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Analysis of Broadband Services Diffusion in OECD 30 Countries: Focusing on Open Access Obligations

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Abstract

Deployment of broadband for everyone has become a major policy objective in many countries, including Japan and the U.S. Recently, the U.S. announced a National Broadband Plan which is 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. First, considering the ratios by broadband technologies, we categorize major countries into "CATV (BB) type," "DSL type" and "FTTx type." Then, the paper postulates the following four hypotheses by an international comparison method: (1) initial conditions of Cable TV around year 2000 promote CATV (BB) diffusion; (2) open access obligations on copper subscriber lines affect DSL diffusion; and (3) relative connection speed of FTTx to DSL and (4) business strategy of operator for investment in FTTx influence FTTx diffusion. Finally, the paper empirically proves the above hypotheses by 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.

Keywords: OECD, Broadband, FTTx, DSL, CATV (BB), open access obligations, unbundling, collocation; panel data analysis, instrumental variable method

* The views expressed in this paper represent the personal opinions of the author. They do not necessarily represent the views of KDDI Group.

1. INTRODUCTION

Promoting rapid nationwide deployment of broadband services (CATV (BB)[1)], DSL and FTTx) has become an important agenda item for many countries, including Japan and the U.S. The former has implemented a scheme aimed at providing broadband connections to every household by 2015, while the latter is pressing ahead with a National Broadband Plan, the objective of which is to provide 100Mbps broadband services to 100 million households. 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.

How new products expand their diffusion into markets has been extensively studied by Bass [1969], Vijay, Eitan and Bass [1990], and Atkinson, Bob, Noam, and Schultz [2010], and the patterns of diffusion have been found to be affected by factors such as initial conditions, 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. This paper, therefore, attempts to identify possible factors affecting broadband diffusion in OECD 30 member countries. In so doing, it categorizes these countries into three types and analyzes the influencing factors by comparing these types.

We used the following methodology for this paper: OECD 30 member countries were classified into three categories: CATV (BB), DSL and FTTx type. For each type, we postulate hypotheses on diffusion factors 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 rigorous empirical method such as panel data methods with instrumental variables. Thus the diffusion processes for these three broadband technologies were empirically analyzed by separately 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 verify 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 [2006], Akematsu [2008a], [2008b], and Akematsu and Tsuji [2007] 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.

In contrast, this paper comprehensively analyzes three broadband technologies in OECD 30 member countries. This paper firstly classifies those countries into three different categories, 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. Data covers the number of subscriber, price, speed, market share of each operator, open access obligations upon subscriber lines, in each OECD 30 member countries in three broadband technologies. Fiona [2009] analyzes diffusion patterns since 2006 but does not address the transitions that have taken place since around 2000; neither does it contain a factor analysis by the three technologies.

In the next chapter, as preparing for the hypotheses of factors affecting broadband services diffusion, this paper classify OECD 30 member countries into "CATV(BB) type," "DSL type" and "FTTx type" countries to make analysis easily.

3. INTERNATIONAL CATEGORIZATION OF BROADBAND SERVICES

In the first decade of the 21st century, broadband provision has developed at a staggering rate, and now boasts three different technological types: CATV (BB), DSL, and FTTx. DSL uses pre-laid metal subscriber lines, while, FTTx uses fiber optic subscriber lines, which are currently being laid. Therefore, it is difficult to identify general diffusion factors such as government policies and business strategies of operators by examining only one country.

Accordingly, as we use OECD 30 member countries, market shares by broadband technology in those countries are shown in Figure 1.

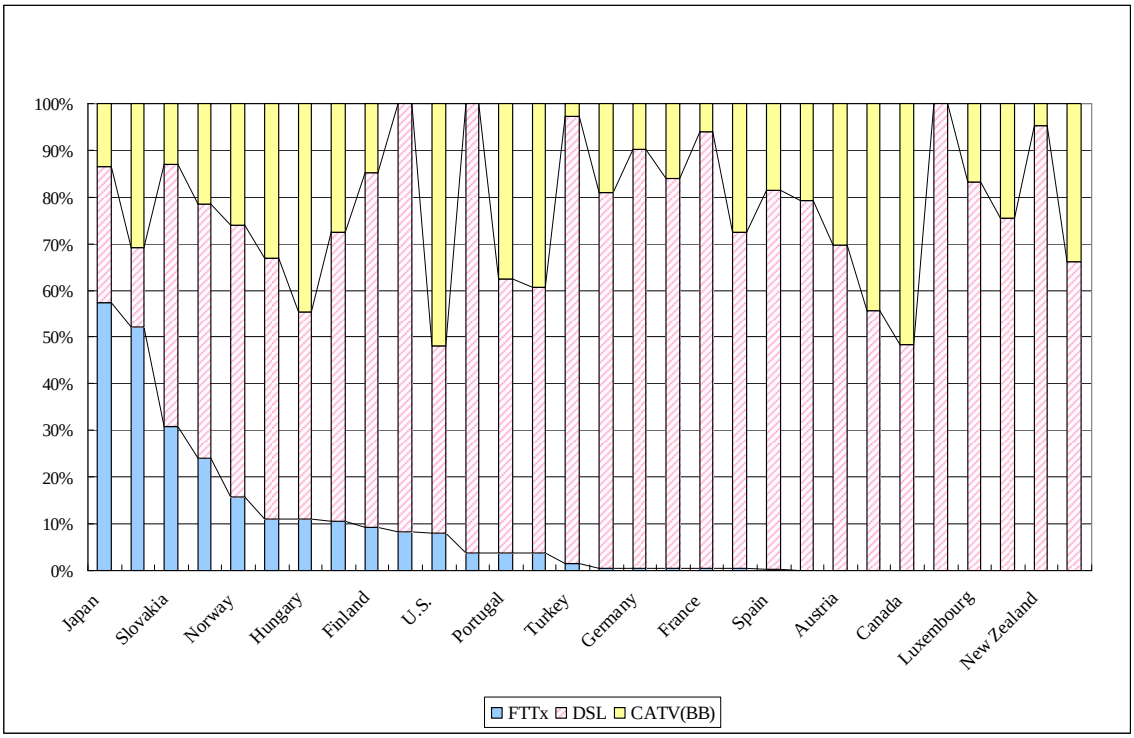

Figure 1: Broadband market share by technology in each country (2010 Q2)
Source: National Regulatory Authorities and operators

Countries with high proportions than average of CATV (BB) diffusion, such as the U.S. and the Netherlands, are classified as “CATV (BB) type,” while France, Germany and other European countries where DSL is high proportions than average are classified as “DSL type,” as described in Table 1. Countries where FTTx is high proportions than average, such as Korea and Japan, are classified as “FTTx type.”

In the following chapter, we analyze the features of the above-mentioned types

and raise their diffusion factors as hypotheses by international comparison method.

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. FEATURES AND HYPOTHESES OF FACTORS AFFECTING PROMOTION OF EACH BROADBAND SERVICE

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 open access obligations and raise up 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)].

Due to the technical reason, open access obligations upon CATV (BB) subscriber

lines did not works well and accordingly did not affect CATV (BB) services diffusion.

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

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 Unit: %

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 subscriber lines for the Internet. 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 technology. CATV (BB) subsequently had an influence on both DSL and FTTx diffusion.

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 (broadcast) household diffusion rates. The consolidation of CATV operators in the U.S. and the Netherlands occurred around 2000.

Table 3: CATV home passed household diffusion rates

(ratio of home passed to all households)

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 Unit: %

Table 4: CATV (broadcast) household diffusion rates

(ratio of subscribers to households)

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 Unit: %

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. These discussions postulate the hypothesis related to CATV (BB) as follows:

Hypothesis I: CATV (BB) was promoted by initial conditions

4.2. DSL Diffusion

4.2.1. Features of DSL

To provide DSL services, telecommunications operators use pre-laid copper local loops owned by dominant telecommunications operator. As phone call services use same copper subscriber lines, those lines have already laid in nationwide in OECD member countries. On the other side, dominant telecommunications operator provides traditional services such as analogue phone, ISDN, leased circuits and so on and earns related revenue. DSL allows subscribers to use no less convenient and inexpensive than traditional services mentioned above. Thus, dominant telecommunications operator often is reluctant to provide DSL services, because providing DSL result in losing their current revenue.

As for DSL, open access obligations on copper subscriber lines works well, because from the viewpoint of technical reason it allows competitors to provide fully competitive DSL services against dominant operator and from the viewpoint of service area copper subscriber lines had laid in nationwide in OECD member countries for phone call. Obligations include unbundling, collocation and the setting of access charges by regulators. Even if dominant telecommunications operator is reluctant to provide DSL for its subscriber, once open access obligations were implemented, dominant operator has to jump into DSL. If not, competitors take all of the DSL market.

4.2.2. Hypotheses of Factors Affecting DSL Diffusion

Figure 2 indicates the relationship of DSL household diffusion rates and open access obligations in OECD measure countries. We can easily find out that after open access obligation were implemented in mainly around 2000, DSL household diffusion rates grew up.

As for New Zealand, household diffusion rates grew up slowly than other countries before implementation of open access obligation in 2003, and the rates grew up rapidly after 2004. As for UK, although open access obligation were implemented in 2000, charges of unbundling were high and other way than unbundling were prevailed,[2)] the household diffusion rates grew up slowly before 2003, and then the charge of unbundling were reduced down to about -70% than before unbundling became effective and the household diffusion rates grew up rapidly.

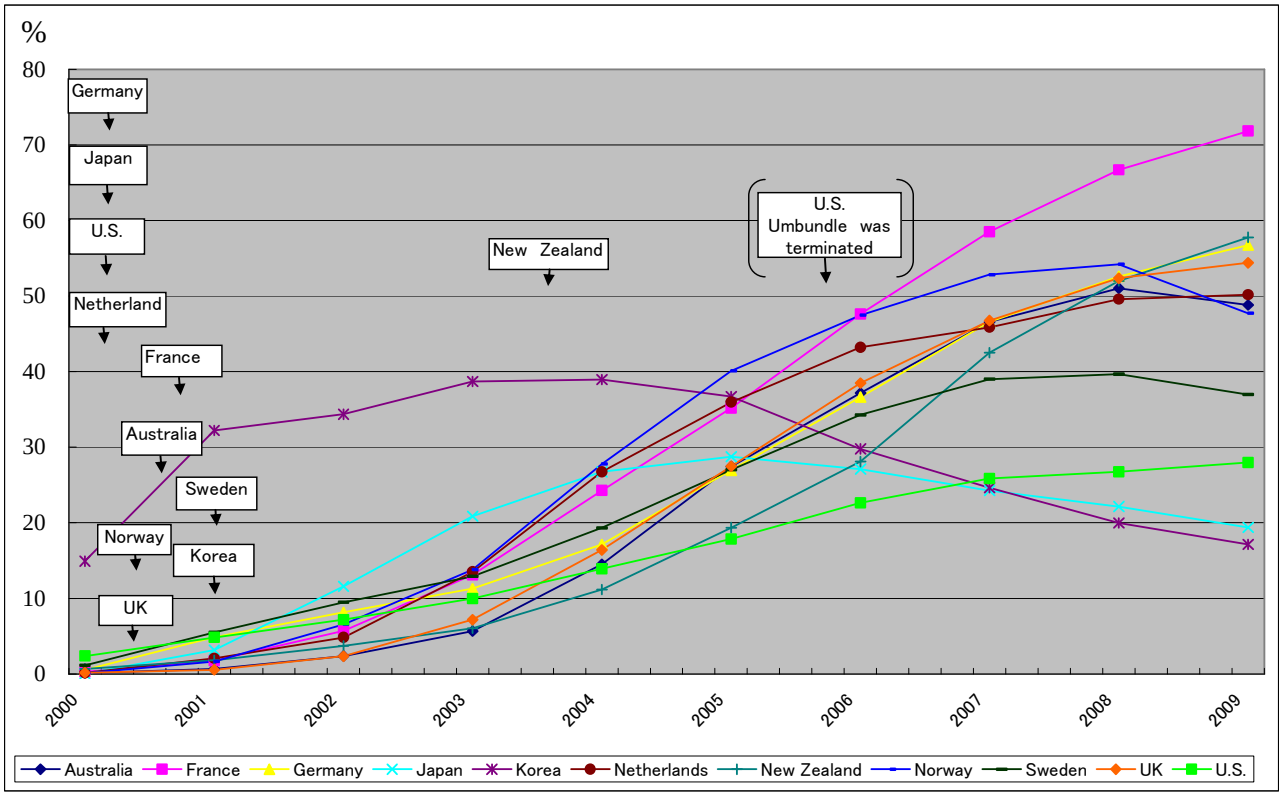

Figure 2: DSL Household diffusion rates and unbundling

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

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 II: DSL diffusion was promoted by deregulations such as unbundling

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 estimation.

4.3.1. Features of FTTx: Japan

4.3.1.1 FTTx diffusion and DSL peak-out

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.

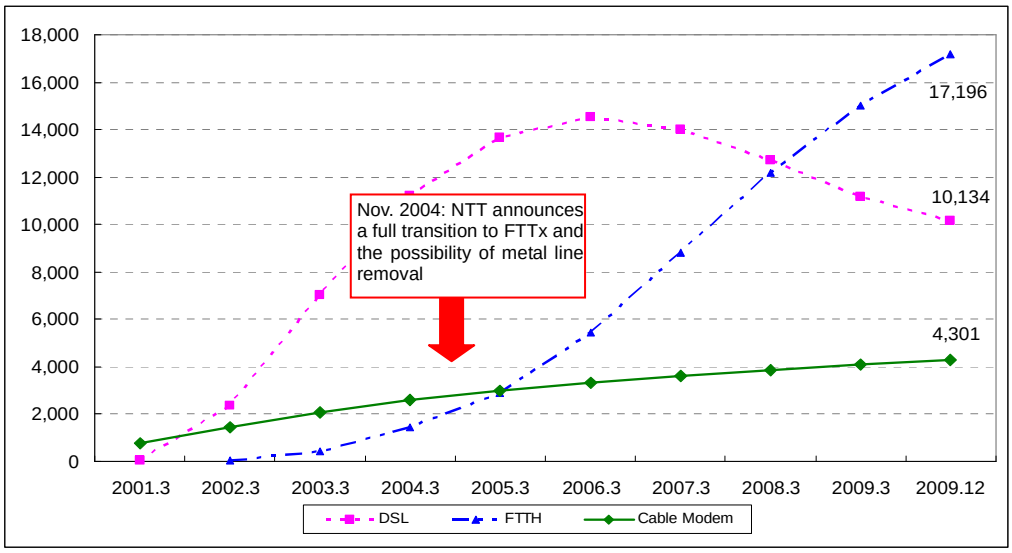

Figure 3: The number of broadband subscribers in Japan

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

4.3.1.2. Government 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.

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.

4.3.1.3. FTTx competition

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.

4.3.1.4. Business strategies

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 (broadcast) 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

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. Unit: %

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

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. Unit: %

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

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. Unit: %

4.3.2. Features of FTTx: Korea

4.3.2.1. 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.

4.3.2.2. Development of DSL and FTTx diffusion

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.

4.3.3. 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 III: faster relative speed of FTTx to DSL promoted FTTx diffusion.

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

In what follows, we attempt to prove the above hypotheses.

5. ESTIMATION OF HYPOTHESES

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.

The following three equations of the technologies are estimated, namely FTTx, DSL and CATV:

(1)

$$FTTx = \beta_0 + \beta_1 Price^{FTTx} + \beta_2 Price^{DSL} + \beta_3 Price^{CATV} + \beta_4 Speed^{FTTx} + \beta_5 (Speed^{DSL} / Speed^{FTTx}) * (FTTx\ type\ country) * (Year\ after\ 2009\ dummy) + \beta_6 (investment\ decision) + \beta_7 (Year\ dummy\ 2004-2009) + u$$

(2)

$$DSL = \beta_0 + \beta_1 Price^{DSL} + \beta_2 Price^{CATV} + \beta_3 Price^{FTTx} + \beta_4 Speed^{DSL} + \beta_5 (Unbundling) * (DSL\ type\ country) + \beta_6 (Year\ dummy\ 2004-2009) + u$$

(3)

$$CATV = \beta_0 + \beta_1 Price^{CATV} + \beta_2 Price^{FTTx} + \beta_3 Price^{DSL} + \beta_4 Speed^{CATV} + \beta_5 (CableTV) * (CATV\,(BB)\ type\ country) + \beta_6 (Year\ dummy\ 2004-2009) + u$$

where $Price^{FTTx}$, $Price^{DSL}$, $Price^{CATV}$, $Speed^{FTTx}$, $Speed^{DSL}$, *and* $Speed^{CATV}$ stand for prices and speed of each technology, respectively. In these equations, the hypotheses we aim to verify are introduced in the following way:

(i) FTTx model (1) and Hypothesis III and Hypothesis IV: the cross term of the relative connection speed between FTTx and DSL indicated as (DSL/FTTx) and FTTx type countries (dummy) represents Hypothesis I in the FTTx type countries. If the coefficient of the cross term is negative, then in those countries subscribers switch 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 IV, 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;

(ii) DSL model (2) and Hypothesis II: unbundling is a specific characteristic of DSL diffusion, and Hypothesis II 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 including of unbundling.

(iii) CATV model (3) and Hypothesis I: Hypothesis I 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.

5.2. Result of estimation

As price variables are endogenous, we utilized instrumental variables in panel estimations 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 X, all three models cleared the Sargan's 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.

According to the result of estimation, 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 ($p<0.05$) which is inelastic, and the cross elasticity with respect to FTTx 0.39 ($p<0.05$) which is also inelastic. Those of CATV are, however, not significant for both elasticity. Therefore, these results present that FTTx and DSL are substitutes each other as for their prices, but there are no relationships between these two technologies and CATV.

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 half as much as former two. These results imply that the faster the connection speed of each technology, the more it promoted the diffusion.

Let us discuss the results related to the hypotheses, that is, the factors promoting each technology. 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 verifis Hypothesis IV.

Next, the result of the DSL model 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 II is verified.

Finally, 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 condition such as the number of Cable TV subscribers in 2000 is important for the CATV diffusion. Although the coefficient of the cross term (0.08) is low, there are other initial conditions such as the CATV homepass diffusion rate. Such conditions will be examined in the next study. Thus Hypothesis I is proved.

Table 8:Result of estimation

	(1) FTTx	(2) DSL	(3) CATV
Price (FTTx)	**-6.394*** [2.019]**	**0.385** [0.172]**	0.017 [0.113]
Price (DSL)	**1.189* [0.689]**	**-0.951** [0.419]**	-0.043 [0.116]
Price (CATV)	**1.611** [0.763]**	0.143 [0.208]	0.137 [0.339]
Speed (FTTx)	**0.414* [0.240]**		
Speed (DSL)		**0.537*** [0.050]**	
Speed (CATV)			**0.281*** [0.021]**
Cross term (FTTx type country * relative speed (DSL/FTTx: after '09))	**-0.668*** [0.238]**		
Carriers' investment decision on FTTx investment (2004 Q4 for Japan and 2006 Q4 for Korea, for example)	**1.634** [0.689]**		
Cross term (DSL type country * unbundling (dry copper))		**0.901*** [0.212]**	
Cross term (CATV(BB) type country * No. of Cable TV subscribers (in 2000))			**0.080*** [0.017]**
Constant		14.338*** [1.026]	11.467*** [1.131]
Observations	236	327	289
Number of countries	19	20	19
Chi-squared	66.47***	163.9***	261.68***
Overidentification restrictions (Hansen's J statistic)	0.57	0.00	0.00
(P-value)	0.451	1	1

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

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.

6. CONCLUSION

The objective of this paper is to verify the hypotheses which are postulated by international comparison of data of OECD 30 countries based on Shinohara, Sakaibara and Tsuji [2010a], [2010b]., and according to rigorous panel data method, the factors related to CATV and DSL are extracted such as initial conditions of Cable TV and deregulation, respectively. These are common to 30 OECD member countries. As for FTTX, however, is rather difficult to obtain common reasons its diffusion due to data availability. It is extremely difficult to collect the same data in all member countries. This limits the analysis. Although carriers' positive attitude towards investment in the optical fiber networks is admitted as an important factor[4)], it is difficult to collect such data for all countries.

An alternative variable is whether DSL diffusion passed its peak or not in each member countries. If a member country experienced the peak of DSL, then carriers wont 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 to FTTx, which is only remaining business opportunity, and accordingly this accelerates investment in FTTx.

There is another methodological development for future study. The methodology of this paper is to prove hypotheses we already postulated, but according to data

collected, we can construct hypothesis using data mining method, for example. Since FTTx is ongoing phenomena, it seems to be difficult to establish hypothesis which coincide with the realty. Then data mining is a possible approach.

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) Wholesale (bit stream). Speed of DSL were set and limited by dominant operator in wholesale. Refer OFCOM [2007] (2.24, 5.8, etc) and Shinohara, Sakaibara and Tsuji [2010a].

4) See Atkinson, Noam, and Schultz [2010], for example.

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