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**Conference Paper**

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# Panel Data Analysis of Factors of Broadband Services Diffusion in OECD Countries: Focus on Deployment and Migration

**Abstract**

Deployment of broadband, particularly, FTTx, is now one of major policy objectives in many countries, including Japan, Korea, and the U.S., for example. The U.S. announced a National Broadband Plan which aimed at providing 100 million households with access to 100 Mbps broadband services by 2020. The purpose of this paper is to conduct an empirical analysis to identify factors affecting broadband service diffusion in OECD 30 member countries. In so doing, by considering the diffusion ratios of three broadband technologies, 30 countries are categorized into types, namely "CATV (BB)," "DSL" and "FTTx." Then, the paper identifies the following factors which promote broadband services by an international comparison method: (1) initial conditions of Cable TV around year 2000; (2) open access obligations on copper subscriber lines; (3) relative connection speed of FTTx to DSL; and (4) business strategy of operators for investment in FTTx influence FTTx diffusion. (1) promotes CATV diffusion, (2) promotes DSL and FTTH, and (3) and (4) influence FTTH diffusion. Finally, the paper empirically verifies the above hypotheses and the migration process among three services using panel data model, which take care of the endogeneity problem using instrumental variable method. This analysis will provide an important basis for national broadband policy formulation in individual countries.

**JEL codes**: L96, O33, O57

**Keywords**: OECD, broadband, FTTx, DSL, CATV, migration, unbundling, collocation, panel data analysis, instrumental variable method

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## 1. INTRODUCTION

Promoting rapid nationwide deployment of broadband services including CATV (BB)[1)], DSL and FTTx has become an important national agenda for many countries, including Japan, Korea, the U.S. and the EU, for example. Japan has implemented a scheme aimed at providing broadband connections to every household by 2015, while the U.S. is pressing 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 of broadband adoption 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. Accordingly, deployment and migration of broadband have become policy issues in all OECD countries.

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. Taking the example of Japanese broadband subscriptions by technology type, as shown in Figure 1and 3, the diffusion curves have different shapes, indicating that they are influenced by different factors. The same can be found in other OECD 30 member countries, and their diffusion patterns seem to be different. This paper, therefore, attempts to identify factors affecting broadband diffusion in OECD countries, that is, to answer how and why the diffusion 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 which were already discussed in Shinohara, Sakaibara and Tsuji [2010a], [2010b]. The objective of this paper is to prove these 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.

This paper is organized as follows: in the next chapter, a survey of related literature is discussed, and in Chapter 3 we classify major countries into three categories: (1) CATV (BB) type; (2) DSL type; and (3) FTTx type based on our previous papers. Chapter 4 derives hypotheses of each type are discussed and Chapter 5 verifies these hypotheses using data of OECD 30 countries by empirical panel data analysis. Brief conclusions are provided in Chapter 6.

## 2. PREVIOUS STUDIES

With respect to studies on broadband diffusion factors, there have been various opinions and discussions regarding government policies such as deregulation and facilitation of competition, business strategies of operators, attributes of individual countries and the scope of one single country or region, or of multiple countries.

Regarding papers on single country, one example can be found in a U.S. Federal Communications Commission (FCC) paper (FCC [2010]) which focuses on income and other characteristics across the U.S. Similarly, Tsuji and Tomizuka [2006], and Akematsu [2008a], [2008b] analyzed DSL diffusion factors for Japan and concluded that the driving force of DSL diffusion was the open access policy for copper local loops, including unbundling, collocation and access charges.

In the multiple countries context, the Berkman Center for Internet and Society, Harvard University (Berkman Center [2010]) also analyzed a wide range of broadband diffusion factors, including competition-related issues such as government policies on broadband diffusion and competition, operators' investments and other factors. In addition to the above, Tanaka [2008] studied mainly as for Japanese broadband market including the relationship among CATV (BB), DSL and FTTx by empirical analysis and Korean broadband market. Tsuji and Akematsu [2009], [2010] analyzed FTTx diffusion and migration process in the Japanese FTTH market. Lee and Marcu [2007], and Lee and Brown [2008] compared fixed broadband diffusion in OECD countries using panel data and identified the factors promote broadband. This is the first analysis of OECD countries, but they categorized broadband by access speed, not by three technologies.

In contrast, this paper comprehensively analyzes three broadband technologies in OECD 30 member countries. This paper firstly classifies those countries into three different categories explicitly, namely "CATV (BB) type," "DSL type" and "FTTx type"

to grasp the characteristics of broadband market. Another feature of this paper that we study those countries empirically using panel data tracking back to around the year of 2000 to analyze factors affecting diffusion, although other papers including Lee and Marcu [2007], and Lee and Brown [2008] covered data from around 2006. Data of this paper covers various variables including the number of subscriber, price, speed, market share of each operator, open access obligations upon subscriber lines, in each OECD 30 member countries in each three broadband technologies. Fiona [2009] also analyzes diffusion patterns since 2006 but does not address the transitions that have taken place since around 2000; neither does it conduct analysis by the three technologies.

## 3. CATEGORIZATION OF COUNTRIES BY BROADBAND SERVICES

Figure 1 compares relative share of subscribers of thee broadband services in OECD 30 countries and these are categorized into three types according the following procedure. First, the average market shares of three broadband services are calculated. If the share of one country of particular broadband services is larger than this international average, then this country categorized as the type of this technology. For example, the U.S. and the Netherlands have higher proportions than the OECD average of CATV (BB) diffusion, and they are classified as "CATV (BB) type," while France, Germany and other European countries whose DSL is higher proportions than the average are classified as "DSL type." Countries whose FTTx have larger proportions than the average, such as Korea and Japan, are classified as "FTTx type." Table 1 shows the list of countries in three broadband technologies. It should be noted that one country can appear more than one category. Most of European countries are of DSL type, while the U.S., the Netherlands, Canada and Hungary have larger shares in the CATV market. FTTH is rather new technology and only eight countries have market shares more than 10%. Among them, Japan and Korea have remarkable large shares which are more than 50%.

The objective of the paper is to examine why those countries are categorized into particular type, that is, to identify what kind of factors causes the difference.

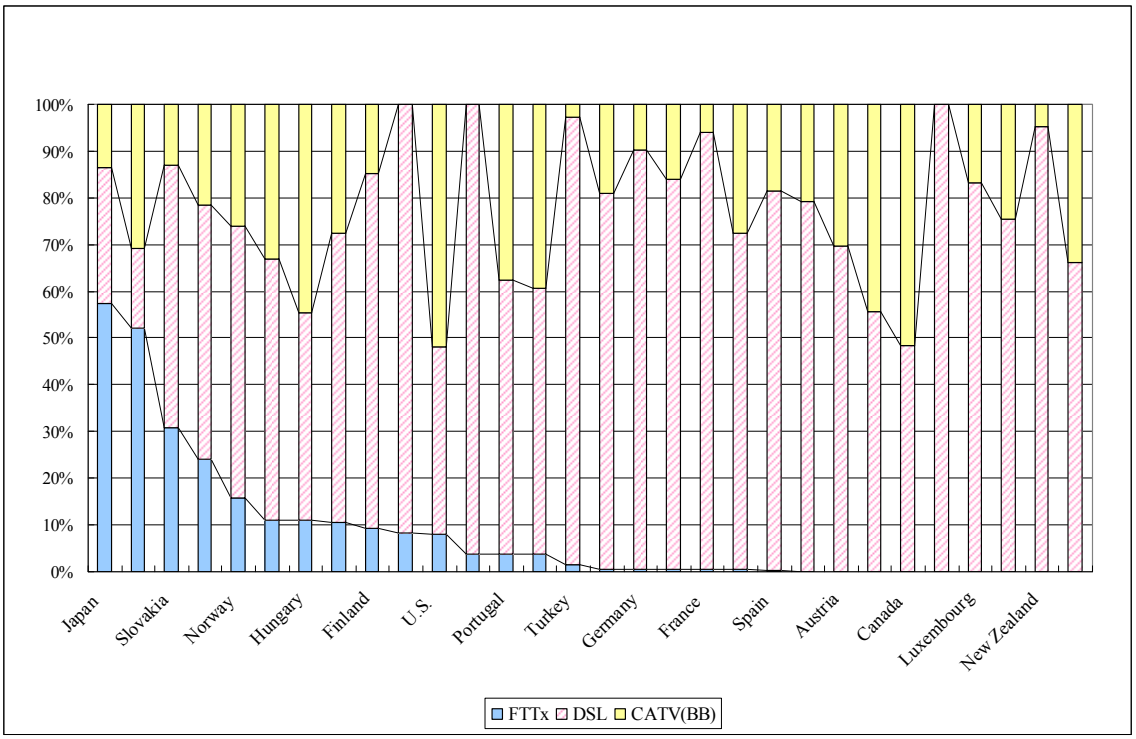


Figure 1: Broadband market share by technology in each country (2010 Q2)

Source: National Regulatory Authorities and operators

Table 1: Categorized countries into three technologies

| CATV(BB) | DSL | FTTx |
|---|---|---|
| Austria | Australia | Czech Republi |
| Belgium | Austria | Denmark |
| Canada | Finland | Finland |
| Czech Republi | France | Hungary |
| Denmark | Germany | Japan |
| Hungary | Greece | Korea |
| Korea | Iceland | Norway |
| Mexico | Ireland | Slovakia |
| Netherlands | Italy | Sweden |
| Norway | Luxembourg | |
| Poland | Mexico | |
| Portugal | New Zealand | |
| Switzerland | Spain | |
| U.S. | Switzerland | |
| | Turkey | |
| | UK | |

## 4. DIFFUSION OF THREE BROADBAND SERVICES

Three broadband services have been sequentially developed in major OECD countries. First, CATV (BB) was implemented in the mid-1990s. DSL emerged around 2000. Then, major countries began introducing FTTx from the early 2000s. This chapter analyzes features and hypotheses of diffusion factors as for CATV (BB), DSL and FTTx, respectively, based on international comparison of data.

### 4.1. CATV (BB) Diffusion

#### 4.1.1. Features of CATV (BB)

CATV (BB) type countries experienced steady increases in CATV (BB) household diffusion rates from around 2000, eventually attaining roughly 30% CATV (BB) household diffusion rates by 2009 (see Table 2)[2)]. Since CATV technology is different from other broadband technologies, open access obligations upon CATV (BB) subscriber lines was not asked by other technologies nor became a policy issue. Accordingly policy did not affect much CATV (BB) services diffusion.

Table 2: CATV (BB) household diffusion rates
(ratio of subscribers to households)

unit: %

| Types of technologies | | | Country | Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CATV(BB) | DSL | FTTx | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| | | | Australia | 0.9 | 1.5 | 2.3 | 3.3 | 5.2 | 6.7 | 7.7 | 10.5 | 11.1 | 10.9 |
| | ✓ | | France | 0.5 | 0.8 | 1.1 | 1.6 | 1.8 | 2.2 | 2.7 | 2.8 | 3.4 | 4.0 |
| | ✓ | | Germany | 0.0 | 0.1 | 0.1 | 0.2 | 0.4 | 0.6 | 1.2 | 2.5 | 4.0 | 5.8 |
| | | ✓ | Japan | 1.3 | 2.7 | 4.0 | 5.0 | 5.8 | 6.4 | 7.0 | 7.4 | 7.8 | 8.2 |
| ✓ | | ✓ | **Korea** | **9.9** | **18.3** | **21.6** | **23.2** | **23.5** | **22.5** | **28.1** | **27.3** | **27.3** | **27.4** |
| ✓ | | | **Netherlands** | **3.6** | **6.6** | **11.3** | **13.9** | **17.0** | **22.0** | **28.1** | **30.7** | **30.5** | **32.4** |
| | ✓ | | New Zealand | 0.0 | 0.2 | 0.3 | 0.4 | 0.7 | 1.0 | 1.7 | 3.0 | 3.6 | 4.0 |
| ✓ | | ✓ | **Norway** | **0.8** | **2.3** | **2.6** | **3.5** | **4.6** | **6.5** | **8.7** | **11.5** | **15.7** | **19.6** |
| | | ✓ | Sweden | 1.3 | 2.6 | 3.5 | 4.7 | 5.2 | 7.0 | 10.2 | 12.2 | 12.9 | 12.9 |
| | ✓ | | UK | 0.1 | 0.8 | 3.1 | 5.4 | 8.0 | 10.4 | 11.9 | 13.1 | 14.2 | 14.5 |
| ✓ | | | **U.S.** | **3.5** | **6.8** | **10.3** | **15.1** | **19.4** | **23.7** | **28.2** | **31.7** | **35.7** | **36.8** |

Source: OECD

According to the trends of CATV (BB) diffusion rates, they seem to grow at the constant rates, since no large upheavals were found in all countries, that is, CATV (BB)

diffusion is independent of other broadband technologies. This is resulted in the nature of CATV technology. This postulates the following first hypothesis:

**Hypothesis I: CATV (BB) diffusion is independent of other two technologies**

### 4.1.2. Hypotheses of factors affecting CATV (BB) diffusion

The year of 2000 is generally regarded as the dawn of the broadband age, which is why we have taken 2000 as the base year for broadband services diffusion. Prior to 2000, Cable TV was popular for viewing TV programs, and the cable network was easily converted to their coax subscriber lines for the Internet access. Thus CATV (BB) became the first popular access network. The number of household which described Cable TV at the year is referred to as the initial condition for CATV (BB), and it is easily understand that this initial condition affected CATV (BB) diffusion directly because, at the time of its inception, there was no other competing broadband technologies. CATV (BB) subsequently had an influence on both DSL and FTTx diffusion.

Table 3: CATV home passed household diffusion rates
(ratio of home passed to all households)

unit: %

| Types of technologies | | | Country | Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CATV(BB) | DSL | FTTx | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
| | | | Australia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | ✓ | | France | 0.0 | 34.5 | 35.7 | 35.7 | 35.6 | 0.0 | 0.0 | 0.0 |
| | ✓ | | Germany | 0.0 | 68.4 | 67.9 | 67.5 | 67.2 | 0.0 | 0.0 | 0.0 |
| | | ✓ | Japan | 39.0 | 44.3 | 47.9 | 50.1 | 52.3 | 54.5 | 56.0 | 58.0 |
| ✓ | | ✓ | **Korea** | **55.4** | **59.0** | **70.3** | **0.0** | **0.0** | **68.7** | **66.4** | **66.9** |
| ✓ | | | **Netherlands** | **0.0** | **0.0** | **97.9** | **97.0** | **96.3** | **95.7** | **95.0** | **98.0** |
| | ✓ | | New Zealand | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ✓ | | ✓ | **Norway** | **0.0** | **0.0** | **59.7** | **61.9** | **61.5** | **60.9** | **60.1** | **0.0** |
| | | ✓ | Sweden | 0.0 | 0.0 | 62.4 | 62.3 | 62.0 | 62.2 | 62.4 | 55.0 |
| | ✓ | | UK | 0.0 | 0.0 | 48.5 | 48.5 | 50.0 | 50.0 | 50.0 | 50.0 |
| ✓ | | | **U.S.** | **96.8** | **96.4** | **96.9** | **97.8** | **99.1** | **100.0** | **96.0** | **96.3** |

Source: OECD

As for broadband diffusion trends after 2000, Table 3 shows that, at nearly 100%, the U.S. and the Netherlands have much higher CATV homes passed diffusion rates

than any other country. Similarly, Table 4 shows that the U.S. (approximately 60%) and the Netherlands (approximately 90%) also have extremely high CATV (broadcasting) household diffusion rates. The consolidation of CATV operators in the U.S. and the Netherlands started around 2000, and larger CATV companies could invest more in upgrading their networks to enable to access to the Internet.

Table 4: CATV (broadcast) household diffusion rates
(ratio of subscribers to households)

unit: %

| Types of technologies | | | Country | Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **CATV(BB)** | DSL | FTTx | | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** |
| | | | Australia | 18.5 | 0.0 | 19.3 | 19.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| | ✓ | | France | 12.1 | 12.8 | 13.8 | 14.0 | 14.2 | 14.1 | 14.3 | 0.0 |
| | ✓ | | Germany | 53.5 | 52.8 | 53.5 | 51.7 | 53.0 | 57.3 | 55.0 | 50.9 |
| | | ✓ | Japan | 39.4 | 44.3 | 48.0 | 50.1 | 52.3 | 54.5 | 55.6 | 57.1 |
| ✓ | | ✓ | **Korea** | **16.2** | **32.6** | **45.2** | **67.1** | **74.2** | **79.1** | **77.3** | **79.0** |
| ✓ | | | **Netherlands** | **89.2** | **89.8** | **89.3** | **91.3** | **90.8** | **89.6** | **89.2** | **0.0** |
| | ✓ | | New Zealand | 1.5 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ✓ | | ✓ | **Norway** | **42.8** | **42.5** | **42.4** | **42.6** | **42.2** | **44.3** | **44.6** | **51.6** |
| | | ✓ | Sweden | 50.4 | 52.4 | 52.5 | 53.1 | 53.8 | 53.6 | 51.5 | 52.3 |
| | ✓ | | UK | 14.5 | 14.3 | 13.5 | 13.0 | 13.1 | 13.0 | 13.2 | 13.5 |
| ✓ | | | **U.S.** | **64.3** | **64.3** | **61.5** | **60.8** | **54.8** | **52.7** | **57.7** | **56.4** |

Source: OECD

The initial conditions for CATV (BB) Type countries in 2000 can be summarized as follows: (1) from a facility basis perspective, CATV homes passed household diffusion rates were high; (2) from a customer base perspective, CATV (broadcast) had a high household diffusion rate; and (3) from the perspective of availability of investment funding, CATV operators were consolidated. According to these discussions, the difference in CATV (BB) diffusion rates can be explained by that of initial conditions in year 2000, and this postulates the following hypothesis related to CATV (BB):

**Hypothesis II: CATV (BB) was promoted by initial conditions around 2000**

### 4.2. DSL Diffusion

#### 4.2.1. Features of DSL

To provide DSL services, DSL operators must use pre-laid copper local loops for

phone call services owned by incumbent telecommunications operators. Incumbent telecommunications operators provide traditional services such as analogue phone, ISDN, leased circuits and so on, and those are their major sources of revenues. DSL allows subscribers to use no less convenient and inexpensive than traditional services mentioned above. Thus, incumbent telecommunications operators were often reluctant to provide DSL services, because they were afraid that providing DSL resulted in losing their current revenues[3]. Under these circumstances, in order promote DSL services, telecommunications authorities initiated deregulations on telecommunications related to copper subscriber lines. They intended to promote DSL in the competitive framework. Typical policy measures consisted of (i) unbundling, (ii) line sharing; and (iii) connection charges; and (iv) collocation[4]. This paper refers these three rules to as "open access obligations." After implanting this policy, many DSL operators entered in the market, and they compete each other. In all counties, open access obligations were the most successful deregulation for the diffusion of DSL, since new entrants needed not deploy new copper subscriber lines and just used existing lines and this leads to service-based competition[5]. Without this deregulation, DSL diffusion could not have realized. In this sense, unbundling is the most important and this represents open access obligations in what follows.

#### 4.2.2. Hypotheses of Factors Affecting DSL Diffusion

Figure 2 indicates the relationship of DSL household diffusion rates and time of implementing unbundling deregulation in OECD countries. It is easily seen that after unbundling was implemented around 2000 and since then, DSL household diffusion rates grew up sharply. The typical example of this phenomenon can be found in New Zealand, in which household diffusion rates grew up slowly before implementation of unbundling in 2003, but the situation has changed entirely after 2004 when unbundling was introduced. Its DSL grew up rapidly since then. As for the UK, on the other hand, open access obligations were implemented in 2000, but connection charges were rather high and the household diffusion rates grew up slowly before 2003[6]. Then connection charges were reduced down to about -70% than before, and accordingly the household diffusion rates grew up rapidly.

From the reason mentioned above, open access obligations upon copper subscriber lines would affect DSL diffusion, and this can be postulated as hypothesis II, which can be described as follows:

**Hypothesis III: DSL diffusion was promoted by deregulations such as unbundling**

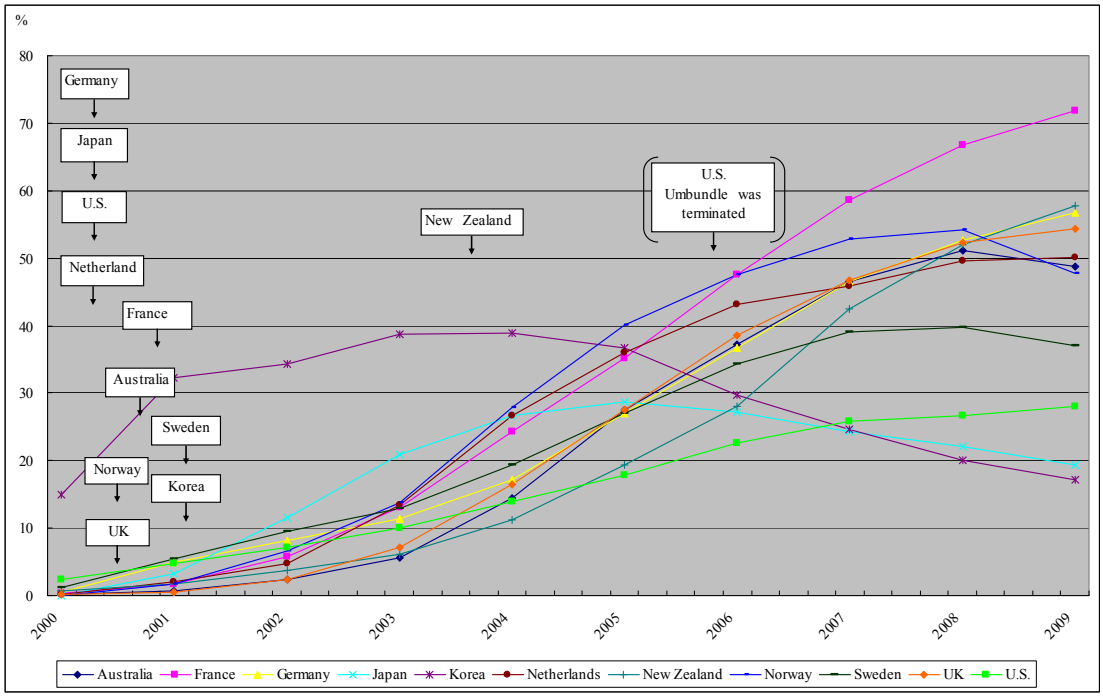


Figure 2: DSL Household diffusion rates and unbundling

Note: Countries unbundling were implemented before 2000 are indicated in 2000 with arrow.

### 4.3. FTTx diffusion type

As both Japan and Korea are typical FTTx type countries, here we analyze those countries in more detail. Based on the discussion, proper factors are selected for empirical study.

#### 4.3.1. Features of FTTx diffusion

FTTx technology is based on fiber optic subscriber lines which were entirely new at that time, and without deploying it FTTx was not realized. In addition to technology, demand, supply and policy are required for development of a new network. Since in most countries, FTTx was determined to develop in the competitive framework, factors related to demand and supply of FTTx are essential. As for the former, FTTx provided the fastest access speed in comparison with other existing broadband services, and this

was the most important merit of FTTx. The emergence of FTTx caused migration from DSL, since the former had much faster speed than the latter. Regarding the latter, operators which wished to provide FTTx services have to deploy the optical fiber network which required huge amounts of fund and other resources. Moreover, as mentioned in the DSL diffusion, FTTx services might spoil the revenues from existing copper or DSL services. In ex-ant, investment in FTTx was quite risky and managerial decision-making was also essential. In what follows, by using Japanese experience of FTTx as an example, factors affect FTTx will be examined.

### 4.3.2. Features of FTTx: Japan

#### (1) Migration: DSL peak-out

In case of Japan, spread of FTTx started accelerating around 2005, with this technology eventually securing a larger share than that of DSL in June 2008, and assuming the lead in the broadband market, as shown in Figure 3. Due to the widespread diffusion of FTTx, DSL experienced a peak-out in March 2006. As for other counties categorized the FTTx type countries, the peak-outs of DSL diffusion are found in Korea (2005 Q1), Finland (2008 Q2), Sweden (2008 Q1), Norway (2008 Q2), Denmark (2008 Q3), and Hungary (2010 Q1), while no peak-out is fund in Czech and Slovakia.

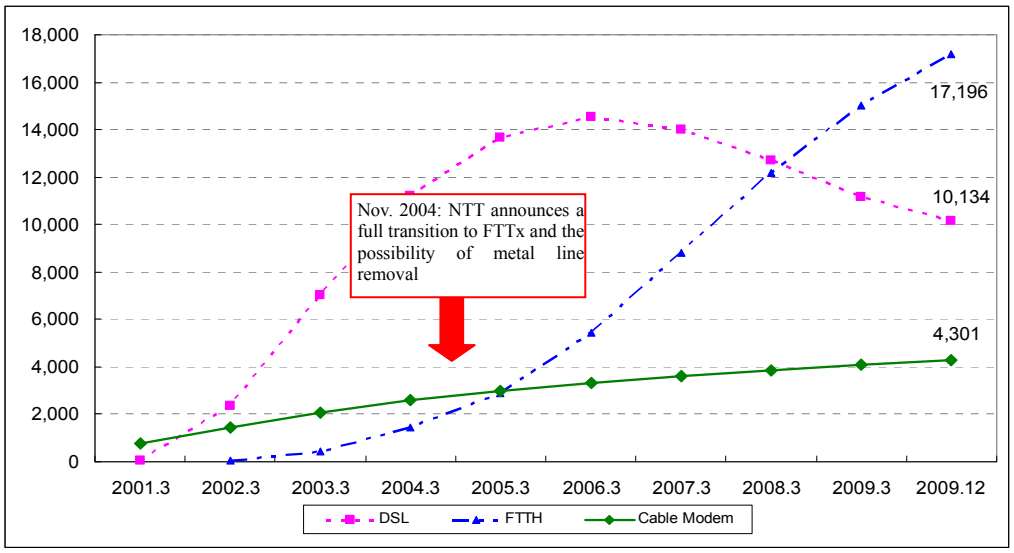


Figure 3: The number of broadband subscribers in Japan

Source: Ministry of Internal Affairs and Communications, and various company publications

**(2) Policies on and market conditions for FTTx**

Unlike other broadband services that use pre-laid metal subscriber lines, FTTx requires fiber optic subscriber lines. The Japanese government has started working on a series of FTTx diffusion policies but, given the state of telecommunications in Japan, diffusion is bound to depend heavily on capital investment by NTT East, NTT West and other operators[7].

NTT East and NTT West, the dominant operators, are obligated to open up their fiber optic subscriber lines, as was the case with DSL service metal subscriber lines. This requirement, like the DSL requirement, is aimed at establishing unbundling, collocation, and access charges in order to enable other operators to offer services that can compete with those offered by NTT East and NTT West. However, because the technical characteristics of fiber optic technology limit effectiveness of unbundling to a certain level, competitors cannot actually provide products that are fully competitive against those of NTT East and NTT West.

**(3) Competition in the FTTH market**

Japanese FTTx services are provided by NTT East, NTT West and other competitors, including telecommunication subsidiaries of electricity companies that serve regional communities. Although individual electric company services are competitive with NTT services in some areas, NTT East's and NTT West's combined national FTTx market share is consistently on the rise. It passed the 70% mark in December 2009.

NTT East's and NTT West's combined total broadband market share is also on an upward trend, having increased from 25.2% in March 2002 to 51.6% as of December 2009.

**(4) Business strategies of carriers**

The growing diffusion of FTTx and the phasing out of DSL have come to prominence since NTT East and NTT West, owners of copper local loops, announced in November 2004 their intention to make a complete transition to optical networks and floated the possibility of terminating metal subscriber lines as shown in Figure 3.

This development has created three major problems for competitors that had previously focused on DSL services. First, NTT's announcement regarding possible

termination of metal subscriber lines has made it increasingly difficult to concentrate primarily on DSL and has forced the providers to become more cautious about continued investment in management resources. Second, NTT's full transition to FTTx would mean a smaller DSL market and higher-speed broadband services across the whole, thereby putting pressure on competitors to also move from DSL to FTTx. Third, competitors were unable to offer FTTx services which were sufficiently competitive with those of NTT and, thus, it was difficult for them to develop their broadband service operations. In fact, Softbank, which had secured a share comparable to that of NTT in the DSL market, abandoned its plans to make a full-scale entry into the FTTx market (deciding not to provide FTTx as a Softbank service), and now sells NTT East's and NTT West's FTTx services.

On the other hand, NTT East and NTT West, as the dominant operators, were influenced to make this move by five major reasons:

(1) Since they are strictly fixed-line (not mobile) operators, they wanted to concentrate on enhancement of management resources, including capital investments, in order to establish FTTx as a mainstay business;
(2) They wanted to pool resources toward optical subscriber lines only and thereby avoid the double burden of having to manage and maintain both metal and optical subscriber lines;
(3) They were locked in a battle with Softbank for DSL share supremacy, with both tied at roughly 35% (NTT had provided all domestic telecommunications services prior to the 1985 liberalization), as shown in Table 5;
(4) They have raised the possibility of removal of metal subscriber lines, which are vital to DSL services. They had no intention of reinforcing the permanency of DSL; and,
(5) They planned to shift 50% of their combined customer base to FTTx by 2010.

As described above, we could assume that the fierce competition between operators in the DSL arena fueled by the provisions of broadband competition policies that opened up metal subscriber line infrastructures, prompted NTT East and NTT West to shift to FTTx. As a result of having concentrated its management resources into FTTx and made aggressive capital investment moves, NTT succeeded in extending its lead over its competitors. Its shares of the FTTx and total broadband markets climbed to

70% and 50%, respectively, as shown in Table 6 and Table 7. It would appear that the decision by the dominant operator, which owns the metal lines, to transition its business entirely toward the optical subscriber network, and the possibility that metal subscriber lines could be removed were to some degree influential on the rapidity of FTTx diffusion in Japan and the DSL peak-out.

Hence, the development of broadband diffusion in Japan can be summarized as follows: First, with respect to the early stages of broadband (CATV (BB) and DSL), CATV (BB) did not spread due to the fact that in 2000, the conditions for CATV (broadcasting) diffusion in terms of infrastructures, customer base, and provider aggregation were not satisfied. Second, beginning in 2001, broadband competition policies, which opened up metal subscriber line infrastructures, helped DSL to spread in bursts. In the later stage of broadband (FTTx), NTT East and NTT West, faced with heated-up competitor opposition that helped to drag their combined share of the DSL market down to a tie for the lead (35%), decided to make capital investments in optical subscriber lines, prompting the shift from DSL to FTTx.

Table 5: Comparison of DSL market share by operators in Japan with Korea

unit: %

| **Japan** | **2001.3** | **2002.3** | **2003.3** | **2004.3** | **2005.3** | **2006.3** | **2007.3** | **2008.3** | **2009.3** | **2010.3** |
|---|---|---|---|---|---|---|---|---|---|---|
| Softbank BB | 0.0 | 20.6 | 31.1 | 35.8 | 34.9 | 34.8 | 36.8 | 37.8 | 38.4 | 38.7 |
| NTT East | 24.1 | 21.6 | 20.4 | 20.4 | 20.7 | 20.7 | 19.9 | 19.0 | 18.4 | 17.5 |
| NTT West | 14.2 | 19.1 | 16.0 | 16.1 | 17.4 | 18.5 | 18.1 | 17.7 | 17.3 | 17.3 |
| eAccess | 0.0 | 0.0 | 13.6 | 13.3 | 13.3 | 13.2 | 13.7 | 14.6 | 15.5 | 23.5 |
| Acca Networks | 0.0 | 0.0 | 0.0 | 10.4 | 9.4 | 8.6 | 7.8 | 7.5 | 7.1 | 0.0 |
| Others | 61.8 | 38.8 | 19.0 | 4.0 | 4.3 | 4.3 | 3.6 | 3.5 | 3.3 | 3.0 |
| Sum | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| **Korea** | | **2001.1** | **2002.1** | **2003.1** | **2004.1** | **2005.1** | **2006.1** | **2007.1** | **2008.1** | **2009.1** |
| KT | | 75.0 | 76.8 | 79.6 | 81.9 | 84.3 | 86.5 | 89.1 | 90.7 | 93.3 |
| SK broadband | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.2 | 5.3 |
| Hanaro Telecom | | 22.7 | 20.9 | 18.3 | 16.1 | 14.2 | 11.5 | 8.9 | 0.0 | 0.0 |
| Thrunet | | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Onse | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| LG Dacom | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Dreamline | | 2.2 | 1.4 | 1.1 | 0.8 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 |
| Others | | 0.0 | 1.0 | 1.1 | 1.3 | 0.9 | 1.6 | 1.9 | 2.1 | 1.4 |
| Sum | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Source: National Regulatory Authorities, operators and OECD.

Table 6: Comparison of FTTx market share by operators in Japan and Korea

unit: %

| **Japan** | **2002.3** | **2003.3** | **2004.3** | **2005.3** | **2006.3** | **2007.3** | **2008.3** | **2009.3** | **2010.3** |
|---|---|---|---|---|---|---|---|---|---|
| NTT East | 17.3 | 26.4 | 29.4 | 30.6 | 34.7 | 38.6 | 40.8 | 41.9 | 42.3 |
| NTT West | 8.6 | 20.9 | 28.5 | 26.9 | 28.0 | 30.4 | 31.4 | 32.2 | 32.1 |
| Subsidiaries of Electric Power Companies | 0.0 | 0.0 | 12.1 | 16.2 | 17.0 | 10.8 | 10.8 | 9.5 | 9.2 |
| KDDI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.6 | 5.8 | 7.1 | 8.0 |
| USEN | 0.0 | 0.0 | 9.9 | 9.7 | 8.7 | 6.2 | 4.6 | 3.4 | 3.0 |
| Others | 74.1 | 52.7 | 20.1 | 16.7 | 11.6 | 7.3 | 6.6 | 5.9 | 5.3 |
| Sum | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| **Korea** | **2001.1** | **2002.1** | **2003.1** | **2004.1** | **2005.1** | **2006.1** | **2007.1** | **2008.1** | **2009.1** |
| KT | 81.9 | 48.1 | 48.7 | 49.3 | 44.3 | 46.2 | 43.4 | 42.3 | 41.0 |
| SK broadband | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 23.7 | 23.2 |
| Hanaro Telecom | 6.9 | 32.7 | 30.5 | 28.1 | 27.4 | 26.8 | 26.9 | 0.0 | 0.0 |
| Thrunet | 0.0 | 0.7 | 0.5 | 0.4 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Onse | 0.0 | 0.7 | 0.4 | 0.2 | 2.3 | 0.9 | 0.0 | 0.0 | 0.0 |
| LG Powercomm | 0.0 | 0.0 | 0.0 | 0.0 | 5.2 | 16.9 | 22.0 | 26.1 | 28.4 |
| LG Dacom | 11.3 | 6.5 | 6.6 | 6.6 | 7.6 | 2.1 | 1.2 | 0.4 | 0.2 |
| Dreamline | 0.0 | 0.3 | 0.4 | 0.5 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Others | 100.0 | 11.0 | 12.9 | 15.0 | 11.4 | 7.1 | 6.5 | 7.6 | 7.2 |
| Sum | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Source: National Regulatory Authorities, operators and OECD.

Table 7: Comparison of broadband market share by operators in Japan and Korea

unit: %

| **Japan** | **2001.3** | **2002.3** | **2003.3** | **2004.3** | **2005.3** | **2006.3** | **2007.3** | **2008.3** | **2009.3** | **2010.3** |
|---|---|---|---|---|---|---|---|---|---|---|
| NTT East | 2.0 | 13.4 | 16.2 | 17.8 | 19.0 | 21.0 | 23.4 | 25.7 | 27.5 | 28.1 |
| NTT West | 1.2 | 11.8 | 12.8 | 14.6 | 16.1 | 18.1 | 19.7 | 21.1 | 22.3 | 22.5 |
| Softbank | 0.0 | 12.6 | 22.9 | 26.3 | 24.6 | 22.0 | 19.9 | 17.1 | 14.4 | 11.6 |
| Eaccess | 0.0 | 0.0 | 10.0 | 9.8 | 9.3 | 8.2 | 7.3 | 6.4 | 5.7 | 7.0 |
| KDDI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 2.2 | 2.4 | 3.5 | 4.3 |
| Others | 96.8 | 62.2 | 38.1 | 31.5 | 30.9 | 29.9 | 27.5 | 27.3 | 26.5 | 26.5 |
| Sum | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| **Korea** | | **2001.1** | **2002.1** | **2003.1** | **2004.1** | **2005.1** | **2006.1** | **2007.1** | **2008.1** | **2009.1** |
| KT | | 49.7 | 47.3 | 49.3 | 51.0 | 51.2 | 45.2 | 44.3 | 43.4 | 42.5 |
| SK broadband | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 22.9 | 23.5 |
| Hanaro Telecom | | 26.5 | 27.6 | 25.2 | 23.1 | 22.7 | 25.7 | 24.9 | 0.0 | 0.0 |
| Thrunet | | 16.8 | 12.5 | 11.6 | 10.8 | 6.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Onse | | 3.1 | 4.3 | 3.8 | 3.3 | 2.9 | 1.6 | 0.0 | 0.0 | 0.0 |
| LG Powercomm | | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 | 8.6 | 11.7 | 14.1 | 15.4 |
| Others | | 3.9 | 8.2 | 10.2 | 11.9 | 14.1 | 18.9 | 19.1 | 19.6 | 18.6 |
| Sum | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Source: National Regulatory Authorities, operators and OECD.

### 4.3.3. Features of FTTx: Korea

**(1) DSL and FTTx diffusion**

In the case of Korea, competitors initially jumped into FTTx, because (1) there were only inadequate open access regulations covering Korean Telecom (KT)'s copper lines for DSL, and (2) competitors had installed their fiber lines right to the doors of households. So, the competitors did not have to stay with DSL and were able to jump into FTTx.

(2)

In Korea, since 2001, market share by broadband technology has fluctuated dramatically, as shown in Table 5, Table 6 and Table 7, while KT and other competitors have settled into a dead heat in the race for market share.

The process of development of ADSL and FTTx diffusion in Korea can be described as follows:

(1) After ADSL was launched in April, 1999, Hanaro Telecom, a competitor, used an electric power company's rights of way to bring its own fiber optic lines to customers in adjacent neighborhoods and began providing services;
(2) Korea Telecom (KT), the dominant operator, kept pace by launching its own ADSL services in June of the same year;
(3) The unbundling of KT's copper local loop was institutionalized at the end of 2001; however, there were no rule for the setting of access charges by the NRA. Hanaro avoided having to make active use of the unbundled copper local loops (dry copper), choosing instead to shift from DSL to FTTx (see Table 6);
(4) As a result, KT continued to maintain a massive share of the DSL market (around 93% by the end of 2009). DSL peaked-out in 2003;
(5) Meanwhile, in the FTTx market – the main battleground – KT's share has leveled out at around 50% since 2002 in the face of stiff competition (see Table 6);
(6) In 2005, LG Powercom entered the FTTx market using a power company's lines; and
(7) In 2006, KT announced plans to create a full-subscriber FTTH network by 2010.

### 4.3.4. Hypotheses of Factors Affecting FTTx Diffusion

In order to postulate hypothesis, we have to pay attention to data: whether

suitable data are found. If we focus on good hypotheses but there are no data available, then we cannot estimate them. Here let us summarize the discussions so far and find the suitable variables which represent them. Possible factors of FTTx diffusion are summarized as follows: (1) competition with DSL; (2) unbundling; and (3) competition and business strategy.

(1) At the beginning of FTTx was introduced, DSL was still growing, but gradually it has been taken over by FTTx in FTTX type countries. In addition to Japan and Korea, among FTTX type countries, Finland, Norway and Sweden have experienced the DSL's peak-out. The major factor of this migration is that consumers chose faster speed of FTTx. From this viewpoint, relative speed of FTTx to DSL can be taken as a factor of migration. In estimation, we take the ratio of maximum speed available of DSL over that of FTTx in those countries as a variable.

(2) Unbundling in FTTx is a quite touchy issue to regulators, in spite of DSL. In case of DSL, fixed telephone is already universal service and the network was completed all over the country. There was less problems for the introduction of DSL. FTTx, on the other hand, have to deploy the optical fiber network, which requires huge funds and is risky. The best strategy for carriers is to wait for investment: if some carriers deployed the network, they can use it. This implies carriers dared not to deploy. Most of countries, therefore, introduced unbundling regulation.

(3) Only dominant carriers in Japan and Korea declared the termination of copper lines implying they had to concentrate their business resources to FTTx. In particular, Japanese NTT locals invested heavily in the deployment of optical fiber networks by taking risks. Eagerness to invest FTTx is taken as a variable for business strategy, and the year of the declaration of copper lines' termination is selected as a proxy for this. Thus hypotheses related to FTTx are presented as follows:

**Hypothesis IV: faster relative speed of FTTx to DSL promoted FTTx diffusion.**

**Hypothesis V: the termination of copper lines shows business strategy of investment in FTTx**

In what follows, we attempt to verify the above hypotheses using panel data analysis.

## 5. PANEL DATA ESTIMATION

Let us examine the hypotheses we proposed in the previous section using a rigorous estimation method.

### 5.1. Model for estimation

In this estimation, we use panel data model based on the 30 OECD countries. In estimation, care should be taken for the endogeneity problem, since some variables are endogenous and resulting estimations cannot identify whether the relationship between dependant and explanatory variables is causality or simple correlation.

In estimation, dependent variables contain the number of subscribers of FTTx, DSL, and CATV (BB), while independent variables price and connection speed of each technology, and so on. It should be noted that variables related to characteristics of member countries were not introduced in the above equations, since *income*, which is a typical example, had such a strong impact that it explained the equations, that is, all other variables became insignificant. Thus we omitted country's characteristics from the estimation equations.

**Theoretical model**

According to Berry (1994), the utility of consumer $i$ for product $j$ (such as CATV, DSL, and FTTx in this case) does not depend on the product itself, but on the characteristics of the product. The utility of consumer $i$ for product $j$ is thus given as follows.

$$u_{ij} = x_j\beta + P\alpha + \xi_j + \varepsilon_{ij}\,, \tag{1}$$

where $x_j$ denotes observed product characteristics such as the connection speed, and $P$ the subscription charges of each of technologies, $\zeta_j$ unobserved product characteristics, $\varepsilon_{ij}$ the error term. In estimating with the aggregate data, the mean utility level of each product $\delta_j$ plays an important role, defined as follows.

$$\delta_j \equiv x_j\beta + P\alpha + \xi_j\,. \tag{2}$$

In this framework, the mean utility level determines the market share of each product $s_j$, and thus it can be expressed as a functional form $g(\,)$ by $\delta_j$, or ($x_j$, $P$, $\zeta_j$),

$$s_j = g(\delta_j) = g(x_j, P, \xi_j) \,. \tag{3}$$

Assuming $\varepsilon_{ij}$ in the equation (1) based on the extreme value distribution, the market share of product $j$ can be formulated by the ordinary logit function,

$$s_j = g(\delta_j) = \frac{e^{\delta_j}}{(\sum_{k=0}^{3} e^{\delta_k})} \,. \tag{4}$$

Taking the logarithm of (4),

$$\log(s_j) = \log\{g(\delta_j)\} = \delta_j - \log(\sum_{k=0}^{3} e^{\delta_k}) \,. \tag{5}$$

Then we define the "outside good," where consumers do not subscribe to any broadband services by using $j = 0$, and considering the mean utility level of outside good is normalized to zero (thus $\delta_0 = 0$). We obtain the equation as follows.

$$\log(s_j) - \log(s_0) = \delta_j = x_j\beta + P\alpha + \xi_j \,. \tag{6}$$

Finally, we formulate the model for estimation for three technologies by definition of diffusion index as $D_j = \log(s_j) - \log(s_0)$, and the characteristics of products in more detail.

$$\begin{aligned} D_{CATV} = {} & \xi_{CATV} + \alpha_1 P^{CATV} + \alpha_2 P^{FTTx} + \alpha_3 P^{DSL} + \beta_1 S^{CATV} \\ & + \beta_2 C * (CATV\,(BB)\ type\ country) \end{aligned} \tag{7}$$

$$\begin{aligned} D_{DSL} = {} & \xi_{DSL} + \alpha_1 P^{DSL} + \alpha_2 P^{CATV} + \alpha_3 P^{FTTx} + \beta_1 S^{DSL} \\ & + \beta_2 U * (DSL\ type\ country) \end{aligned} \tag{8}$$

$$D_{FTTx} = \xi_{FTTx} + \alpha_1 P^{FTTx} + \alpha_2 P^{DSL} + \alpha_3 P^{CATV} + \beta_1 S^{FTTx} + \beta_2 (investment\ decision) + \beta_3 (S^{FTTx} / S^{DSL}) * (FTTx\ type\ country) * (Year\ after\ 2009\ dummy) \quad (9)$$

where $S^j$ stands for the connection speed of product $j$ which is regarded as one of the characteristics of product, $U$ the unbundling of dry copper that is regarded as one of the exogenous shift parameters (dummy variable) affecting diffusion of DSL, and $C$ the number of subscribers of Cable TV as of 2000 which is also the exogenous shift parameter on the CATV diffusion. The term ($S^{FTTx}$ / $S^{DSL}$) in equation (9) is a mathematical expression of migration from DSL to FTTx in the FTTx type countries. If the coefficient of the cross term is negative, then in those countries subscribers have been switching from DSL to FTTx because of latter's faster connection speed.

Let us explain the above equations in more detail with respect to the hypotheses mentioned earlier. Regarding Hypothesis I, all prices of three broadband technologies are included in three equations, and then the signs of their coefficients show whether they are substitutes or not. The rest of hypotheses are included in the equations in the following way.

**Hypothesis II:**

These hypotheses are incorporated in equation (7) which is presented in the cross term of the number of subscribers of Cable TV as of 2000 and CATV type countries (dummy). If its coefficient is positive, then CATV diffusion was enhanced by the initial conditions of Cable TV.

**Hypothesis III:**

DSL equation (8) includes Hypothesis III which is presented by the cross term of unbundling of dry copper (if implemented, it takes 1, while if not implemented, it takes 0) and DSL type countries (dummy). If its coefficient is positive, then the cross term shows that DSL was promoted by the deregulation of unbundling.

**Hypothesis IV and V:**

FTTx equation (9) includes the cross term of the relative connection speed between FTTx and DSL indicated as (FTTx/DSL) and FTTx type countries (dummy) represents Hypothesis IV in the FTTx type countries. If the coefficient of the cross term is negative, then in those countries subscribers have been switching from SDL to FTTx due to faster FTTx's connection speed. In addition, *investment decision* is introduced as an explanatory variable (dummy) which represents Hypothesis V, which takes 1 at the period 2004 Q4 and after, while takes 0 before 2004 Q4 for Japan. Similarly it takes 1 at

the period 2006 Q4 and after, while takes 0 before 2006 Q4 for Korea. Moreover, since the migration is clear phenomena since 2009, a dummy variable denoted *Year after 2009* is also attached;

The data for estimation consists of OECD 30 member countries covering about 10 years, and a variety of diffusion patterns exists even in these countries. It should be noted that specific characteristics, such as the number of subscribers of Cable TV ($C$) in equation (7), the unbundling of dry copper ($U$) in the equation (8), and the relative speed ($S^{FTTx} / S^{DSL}$) in the equation (9) are included for only corresponding "diffused country" of each technology, respectively. The definition of diffused country is countries whose penetration ratio is more than half among 30 countries.

**5.2. Result of estimation**

As price variables are endogenous, instrumental variables in panel estimations is used in such a way that the market shares of each technology (one period earlier) are included as instrumental variables in order to handle the endogeneity problem. As shown in Table 8, all three equations satisfy the Hansen test for overidentification restrictions. Moreover, two panel data models are estimated, namely fixed-effects and random-effects model, and we attempted to specify the proper model by Hausman test. All estimations selected the random-effects model.

The estimation results shown Table 8 reveals interesting observations. It shows elasticity of services in terms of price and speed. The price elasticity of FTTx shows -6.39 ($p<0.01$) which is elastic, and the cross price elasticity with regard to DSL 1.19 ($p<0.10$) which is also elastic. On the other hand, the price elasticity of DSL indicates -0.95 ($p<0.05$) and the cross elasticity with respect to FTTx 0.39 ($p<0.05$). These are less elastic in comparison with those of FTTx. If subscribers face the reductions in prices at the same percent, they tend to select FTTx more than DSL. This suggests the tendency of migration from DSL to FTTx.

As for connection speed, its elasticity of FTTx and DSL similarly amounts 0.53 ($p<0.10$) and 0.54 ($p<0.01$), respectively, while 0.28 ($p<0.01$) for CATV which is as half as former two. These results imply that the faster the connection speed of each technology, the more it promoted their diffusion.

Table 8: Result of estimation

| | (7)<br>CATV | (8)<br>DSL | (9)<br>FTTx |
|---|---|---|---|
| Price (CATV) | 0.137<br>[0.339] | 0.143<br>[0.208] | **1.611****<br>**[0.763]** |
| Price (DSL) | -0.043<br>[0.116] | **-0.951****<br>**[0.419]** | **1.189***<br>**[0.689]** |
| Price (FTTx) | 0.017<br>[0.113] | **0.385****<br>**[0.172]** | **-6.394*****<br>**[2.019]** |
| Speed (CATV) | **0.281*****<br>**[0.021]** | | |
| Speed (DSL) | | **0.537*****<br>**[0.050]** | |
| Speed (FTTx) | | | **0.414***<br>**[0.240]** |
| Cross term (CATV(BB) type country * No. of Cable TV subscribers in 2000) | **0.080*****<br>**[0.017]** | | |
| Cross term (DSL type country * unbundling (dry copper)) | | **0.901*****<br>**[0.212]** | |
| Cross term (FTTx type country * relative speed (FTTx/DSL after 2009)) | | | **-0.668*****<br>**[0.238]** |
| Carriers' investment decision on FTTx investment (2004 Q4 for Japan and 2006 Q4 for Korea) | | | **1.634****<br>**[0.689]** |
| Constant | 11.467***<br>[1.131] | 14.338***<br>[1.026] | 7.358<br>[4.764] |
| Observations<br>Number of countries | 289<br>19 | 327<br>20 | 236<br>19 |
| Chi-squared (Wald test) | 261.68*** | 163.9*** | 66.47*** |
| Hausman test<br>(P-value) | 0.12<br>1 | 5.35<br>0.866 | 7.41<br>0.829 |
| Overidentification restrictions (Hansen's J statistic)<br>(P-value) | 0.00<br>1 | 0.00<br>1 | 0.57<br>0.451 |

Note 1: Standard errors are in brackets.
Note 2: *, **, and *** indicate the significance level at 10%, 5%, and 1%, respectively.
Note 3: Year dummy variables (2004 - 2009) are included as control variables.
Note 4: Instrumented: Price
Note 5: Instruments: 1 period lag of market share of each technology, other explanatory variables

Let us examine hypotheses one by one according to the estimation results.

**Hypothesis I:**

As shown in Table 8, all prices including its own are not significant in CATV equation (7), implying that it is independent of competition from other DSL and FTTx. On the other hand, only FTTx is significantly influenced by CATV price, and it is competing with CATV, while DSL is not. This indicates CATV and DSL are

independent each other, which seems to be a natural result of their technological difference, the former uses coax while the latter copper lines. This verifies Hypothesis I.

**Hypothesis II:**

As for the result of CATV, the cross term of the number of subscribers of Cable TV (as of 2000) and CATV type countries is 0.08 ($p<0.01$), which reveals that the initial conditions such as the number of Cable TV subscribers is important for the CATV diffusion[8]. Thus Hypothesis II is proved.

**Hypothesis III:**

The result of DSL equation (8) shows that the cross term between the unbundling of dry copper and DSL type countries is 0.90 ($p<0.01$). This proves that unbundling promotes DSL diffusion, and Hypothesis III is verified.

**Hypothesis IV and V:**

As for FTTx, the cross term of relative connection speed with DSL and FTTx type countries is -0.67 ($p<0.01$) after 2009. This can be interpreted that the improvement of a relative speed of FTTx in comparison with DSL promotes the migration from DSL to FTTx. Since the migration is clear after 2009 in FTTx type countries, this coincides with the realty. Thus this verifies Hypothesis III. Regarding to carriers' *investment decision* on FTTx, its coefficient is 1.63 ($p<0.05$), which also verifies Hypothesis IV.

The result obtained in the empirical study can be summarized as follows:

- FTTx and DSL are substitutes each other with respect to their prices, but there are no relationships with CATV.
- Connection speed is important for the diffusion of all broadband services.
- The diffusion of FTTx requires the migration from DSL, which was achieved by the relative connection speed in comparison with DSL. In addition, since investment in FTTx required fugue amounts of fund and it is risky to carriers, carriers' decision-making on FTTx investment is also important.
- For the diffusion of DSL, the unbundling of dry copper was essential.
- For the diffusion of CATV, the initial condition such as the number of Cable TV subscribers is important, since Cable TV was easily converted to the Internet connection.

### 5.3. Discussions

Unbundling regulations contains various implementations, and this paper focuses

on unbundling in the narrow sense in order to make empirical analysis simple. This variable can be categorical, as Lee and Brown [2008], that is, if all of four deregulations are implemented, then the variable takes four, and so on.

As for managerial strategy, the amount of investment in fiber optical subscriber lines is another proxy for this, but it is difficult to obtain the financial data from operators, since it is confidential. Thus, the termination of copper subscriber lines is taken as a variable, but only Japan and Korea announced the termination. There is another possible proxy variable such as the year operators realized speed of FTTx become over 100Mbps, which indicates they focused on FTTx services rather than those of DSL.

This paper does not deal with market competition and deployment of FTTx due to the availability of related data, but this is an essential policy issue. Most of countries did not implement unbundling fiber optical subscriber lines, because it spoils operators' incentives. From the experience of DSL diffusion, competition in the market promotes diffusion. By introducing HHI in the estimation equation, this can be verified, which is a future work. .

## 6. CONCLUSION

The objective of this paper is to verify the hypotheses which are postulated by international comparison of data of OECD 30 countries. As Lee and Brown [2008] clearly pointed out, previous studies on fixed-broadband diffusion have following limitations: (i) limited number of independent variables; (ii) insufficient number of observations; (iii) lack of refined theoretical explanation; and (iv) inconsistent empirical results. This paper attempts to overcome these limitations and conduct rigorous empirical analysis based on a solid theoretical model and sufficient data not only covering OECD 30 member counties but also covering nearly 10 years since the dawn of broadband, the year 2000. In particular, the diffusion of three broadband technologies are formulated and estimated individually, while Lee and Brown [2008], for example, categorized broadband services by speed such as low, medium, and high speed. The approach of this paper is much suitable to analyze the reality.

Since previous studies covered the period before FTTx services emerged, thus their conclusions do not necessarily reflect the current situation. It is generally agree that the success of DSL diffusion is due to open access obligations or local loop

unbundling, which allowed new entrants enter into the DSL market and competition among DSL operators pushed DSL services to diffuse. In case of FTTx, on the other hand, most of OECD countries did not admit unbundling of FTTx networks. This implies the slow FTTx diffusion is due to this policy. This cannot explain rapid growth of FTTx in Japan and Korea, since two countries maintain the unbundling policy for FTTx. This paper explains this Japanese and Korean miracle of FTTx by managerial strategy of incumbent carriers such as NTT locals and KT investing in optical fiber networks. This factor was often mentioned by Atkinson, Noam, and Schultz [2010], for example, but it is not fully verified by data or by empirical analysis. The symbolic factor is the termination of the copper lines that made above carriers to invest heavily in FTTx. An alternative proxy variable to carriers' enthusiastic attitude toward FTTx is related to whether DSL diffusion passed its peak or not in each member countries. If a member country experienced the peak of DSL, then carriers won't invest more in DSL but in FTTx. The idea behind this is that if the DSL diffusion already passed its peak, carriers have to concentrate their business activities and resources on FTTx, which is only remaining business opportunity, and accordingly this accelerates investment in FTTx.

There are other methodological developments required for future study. The methodology of this paper is to prove hypotheses we already postulated, which is due to the limitation of data. With more data, data mining approaches can be applicable to find hypothesis, for example. Since FTTx is ongoing phenomena, it seems to be difficult to establish hypothesis which coincide with the realty. Then data mining is another possible approach. Many of previous studies analyzed the diffusion from the demand side. Although this paper can incorporate the supply side into the model, more rigorous approach to combine these two approaches.

**NOTES**

1) CATV (BB) is also referred to as cable modem.

2) Household diffusion rates are calculated by the following formula:

Household penetration = (number of residential and business users)/total number of households

3) One example is wholesale which is termed by bit stream. Dominant operators sold

DSL modem with their standards, for example, speed of DSL were set and limited by them in wholesale, and it is said that bit stream was an obstacle for DSL diffusion in some countries. See OFCOM [2007] (2.24, 5.8, etc) and Shinohara, Sakaibara and Tsuji [2010a].

4) Open access obligations are also termed by local loop unbundling (LLU) and its contents are different to authors. Lee and Brown [2008] referred to full unbundling, line sharing, bit stream, and regulation for rental line charges.
5) It is also referred to as intermodal competition or platform competition.
6) This is due to bit stream, as mentioned earlier. .
7) NTT East and East have been investing annually about more than 300billion JPY (US$375million) in networks and equipment related to FTTx, which was more than 15% of total investment. Other competitors could not afford to invest heavily in FTTx like NTT.
8) The coefficient of the cross term is 0.08 and this seems to be low, but other initial conditions such as the CATV homepass diffusion rate may influence. In this estimation, due to multicolleanirity, the latter is not used for an explanatory variable.

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