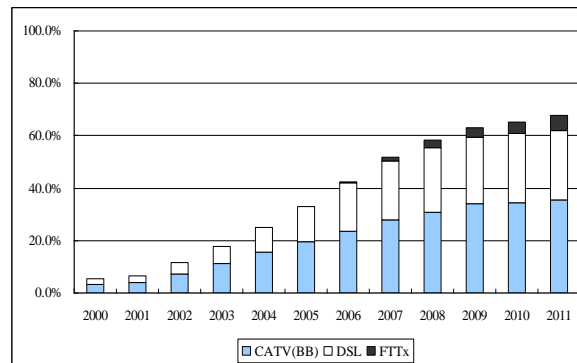


Figure 2-1 CATV (BB) type (US)

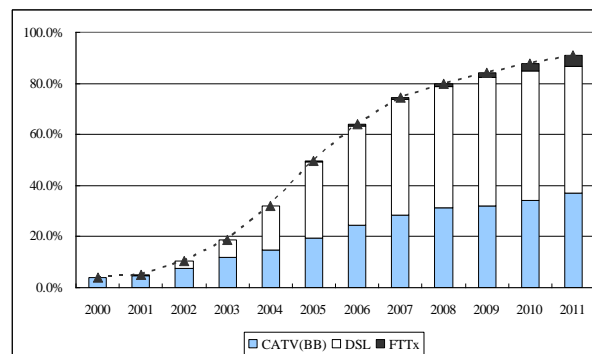


Figure 2-2 CATV (BB) type (The Netherlands)

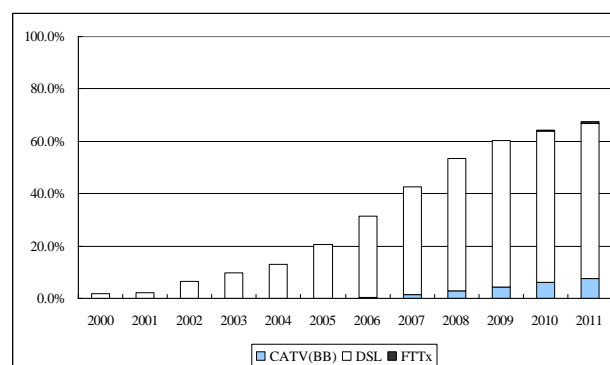


Figure 2-3 DSL type (Germany)

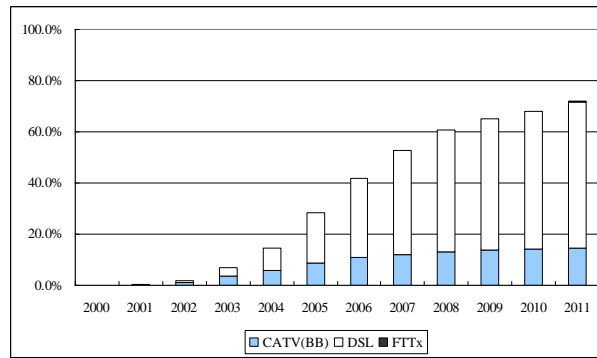


Figure 2-4 DSL type (UK)

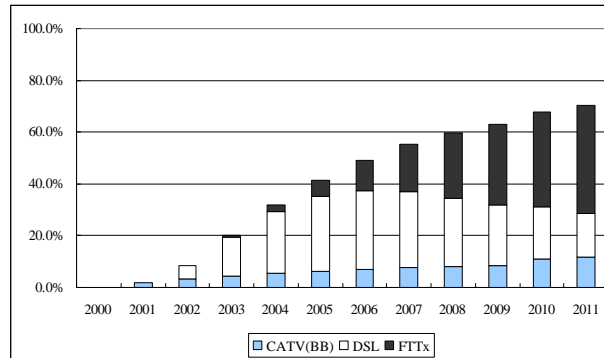


Figure 2-5 FTTx type (Japan)

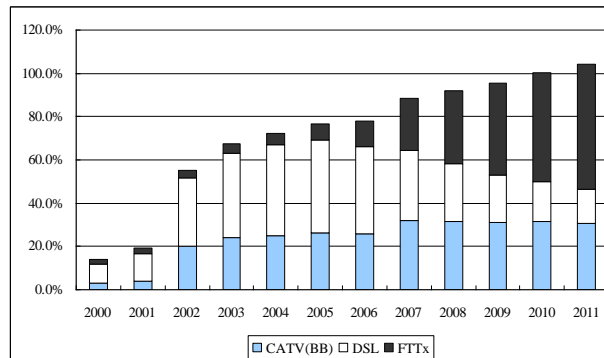


Figure 2-6 FTTx type (Korea)

3.3. HYPOTHESES ABOUT THE FACTORS CONTRIBUTING TO BROADBAND DIFFUSION

Since the broadband market is an industry in which bottleneck facilities exist, one of the main factors is the competition between the dominant carriers owning the existing access network (copper, coax, or optical fiber) and competing carriers entering the market. Deregulation plays an important role in market entry. Important policies include unbundling, collocation and the pricing of the connection charges. Competition brought about through these measures is usually called "*intra-platform competition*," indicating that carriers compete within a market for DSL or FTTx. Meanwhile, *inter-platform competition* implies that the three technologies can be considered as competing against each other. In addition, as a matter of course, lower prices and the increase in communication speed also facilitate diffusion. The following is a summary of the hypotheses set up specifically for the respective technologies.

(i) CATV (BB)

The countries classified as CATV (BB) type include the U.S., Canada, and the Netherlands, for example. In around 2000, when CATV (BB) started, other types of broadband did not exist and CATV (BB) was the sole technology. As shown in Figure 1, while the percentage of

CATV (BB) reached approximately 50% in the U.S. and Canada as of 2010, the percentage is almost 0% in some countries, including Iceland, Italy and Greece. It is assumed that the condition of the CATV broadcasting market around 2000 affected the diffusion of CATV (BB) thereafter. In this paper, the size of the CATV market around 2000 is called "the initial condition" and is assumed to be a factor promoting CATV (BB) diffusion. The factors that are considered to be the initial conditions are primarily indices, such as the household penetration rate of CATV (the customer base), which can provide a basis for diffusion, and the household penetration rate of subscriber lines for CATV (the facility base).⁵

(ii) DSL

As for DSL, several studies have pointed out that the factor contributing to diffusion is the obligatory unbundling of local copper loop. Bauer and Berne [2002] and Distaso, Lupiand and Manenti [2005] carried out international comparative analyses, while Akematsu [2007] analyzed Japan⁶. This paper adopts the same hypothesis.

(iii) FTTx

The most distinguishing feature of FTTx is the ultra high-speed service of 100 or more Mbps, which DSL cannot provide. In Japan, the migration from DSL to FTTx is clearly observed. The reason appears to be the difference in communication speed between FTTx and DSL. With the development of contents, such as video services on the Internet, users develop a tendency to demand high-capacity, high-speed services, which appears to generate migration from DSL to FTTx which has a relatively higher speed.

Distinctive among the countries of the FTTx type are Japan and Korea. FTTx began to grow quickly in Japan around 2004 and in Korea around 2005, which coincides with the period when NTT East and West, holding the largest FTTx share in Japan, and KT, their South Korean counterpart, announced their policy of a complete transition toward FTTx. In the development of the DSL business, the amount of new investment is limited because the metal subscriber line that had already been laid for telephones can be used without additional modification. In contrast, the development of the FTTx business requires a vast investment for laying optical fiber subscriber lines, which are indispensable for the business. Furthermore, dominant carriers are generally considered to be negative toward the provision of any new service that absorbs the revenues of existing services. Such a management attitude is referred to as "cannibalism" (Falch [2007], Cambini and Jiang [2009]). Thus, since DSL takes away the revenues of existing services, such as from telephones and leased circuit, and FTTx does so with regard to DSL by providing a higher-speed service, dominant carriers are said to be reluctant to provide these new services. It can reasonably be said that the remarkable diffusion of FTTx in Japan and South Korea is the result of dominant carriers' management strategy to dare to accept cannibalism and the massive fiber investment mentioned above. In this way, they took a great risk. In contrast, dominant carriers in Europe and the US appear to have avoided such risk. These management strategies can be regarded as having affected the diffusion of FTTx⁷.

⁵ In fact, the correlation coefficients between the diffusion rate of CATV (BB) in 2010 and the values of these indices in 2000 are 0.93 for the former and 0.98 for the latter, both of which are high. This allows us to assume that the initial condition in around 2000 affects the diffusion of CATV (BB).

⁶ A local loop is a subscriber line which connects a subscriber's house to a nearby base station. It is the most important line in the provision of a broadband service.

⁷ KT, the dominant carrier in South Korea, is said to have fallen behind competing carriers in both DSL and FTTx services. The reason is thought to be that KT, seeking to avoid the influence on the existing service for which it had carried out capital investment, lagged behind in terms of its provision of new services, and had no choice but to start DSL and FTTx services to compete with counterparts (Cho [2003]). Meanwhile, in Japan, NTT East and West, having an even market share which matches that of Softbank (Yahoo BB) in DSL (approximately 35% of the market share as of March 2003), appear to have given up the DSL

Based on the above argument, the hypotheses for each technology can be summarized as follows. There is no unbundling obligation of fiber local loop except for Japan. As mentioned, FTTx adoption needs huge amount of carrier's investment. Unbundling obligation results in suppression of investment incentives in optical fiber, since unbundling obligation allows carriers to use fiber local loop of other carries, not of themselves.

Hypothesis I: The diffusion of CATV (BB) is affected by the initial condition around 2000.

Hypothesis II: The diffusion of DSL is promoted by the unbundling of local copper loop.

Hypothesis III: The migration toward FTTx is induced by the increase in its communication speed relative to that of DSL, which also promotes the diffusion of FTTx.

Hypothesis IV: The diffusion of FTTx is affected by the management strategies (fiber investment decisions) of carriers.

Hypothesis V: Unbundling obligation of FTTx suppresses its adoption.

4. ESTIMATING THE FACTORS CONTRIBUTING TO BROADBAND DIFFUSION AND MIGRATION

4.1. ESTIMATION MODELS AND DATA

In order to verify the hypotheses presented in the previous section, estimation models are formulated as follows:

$$D_{it}^T = \alpha_0 + \alpha_1 P_{it}^{CATV} + \alpha_2 P_{it}^{DSL} + \alpha_3 P_{it}^{FTTx} + \alpha_4 H_{it}^{Intra} + \alpha_5 H_{it}^{Inter} + \alpha_6 S_{it}^{CATV} + \alpha_7 S_{it}^{DSL} + \alpha_8 S_{it}^{FTTx} + \alpha_9 C_i + \alpha_{10} U_{it} + \alpha_{11} I_{it}$$

where D^T is the number of subscribers of technology T , P^T is the price of the technology T (monthly price, unit: USD), S^T is the communication speed of the technology T (unit: Mbps), i is the subscript standing for an OECD country and t is the subscript standing for a quarter of a year. Since price and speed are expressed by a logarithm scale, the parameters show respective values of elasticity⁸. H^{Intra} and H^{Inter} are *intra*-platform HHI (the square sum of each carrier's market share) and *inter*-platform HHI (the square sum of each technology's broadband share), respectively. These variables reflect the state of the competition in a market. If there is competition, the share of each carrier and technology falls, which leads to lower values of HHIs, and if competition contributes to broadband diffusion, the coefficients are expected to be negative.

The following is an explanation for each equation. First, in order to verify the first hypothesis, we added C_i to Equation (1) as the diffusion rate of CATV as broadcast in the year 2000⁹. If this coefficient α_9 is positive, the diffusion of CATVs (BB) was affected by the initial condition, which means that Hypothesis I is verified. As for Hypothesis II and V, U_i is added, namely a variable for the unbundling of local loop regarding DSL and FTTx services. The variable U_i is a dummy variable which takes 0 if unbundling is not practiced in that country, while it takes 1 if unbundling is practiced but there are no price regulations, which indicates that dominant carriers obliged to practice unbundling can set connection charges freely. In addition, it takes 2, if unbundling is practiced and, at the same time, existing carriers are regulated in setting their connection charges. A higher value for this dummy variable indicates that the regulations are less strict and that it is easier for new carriers to enter the

business, and they also raised the possibility of abandoning their copper subscriber lines, while at the same time concentrating their management resources on FTTx.

⁸ Income, an important economic variable, has a strong correlation with the explained variable when the sample period extends for as long as nearly 10 years. Therefore, we excluded it from the model as in Cava-Ferreruela and Alabau-Munoz [2006], Atkinson and Hedlund [2008], and Lee [2010].

⁹ C_i is a variable independent of t , since it is the initial condition of 2000.

market. Therefore, a positive coefficient of U_i indicates that DSL was promoted by unbundling¹⁰ deregulation.

Hypothesis III can be verified by the valuables of speed in each technology. A negative coefficient indicates that a higher speed ratio caused users to transfer from DSL to FTTx, in which case Hypothesis III is verified.

The variable I_i denotes the management strategy of the carriers in the fourth hypothesis. It is a dummy variable such that $I_i = 1$ when the decision to invest in FTTx has been made by major carriers in a country and $I_i = 0$ otherwise. Among OECD countries, Japan made such an investment decision in the fourth quarter of 2004 and Korea in the fourth quarter of 2006 and Australia in the second quarter of 2010.

Finally, as for the effect of the trend accompanying a longitudinal data analysis, we controlled it by adding fiscal year dummy variables. In order to avoid complexity, the three estimation equations were analyzed independently, instead of as one simultaneous equations system¹¹.

In the estimation, the quarterly panel data for 30 OECD countries from 2002 to 2010 is used. The data regarding the number of subscribers, prices and communication speeds for each technology are obtained through a survey conducted by Informa Plc. The number of subscribers is known at the level of individual carriers. The *intra*-platform HHI is calculated on this basis. We use the price and communication speed of the highest-speed service provided by the carrier with the largest market share in a country as being representative of that country. The estimated values are dependent on when the services were initiated in each country. The data used in the estimation range in date from 2002 to 2010. It is assumed that the estimation models resemble a demand model which consists of a diffusion rate and price. The variables for prices determined at the market equilibrium (P^{CATV} , P^{DSL} and P^{FTTx}) are endogenous variables. Also, HHIs (both *intra*- and *inter*-platform) derived from the market share and the number of each technology's subscribers is also evidently endogenous variables. In order to deal with this issue of endogeneity, instrumental variables were employed in the estimation. Thus, at least the same number of instrumental variables as that of endogenous variables is needed for the estimation in each technology. Lag values of prices and subscribers are used, which are predetermined endogenous variables under the extent of serial correlation does not occur in each model. In particular, factors for each technology can also be considered from the perspective of providers. This generates the problem of identifiability. In this paper, these factors, pertaining to each technology, are assumed to shift demand exogenously. Since we use panel data in the estimation, we conduct fixed effect instrumental variables estimation and random effect instrumental variables estimation, which are followed by a Hausman test to choose the best model. Furthermore, since the number of instrumental variables and exogenous variables exceeds that of endogenous variables, we check whether the estimated values are identifiable through a test for over-identifying restrictions. Descriptive statistics are summarized in Table 2.

4.2. ESTIMATION RESULTS

The result of the estimation is summarized in Table 3. First, the price elasticity of each equation satisfies the sign condition significantly. The values of own-price elasticity were -2.29 ($p < 0.01$) for CATV (BB), -2.91 ($p < 0.01$) for DSL and -1.98 ($p < 0.01$) for FTTx, all of which were elastic. The values of cross-price elasticity with respect to CATV are 1.44 ($p <$

¹⁰ We follow Lee [2009], [2010] to categorize unbundling regulations into three categories. Distaso, Lupi and Manenti [2005] estimate the effect on broadband diffusion in a more detailed way by adding the cross term of unbundling and HHI (*intra*-platform). However, this method complicates the model yet has failed to provide significant estimations. For this reason, the cross term of unbundling and HHI was excluded from consideration in this paper.

¹¹ Refer to "Conclusion" below for a comparison with the estimation by a simultaneous equations system.

0.1) for DSL and 0.999 ($p < 0.1$) for FTTx. With respect to DSL, the valuables are 0.81 ($p < 0.1$) for CATV (BB) and 3.27 ($p < 0.01$) for FTTx and, with respect to FTTx, 1.13 ($p < 0.1$) for CATV (BB) and 2.199 ($p < 0.05$) for DSL. As for communication speed, all the equations significantly satisfy the sign condition, suggesting that the improvement in the communication speed of a technology contributes to its diffusion. However, the values of speed elasticity are 0.42 ($p < 0.01$) for CATV (BB), 0.34 ($p < 0.1$) for DSL and 1.24 ($p < 0.01$) for FTTx, none of which is elastic.

As for HHI, which is the index for competition, the *intra*-platform HHI of CATV (BB) was -2.23 ($p < 0.01$), which is negatively significant, while those of DSL and FTTx are 0.5092 ($p < 0.1$) and 0.92 ($p < 0.01$), respectively, both of which are positively significant. Therefore, while the competition between carriers in a market promotes the diffusion of CATV (BB), the more oligopolistic or monopolistic DSL and FTTx market indicates that the diffusion is advanced. Meanwhile, the values of *inter*-platform HHIs are all highly significantly negative, showing -1.31 ($p < 0.05$) for CATV (BB), -1.54 ($p < 0.1$) for DSL and -1.77 ($p < 0.05$) for FTTx. Therefore, *inter*-platform competition with competing technologies has a large effect on the diffusion of any of the three technologies. These results regarding market competition are generally consistent with those of the previous studies.

In the result of the F-test, the models are proved to be generally significant. A random effects model is selected for all three equations and instrumental variables estimation is preferred by Hausman test. With the over-identifying restrictions test on endogeneity, the Sargan-Hansen statistic is not significantly observed in the three equations, which allows us to assume that our parameters are adequately identified. From the above results, we can judge the estimation of the model to be comprehensively adequate¹².

Table 2 Descriptive Statistics

Variables	Number of Observations	Average	Standard Deviation	Minimum	Maximum
Log (Number of subscriber (CATV))	1061	12.66	2.14	3	17.82
Log (Number of subscriber (DSL))	1137	13.62	2.1	5.3	17.34
Log (Number of subscriber (FTTx))	544	11.34	2.51	2.3	16.8
Log (price (CATV))	978	3.62	0.35	2.25	4.54
Log (price (DSL))	1105	3.65	0.42	1.55	5.08
Log (price (FTTx))	399	3.91	0.47	2.51	5.51
Log (speed (CATV))	1032	1.73	1.7	-2.06	5.3
Log (speed (DSL))	1117	1.43	1.29	-1.36	3.92
Log (speed FTTx))	426	3.69	0.98	2.08	5.99
Log (HHI (intra-platform))	1091	8.45	0.54	6.37	9.21
Log (HHI (inter-platform))	1186	8.75	0.28	8.11	9.21
Log (Number of CATV subscribers (the year 2000))	1079	14.25	1.42	11.24	17.53
Unbundling of dry copper	1260	1.43	0.86	0	2
Unbundling of fiber local loop	1260	0.11	0.46	0	2
Management decision by carriers (Capital investment decision)	1350	0.03	0.18	0	1

Let us summarize below whether each hypothesis is verified or not. This will be followed by detailed interpretations of these estimated values in the later part of the paper.

¹² In addition, fixed effect models (instrumental variable and non-instrumental variable estimations) and pool estimation models (instrumental variable and non-instrumental variable estimations) were also estimated. But these models were rejected by an F-test, a Lagrange Multiplier test and others. The results were omitted due to limitations of space.

Table 3 Estimation results

	(1) CATV (BB)	(2) DSL	(3) FTTx
Log (price (CATV))	-2.290***	0.809*	1.129*
	[0.644]	[0.443]	[0.644]
Log (price (DSL))	1.439*	-2.910***	2.199**
	[0.816]	[0.641]	[1.032]
Log (price (FTTx))	0.999*	3.272***	-1.979***
	[0.529]	[0.522]	[0.627]
Log (speed (CATV))	0.424***	0.086	0.1
	[0.124]	[0.111]	[0.204]
Log (speed (DSL))	-0.27	0.340*	0.469
	[0.235]	[0.204]	[0.367]
Log (speed FTTx)	0.122	-0.308**	1.244***
	[0.149]	[0.136]	[0.246]
Log (HHI (intra-platform))	-2.228***	0.509*	0.920***
	[0.432]	[0.300]	[0.270]
Log (HHI (inter-platform))	-1.312**	-1.537*	-1.765**
	[0.563]	[0.892]	[0.727]
CATV-type countries × Log (number of CATV subscribers (the year 2000))	0.695***	-0.079***	-0.049*
	[0.112]	[0.022]	[0.026]
DSL-type countries × (unbundling of dry copper)	-0.22	0.533***	-1.836***
	[0.179]	[0.182]	[0.359]
FTTx-type countries × (unbundling of fiber local loop)	-0.098	-1.188***	-1.223*
	[0.304]	[0.316]	[0.649]
Management decision by carriers (capital investment decision)	-1.827***	-0.189	6.407***
	[0.500]	[0.434]	[1.423]
Fiscal year dummy	Included.	Included.	Included.
Constant term	31.727***	-0.381	10.898
	[4.938]	[9.314]	[8.053]
Number of observations	231	234	184
F-test (test of models)	32.84***	5.08***	24.81***
Coefficient of determination (within a group)	0.1995	0.1608	0.2875
Coefficient of determination (among groups)	0.6628	0.2196	0.8145

Values in square brackets [] indicate standard errors.

*, ** and *** indicate the significance levels of 10%, 5% and 1%, respectively.

Hausman test 1: Random effect instrumental variables estimation (REIV) vs. fixed effect instrumental variables estimation (FEIV).

Hausman test 2: Random effect instrumental variables estimation (REIV) vs. Random effects estimation (RE).

Instrumented variables: Price for each technology, intra- and inter-platform HHIs.

Instrumental variables: Lag values of each technology's market share, factors for competing technologies and other explanatory variables.

Source: The author

(i) Hypothesis I

According to the estimation result for CATV (BB), the coefficient of the CATV diffusion rate in the CATV-type countries in 2000 was 0.695, which is significant at the 1% level. Although

the coefficient is small, it revealed that the initial condition of a high CATV diffusion rate promoted CATV(BB)¹³ and hypothesis I as verified¹⁴.

(ii) Hypothesis II

According to the estimation result for DSL, the coefficient of the local loop unbundling in DSL-type countries is 0.533, which is positively significant at the 1% level. Therefore unbundling did promote the diffusion of DSL and the second hypothesis is verified.

(iii) Hypothesis III and IV

With regard to DSL, the coefficient of the speed of FTTx was -0.308, which was negatively significant at the 5% level. Any improvement in the speed of FTTx is a factor that induces migration from DSL to FTTx. This revealed hypothesis III is correct. Also, the estimated value of carriers' decisions to invest in FTTx is 6.407, positively significant at the 1% level, which is also shown to affect the diffusion of FTTx. This revealed hypothesis IV is correct.

(iv) Hypothesis V

Unbundling of local loop is implemented in Japan, but not implemented in the US and European countries. Estimation is carried out by a dummy variable, as well as DSL's case, and the coefficient of the local loop unbundling in FTTx-type countries is -1.223, which is negatively significant at the 10% level. This result reveals that since FTTx market is the basically facility-based competition, implementing unbundling obligation makes dominant carrier's to be reluctant to invest fiber local loop. This revealed hypothesis V is correct. This result shows opposite against DSL' case.

5. DISCUSSION

Thus all five hypotheses regarding the factors contributing to broadband diffusion were verified. Now let us turn to further discussion of these estimation results.

5.1. CHARGES (PRICE ELASTICITY AND SUBSTITUTABILITY)

As shown in the above estimation results, both the own- and cross-price elasticity values significantly satisfied the normal sign condition. That is, the technologies substitute for each other in terms of price. Although there have been no studies that estimated the price elasticity of the three technologies in OECD countries using macro data, the following studies have examined it within a country. Crandall, Sidak and Singer [2002] examined the United States, in which the own-price elasticity of DSL was between -1.2 and -1.5, which was elastic, while the cross-price elasticity of CATV (BB) with regard to DSL was between 0.6 and 0.8. In Ida and Kuroda [2006], although the study does not place importance on the value of cross-price elasticity, the own-price elasticity obtained was -0.88 for CATV (BB), -0.29 for DSL and -1.12 for FTTx, while the cross-price elasticity with regard to the other two technologies was 0.18 for CATV (BB), 0.1 for DSL and 0.6 for FTTx. Although these results cannot be compared in a general sense, since these were obtained through different estimation methods setting different objects for analysis, slightly larger substitutability was obtained in the estimation of this paper, using macro data.

When looking at the individual, estimated values of this paper, it is noticed that price elasticity, in particular that of FFTH, generally shows lower values compared to those of the other technologies. It can be said that, since there are only a few areas in OECD countries where FTTx is prevalent, the lower values reflect the fact that it is immature as a market in

¹³ As explained previously, the household penetration rate for CATV subscriber lines may be included in the initial condition. However, this was excluded from the estimation equation, since it is highly correlated with the rate of CATV diffusion. We also conducted estimation separately by adding the initial value of the household penetration rate with regard to subscriber lines (2000) instead of the rate of CATV diffusion, and obtained similar results.

¹⁴ This also means that the validity of three categories was verified.

terms of price. This price elasticity is expected to rise as diffusion progresses in these countries¹⁵. In the meantime, the value of the price elasticity of DSL with regard to FTTx is estimated to be high, which shows that users will switch to FTTx if its relative price decreases.

5.2. COMPETITION (INTRA- AND INTER-PLATFORM HHIs)

Because of the nature of the broadband market, i.e. that it is an industry with a bottleneck, encouraging market competition is a major issue. In this paper, diffusion was explained by the respective HHIs of two indices, *intra*- and *inter*-platform competitions. This ended up with interesting results, particularly with regard to *intra*-platform competition. That is, while competition contributed to the diffusion of CATV (BB), the opposite result was obtained in the cases of DSL and FTTx. The same applies to the results obtained in Bouckaert, Dijk and Verboven [2010] which researched 20 OECD countries. While there were some cases in which HHI was positively significant in a service-based competition like DSL, they obtained estimated values that were robustly negatively significant with regard to *inter*-platform HHI. All of the 20 countries analyzed in their study were European countries. Distaso, Lupi and Manenti [2005] analyzed 14 European countries and obtained similar results. Some *intra*-platform HHIs were also positively significant. They theoretically derived a result where the effect of intra-platform competition is smaller than that of inter-platform competition (that is, $\partial BB / \partial HHI^{intra} < \partial BB / \partial HHI^{inter}$). In this paper, as shown in Table 1, most of the DSL-type countries are found in Europe, which allows us to assume that this is a general tendency that can be observed in the analysis of DSL markets.

In the meantime, there have been no rigid quantitative analyses of competition indices of the FTTx market. Taking account of the nature of its facility-based competition, that is, optical fiber must be newly laid, only dominant telecommunications carriers and major companies, such as electric power companies, can enter the FTTx market, which leads to a correlation between the phenomenon of diffusion and the existence of an oligopoly or a monopoly. The fact that the *inter*-platform HHI is negatively significant also supports the assumption that the competitors for FTTx carriers will be CATV (BB) and DSL carriers. If migration from DSL to FTTx continues, the FFTH market become more oligopolistic and monopolistic, which pose a problem.

6. CONCLUSION

It has been said that the largest obstacle to any international comparative study of broadband is the limited amount of data (Lee [2009]). In this paper, we use new data for three broadband technologies regarding their prices, access speeds, etc., in 30 OECD countries. This enables us to conduct a comprehensive multi-country analysis including not only CATV (BB) and DSL, which had already been research subjects, but also FTTx, which has shown rapid growth in recent years. The conclusion obtained is generally consistent with results in the past. As for FTTx, this paper succeed in determining new factors contributing to diffusion, such as higher connection speed, unbundling of local loop, and the management strategy of carriers. However, since our models were constructed by verifying hypotheses obtained in previous studies, original and deeper models are required in the future. Let us conclude by presenting a direction for future studies.

First is the introduction of the idea of a lock-in and leverage effect in the migration process. This idea is partly applied to CATV (BB) in this model. That is, viewers of CATV broadcasting tend to subscribe to CATV (BB) continuously. In the case of migration from DSL to FTTx, this means to be locked-in by a particular carrier and to choose the FTTx carrier provided DSL service. While this effect causes migration to FTTx, it raises a problem in terms of competition in a situation where carriers work on their own customers to change to

¹⁵ As an example, the share of NTT East and West in the FTTx market has reached 74.5% (June, 2010). In this connection, in South Korea, where facility-based competition is developing, the market share of the dominant carrier KT is 51.0% (June, 2010).

FTTx. This is called the "leverage effect."¹⁶ "How such an effect affects competition and what kind of policy should be made will be issues that can be examined.

The existence of a network effect has been pointed out as a factor contributing to broadband diffusion. Some studies have estimated it by using a dynamic panel data model, such as system GMM (Economides and Himmelberg [1995], Madden and Coble-Neal [2004], etc.). More solid estimations are expected to be obtained by turning to these methods.

In this paper, we introduce management strategies and incentives to invest in FTTx on the part of carriers. The more accurate variable for this is the amount they invest in FTTx, but it is difficult to obtain this data. Thus this paper used the announcement of carriers to terminate copper subscriber lines or shift to FTTx as a proxy variable. This applies only to Japan, Korea and Australia. It will be necessary to find a more appropriate proxy variable from accounting data or so data in the future¹⁷.

For estimation methods, this paper applied an instrumental variables estimation based on panel data with a single equation for each of the three technologies. Essentially, the three broadband technologies can substitute for one another, for instance, in terms of migration, and a simultaneous equations model would be ideal for the estimation of such a model (Koutroumpis [2009]). Yet, despite the fact that a simultaneous equations system is complicated and requires a sophisticated estimation method, it has been confirmed that the estimated values obtained do not differ significantly from a single equation method¹⁸. The estimation results of this paper, which takes into account endogeneity and analyzes migration and substitutability, although using a single equation, are sufficiently reliable. Needless to say, though, more refined estimation methods need to be explored in the future.

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¹⁶ Tsuji and Akematsu [2009] confirmed the existence of a leverage effect in the estimation of FTTx for NTT East and West in Japan.

¹⁷ An example of a proxy variable is the time when the number of DSL subscribers hits its peak. In fact, almost all countries categorized as FTTx type in Table 1 have passed their DSL peak, in which case carriers needed to transfer their management resources from DSL to FTTx.

¹⁸ For example, Koutroumpis [2009] estimates the economic effects of broadband, focusing on the simultaneity of supply and demand. However, the gap between the estimated values of a simultaneous equation model and an ordinary single equation is very small.

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