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Economic determinants of optical fiber share in total broadband connections in OECD countries

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ABSTRACT

This study realizes the benefits of optical fiber broadband as an economic stimulation thus it analyzes the determinants of optical fiber share in total broadband connections in OECD countries with the focus on the demand-driven factors and the government roles as the stimulator, the regulator and the investor in the optical fiber sector. It constructs a panel data set using the data during 2012-2014 and estimates the fixed and random effects model with the judgment of the best model by Hausman test. The results reveals that the share of optical fiber behaves well according to the demand theory on the own-price and cross-price effects. Education is a must to support the growth of optical fiber. The government roles differ in their effects, i.e. the role of stimulator and the regulation of local loop unbundling enhance the growth of optical fiber deployment and adoption while the role as the investor negatively impacts the share. Moreover, the study also examines the effects of government roles of regulation regarding to intra-platform competition on the unit price of optical fiber. It discovers that initially the larger number of competitors drives the unit price down by their competition, but later after the establishment of giant incumbent firms in the market and gain sufficient market power and the control over prices such that the number of new comers cannot affect the growing trend of the unit price of the optical fiber broadband.

Keywords: Fixed broadband penetration, fixed broadband share, optical fiber internet, optical fiber share, consumer behavior

JEL Classification: L96, L52, D12

1. Introduction

Broadband becomes a crucial technology for work and life in the digital economy. Many studies on broadband diffusion and adoption confirm that broadband contributes to economic growth (Koutroumpis, 2009; Qiang and Rossotto, 2009), macroeconomic productivity and enhanced innovations which lead to positive impact of employment (Katz, 2010). Besides, Federal communications commission (2010) states that broadband network is changing how we educate children, deliver health care, manage energy, ensure public safety, engage government, access, organize and disseminate knowledge.

Fixed broadband especially optical fiber empowers people around the world to access high-speed internet. FTTH Council Europe (2014) mentions that Fiber-optic to the Home (FTTH) is a shining star for the Next Generation Access (NGA) family which is an excellent platform for ultra-high speed access technology. In the fixed broadband market of OECD countries, the growth of optical fiber platform is growing while the growth of DSL is decreasing.

According to OECD (2013), fixed broadband subscribers by DSL platform is still the largest group although the growth becomes steady from 2011 to 2014 (Figure 1). The second largest group belongs to cable platform with a quite constant growth. The subscribers of optical fiber is the smallest group but at the fastest growth.

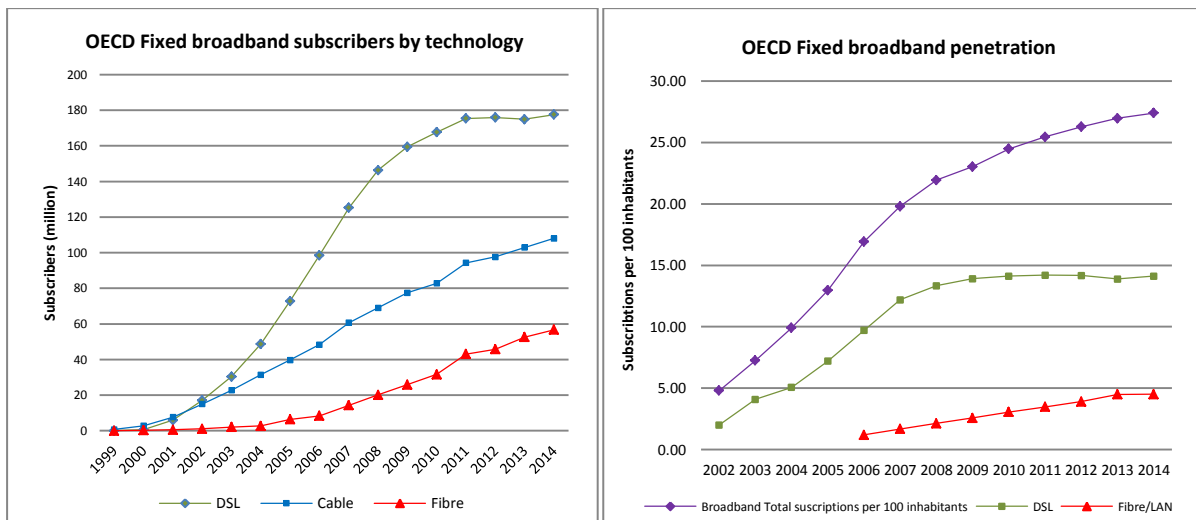


Figure 1: OECD Fixed broadband subscribers by technology

Figure 2: OECD Fixed broadband penetration

Fixed broadband penetration in OECD almost reaches 30 per cent in 2014 (Figure 2). The penetration of DSL platform approaches around 15 per cent while that of optical fiber stays around 5 per cent in the same year.

This study focuses on factors influencing the share of optical fiber in total broadband subscription. It mainly analyses the driving factors of choosing optical fiber among those who have demand for fixed broadband. This is to examine the driving factors that do not depend on the supply-side. The driven demand will eventually be the incentive for operators or investors to build up the supply to serve the emerging demand.

2. Previous studies on broadband diffusion

In previous literature, common factors that influence broadband diffusion mainly consist of price, GDP per capita (PPP), education and population density. Kyriakidou, Michalakelis and Spicopoulos (2013) take these factors into their study but only the population density is significant. Other significant variables in the study includes e-government-online availability, persons employed using computer connected to internet, individuals' level of internet skill, and communications expenditure as a percentage of GDP.

Lee, Marcu, and Lee (2011) analyze the factors that drive the diffusion of fixed broadband in 30 OECD countries during 2000-2008. They select variables categorized into the demand drive, the supply drive and the policy variable. The results show that GDP per capita, education, broadband price, population density are significant. More importantly, they add another policy variable, the unbundling local loop as a percentage of main lines, into the model and discover that it increases the fixed broadband diffusion. Another interesting point is that they find that the platform competition is insignificant to the diffusion.

Local loop unbundling and competition are key policy variables in many studies. Garcia-Murillo (2005) discovers that unbundling in incumbent's infrastructure raises broadband deployment in middle-income countries but not for high-income ones. Grosso (2006) illustrates that competition, income, and unbundling can increase broadband diffusion.

Several studies support that platform competition determines the diffusion. Distaso et al (2006) study 14 European countries during 2000-2004 and discover that inter-platform competition, e.g. fixed and mobile broadband, influence the broadband competition. However, digging to the details in the DSL market, it does not play a significant role. Lee and Marcu (2007) also find that platform competition affects the cable modem diffusion but not the DSL diffusion.

Gruber & Koutroumpis (2012) study 167 broadband network markets and reveal that inter-platform competition does not influence the broadband diffusion. However, this study focuses on broadband access in general. It is still possible that intra-platform competition, e.g. optical fiber and DSL platform of the fixed broadband, may determine high speed access networks, or Next Generation Access (NGAs) but it needs more empirical work to confirm this hypothesis. The insignificance found in their studies may be because the pooled data from 167 countries whose characteristics are diversified. Alternatively, when a study concerns just the inter-platform competition in OECD countries it may find different results since the OECD member countries do not differ much from one another.

While the literature emphasizes on the diffusion of fixed broadband, there are limited number of studies on the diffusion of optical fiber's diffusion. A major work is of Tsuji, Shinohara, and Akematsu (2012) which provides an empirical analysis of factors promoting broadband deployment in OECD countries. The outstanding point of view of this study is at the classification of technologies, i.e. DSL, FTTx, and CATV, such that previous studies do not dig into such the details. The study discovers that higher connection-speed, unbundling of the local loop, and the management strategy of operators all contribute to FTTH diffusion.

3. Government roles

OECD (2008) defines 3 roles of government related to fiber-based networks; the stimulator, the regulator and the investor. For being a stimulator, the government can reduce the price of its own utilities such that telecommunications operators can reduce their costs in the construction of their networks through government-owned utilities. Then the connection cost of optical fiber to new multi-dwelling unit can drop to meet the purchasing power of dwellers. The government can also stimulate the adoption on the demand-side by bundling the public and private demand for telecommunication networks and bargain the connection cost with the operators. However, this kind of bundling must ensure that there is no monopoly power of a dominant operator over the others. Besides, the government can be an initial customer to a newly launched network and be the first to absorb the high cost of operation. Consequently, it prevents the next customers to pay too expensive for the use of the network. Moreover, the more operators use this network, the less service charge paid by the customers due to the economies of scale.

For being a regulator, the government has to ensure fair competition among operators and also among the networks. It is natural that the first mover in the industry takes the advantage of the network and market share. The regulator needs to find a way to balance the market power of the incumbent firm and the new comers. A way to achieve this is to allocate telecommunications resources to assist the smaller firms to survive and grow. Differentiated sets of regulation may be another way to apply to the dominant and small firms. A policy of reducing barriers to access wholesale broadband such as local loop unbundling may also help new entrants to enter the industry at a reasonable cost.

For being an investor, the government has many channels to invest into telecommunications industry. First, it invests by itself into the construction of the networks. Second, it may establish a state enterprise to be an operator in the industry and fulfill the gaps of the networked coverage in remote areas. Third, it can support a firm in terms of joint-venture for the network construction.

4. Share of optical fiber in fixed broadband

This study aims at analyzing the determinants of the share of optical fiber connections in total broadband subscription. The idea is that a country should have a growing share of optical fiber to enhance the speed of internet connection of people and enterprises. However, optical fiber is more expensive than DSL and other traditional platforms. Therefore, the subscription may be limited to a specific group of users. However to promote the optical-fiber broadband in a country, the government should have a clear picture of how the optical fiber grows and how to make it grow further. Thus, the research question is what the determinants of the diffusion of optical fiber are.

It should be noted that the study of the share of optical fiber in total fixed broadband subscription is an inter-platform analysis, i.e. the comparison between optical fiber and other platforms. It focuses on people and enterprises that are customers of fixed broadband and already make decision to use fixed broadband, just make another decision whether to use optical fiber or other platforms. Thus, it needs no comparison between fixed and mobile broadband. It also needs not to include factors related to mobile broadband into the analysis.

For the interpretation of the analysis, it should be also noted that the object of the study is the share of optical fiber over the total fixed broadband. Therefore, an increasing share means that the growth of the optical fiber is higher than that of DSL or other platforms. Besides, the decrease of the share does not mean that the optical fiber shrinks, but the less growth of the optical fiber than that of the other platforms. This relationship is displayed in mathematics as follows:

Definition of the share of fiber connections in total broadband subscriptions:

$$\begin{aligned} & \text{Percentage of fiber connections in total broadband subscriptions} \\ &= \frac{\text{total optical fiber subscription (OF)}}{\text{total broadband subscription (FBB)}} \times 100 \end{aligned}$$

Case I: An increasing share of optical fiber (Comparison between period 1 and 2)

Assigning OF is the subscription of optical fiber
 FBB is the total subscription of fixed broadband
 P is total subscription of other platforms
 $1,2$ is the subscript of the first and second period

$$\begin{aligned} & \frac{OF_2}{FBB_2} > \frac{OF_1}{FBB_1} \\ & \frac{OF_1 + \Delta OF}{OF_1} > \frac{FBB_1 + \Delta FBB}{FBB_1} \\ & 1 + \frac{\Delta OF}{OF_1} > 1 + \frac{\Delta FBB}{FBB_1} \\ & \frac{\Delta OF}{OF_1} > \frac{\Delta FBB}{FBB_1} \\ & \frac{FBB_1}{OF_1} > \frac{\Delta FBB}{\Delta OF} \\ & \frac{FBB_1}{OF_1} > \frac{\Delta OF + \Delta P}{\Delta OF} \\ & \frac{FBB_1}{OF_1} > 1 + \frac{\Delta P}{\Delta OF} \\ & \frac{FBB_1}{OF_1} - 1 > \frac{\Delta P}{\Delta OF} \\ & \frac{FBB_1}{OF_1} - \frac{OF_1}{OF_1} > \frac{\Delta P}{\Delta OF} \\ & \frac{P_1}{OF_1} > \frac{\Delta P}{\Delta OF} \\ & \frac{\Delta OF}{OF_1} > \frac{\Delta P}{P_1} \end{aligned}$$

Case II: A decreasing share of optical fiber (Comparison between period 1 and 2)

It can be referred to the mathematical display in case I that a decreasing share of optical fiber in total fixed broadband can occur when

$$\frac{\Delta OF}{OF_1} < \frac{\Delta P}{P_1}$$

5. Originality and Contribution

5.1 Originality

This study extends the work of Tsuji, Shinohara, & Akematsu (2012) which explain the diffusion of broadband service in 30 OECD countries through 3 key technologies including DSL, FTTx and CATV by prices, speeds of each technology, and competition-concentration indices of inter-platform and intra-platform. However, the paper of Tsuji et al may limit itself to variables on the supply side. To extend the model, this study adds variables on the demand side and government role. The income effect, price effect, substitution effect and educational effect are included on the demand side. The government's role of stimulator, regulator and investor in the broadband sector especially FTTx are also examined in the model.

The originality of this work is at the inclusion of the government role in the regulation of the FTTx sub-sector. It investigates the optimality of the number of operators in the FTTx sub-sector such that it will find whether too many operators in the sub-sector will be harmful or not to the industry. The quadratic form of the model and the new data set on the number of FTTx operators in OECD countries will originally empower this analysis to produce more knowledge to the field.

5.2 Contribution

The results of this paper will shed light on two dimensions. First, it will reveal the behavior of fixed-broadband users in the switching from other broadband technologies to optical fiber, and also the behavior of the new users of FTTx why they choose to use optical fiber rather than other platforms. Second, it will guide the government to play an appropriate role of the stimulation, regulation and investment in the fixed-broadband sector especially the FTTx.

6. Model, Methodology, and Data

There are two sides of the factors that drive the optical fiber share in total fixed broadband connections. First, the demand-driven factor consists of income and education. Second, the supply-driven factors include the price and speed of the internet connections. To form the so-called Almost Ideal Demand (AID) function, the model should include the own price effect, cross price effect and income effect into the model. Moreover, this model also adds the role of government as the stimulator, regulator and investor in the optical fiber sub-sector and expect their effects on the share of optical fiber.

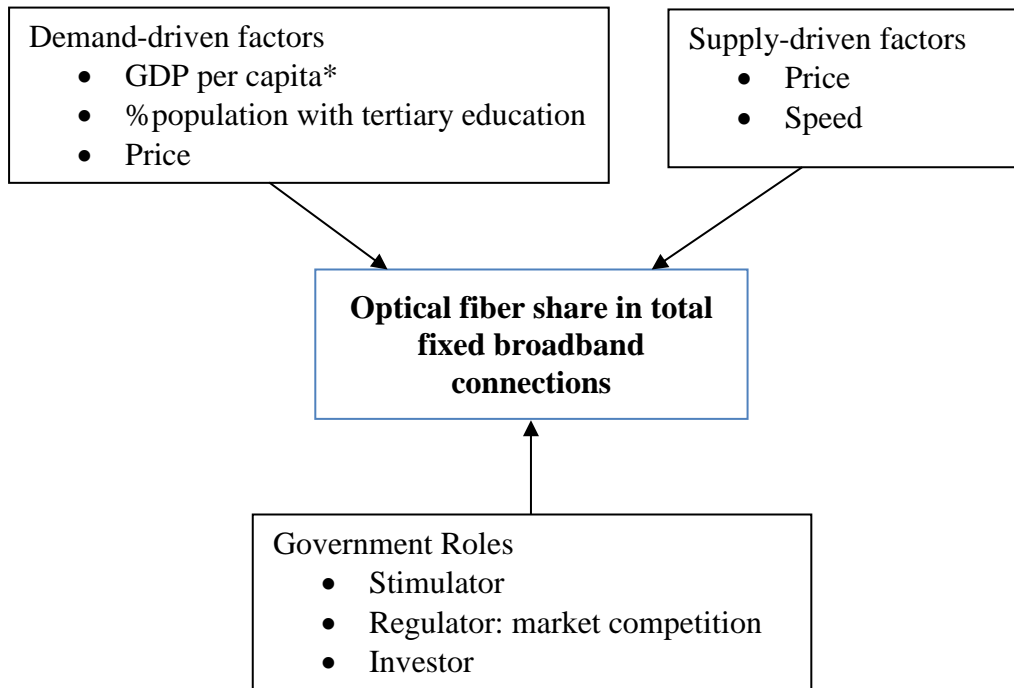


Figure 3: The conceptual framework of the model

The specification of the model can be displayed as follows:

$$OFS = f(INC, OFPM, DSLPM, ED, N, N^2, STIM, LLU, INV)$$

where OFS = Optical fiber share in total fixed broadband connections

INC = Average income of population in the country

$OFPM$ = Optical fiber price per Megabit-second

$DSLPM$ = DSL price per Megabit-second

ED = Percentage of population enrolled in tertiary education

N = Number of firms in fixed broadband sector

N^2 = Number of firms squared

$STIM$ = Dummy variable represents the government role of stimulator

LLU = Local loop unbundling which represents the government role of regulator

INV = Dummy variable represents the government role of investor

Since OECD consists of 33 member countries, the cross-sectional regression may not be suitable for its small number of observations. It may reflect into the insignificance of the variables although they may really affect the share of optical fiber. To avoid this, the study pools the data from 2012 – 2014, 3 years, to construct a panel data set. Total number of observations then reaches 90. However, because of some missing information of variables from some countries, the total observations are 69.

Apparently the methodology to estimate the model is either fixed effects or random effects model. However, the choice of the methodology yet begins from the selection of the country

specific model or time specific model. To justify this, it is important to look at the value of each independent variable. It appears that the variables of government role in each country are the same over time. These are because the governments maintain their roles steadily along the time. They do not change their roles from time to time uncertainly. Thus, the values of these variables are the same in all 3 years which will not reflect the difference of the outcomes in the same country. Therefore, the country specific model may not be suitable to apply.

In contrast, the time specific model analyzes the differences among the government roles of the 33 OECD member countries in a specific time period. Thus, it may yield more interesting results whether the different roles make the differences in the outcomes. Thus, it may be suitable to use the time specific model for the panel data analysis. Moreover, to judge whether the fixed or random effects model is better, the study relies on Hausman test.

6.1 Optical fiber price per Mbps

By demand theory, price affects negatively to the quantity purchased. The data used in the model are prices of packages offered at the maximum speed. However, the speeds of optical fiber broadband in each OECD country differ from one another. Then this analysis measures the unit price in terms of US Dollars per Megabit per second.

6.2 DSL price per Mbps

Since DSL is the majority in fixed broadband service, it is a potential competitor of optical fiber. In the same fashion of the optical fiber's price, DSL packages offered in each country vary in their prices and speeds, thus this model uses the DSL unit price in terms of US Dollars per Megabit per second.

6.3 Income

To represent the income effect, Gross Domestic Product (GDP) per capita measured by the Purchasing Power Parity (PPP) will reflect the income of individuals on average and concern about the purchasing power of people in domestic market.

6.4 Percentage of population with tertiary education

Previous studies on broadband diffusion present the variable of education in many ways, e.g. percentage of GDP spent on education (Koutroumpis, 2009), the UNDP education index which refers to the average years of schooling (Lee, Marcu, & Lee, 2011), and the tertiary graduates in science and technology per 1,000 of population at ages between 20-29 years old (Kyriakidou, Michalakelis, & Sphicopoulos, 2013). Thus, this study represents education by percentage of population with tertiary education. This is because the tertiary education educates people to have skills in the usage of broadband, realize the importance of broadband, and understand the capacity and stability of optical fiber broadband.

6.5 Government role

6.5.1 Stimulator

This study uses a dummy variable to present the government as a stimulator of optical fiber broadband deployment and adoption. The value of the dummy variable is 1 when the government does promote optical fiber deployment, otherwise the value is 0.

6.5.2 Regulator

(1) Competition

This analysis uses the number of FTTx operators (N) to represent the intra-platform competition. It also uses the squared number of the operators (N^2) to investigate the existence of the optimality of the number of operators in FTTx sub-sector.

(2) Local loop unbundling

This is also a dummy variable indicated that the government issue the regulation of local loop unbundling. This dummy variable will be 1 when the local loop unbundling is applied but 0 when this measure is not available in each country.

6.5.3 Investor

The study presents a dummy variable for the role of the government as an investor. The dummy variable takes the value of 1 when the government makes the investment or subsidizes the service provider in optical fiber sub-sector, otherwise it takes the value of 0.

7. Results

The results of the full model face some problems such that the income may be highly correlated with other variables and causes multicollinearity problem. Thus, the income is dropped out by the reason that the differences of individuals' income among OECD countries may not so wide. This justification may not be valid if the study focuses on other countries around the world, but may be acceptable for the OECD which includes the members mainly because of their income levels that meet the standard level of the group.

Moreover, the number of firms and its squares are also dropped out. This is because they are correlated with optical fiber price per Megabit-second. To model their effects alternatively, another regression that presents their effects on the price are conducted. The results of this sub-regression will be shown after the main model.

Therefore, the final model composed of the price effect, cross price effect, government role of stimulator, local loop unbundling and government role of investor. The estimation of this model can be separated into fixed effects model and random effects model as follows:

$$OFS = f(OFPM, DSLPM, ED, N, N^2, STIM, LLU, INV)$$

7.1 Fixed effects model

The result from the fixed effects model shows that the own price effect and cross price effect are consistent to the demand theory. Education and government role of stimulator significantly raise the optical fiber share. The local line unbundling also drives the share. However, the role of government as an investor lessens the share.

7.2 Random effects model

By the random effects model, every variable are as significant as it is in the fixed effects model. However, the coefficients from this model are a little bit larger than that of the previous model. The results from Hausman test reveals that the random effects model is efficient under the null hypothesis. Thus, it is better than the fixed effects model.

Table 1: Determinants of optical fiber share in total fixed broadband connections

<i>OFS</i>	Fixed effect	Random effect
<i>OFPM</i>	-10.42549***	-7.734354**
<i>DSLPM</i>	4.841961**	5.100494**
<i>ED</i>	0.4138339**	0.4097378**
<i>STIM</i>	10.25061***	10.08861***
<i>LLU</i>	9.407726**	10.06158***
<i>INV</i>	-6.557827*	-7.15402*
<i>R-squared: overall</i>	0.3207	0.3273
<i>Number of observations: 69</i>		
<i>Results from the Hausman test: Random effect is better</i>		

Note: *** significance at the 99% level of confidence
 ** significance at the 95% level of confidence
 * significance at the 90% level of confidence

7.3 Effects of government policy on optical fiber unit price

The omission of number of firms and its squares leaves the model lack of information about the optimality of number of firms in fixed broadband sector. This section will find the effects of all the government roles including the role of regulator represented by the number of firms and its squares too. The setting of the model is as follows:

$$OFPM = f(N, N^2, STIM, LLU, INV)$$

The estimation will use both fixed and random effects model again with the judgement suggested by the Hausman test.

7.3.1 Fixed effects model

The results from the fixed effects model shows that the number of firms negatively affects the unit price of optical fiber while its squares positively affect the unit price. This can be seen as a parabolic relationship between the number of firms and the unit price. The function has its minima. It means that by the increase of new comers into the fixed broadband sector, the unit price begins to drop because of the competition among firms. Later it increases along with the number of competitors. This may be because the incumbent firms are big enough to control the market with some monopoly power as a cartel. The sizes of new comers may be smaller and do not affect the incumbents and the market price.

7.3.2 Random effects model

It is again that the result from the random effects model is similar to that of fixed effects model. The coefficients are quite alike but a little bit larger. However, the result from the Hausman test shows that fixed effects model is better.

Table 2: Effects of government roles on optical fiber unit price

<i>OFPM</i>	Fixed effect	Random effect
<i>N</i>	-0.4329317***	-0.5218058***
<i>N</i> ²	0.0444784***	0.0544348***
<i>STIM</i>	1.648134	0.1944922
<i>LLU</i>	-0.0193261	0.0119287
<i>INV</i>	0.0913461	0.07951
<i>R-squared: overall</i>	0.2135	0.2147
<i>Number of observations: 78</i>		
<i>Results from the Hausman test: Fixed effect model is better</i>		

Note: *** significance at the 99% level of confidence
 ** significance at the 95% level of confidence
 * significance at the 90% level of confidence

8. Discussions

The summary of all results from the previous sections suggest that the determinants of optical fiber share in total fixed broadband connections consists of the unit price of optical fiber (negative), unit price of DSL (positive), percentage of population with tertiary education (positive), the government role as a stimulator (positive), local loop unbundling (positive) which represents the government role as a regulator and the government role as investor (negative).

Another impression of the results is that the number of firms in the fixed broadband sector affects the unit price of the optical fiber. The price decreases in the beginning when some operators enter the sector but increases later after the incumbent firms establish market power in the sector while the new entrants are not large enough to impact the drop of the market price.

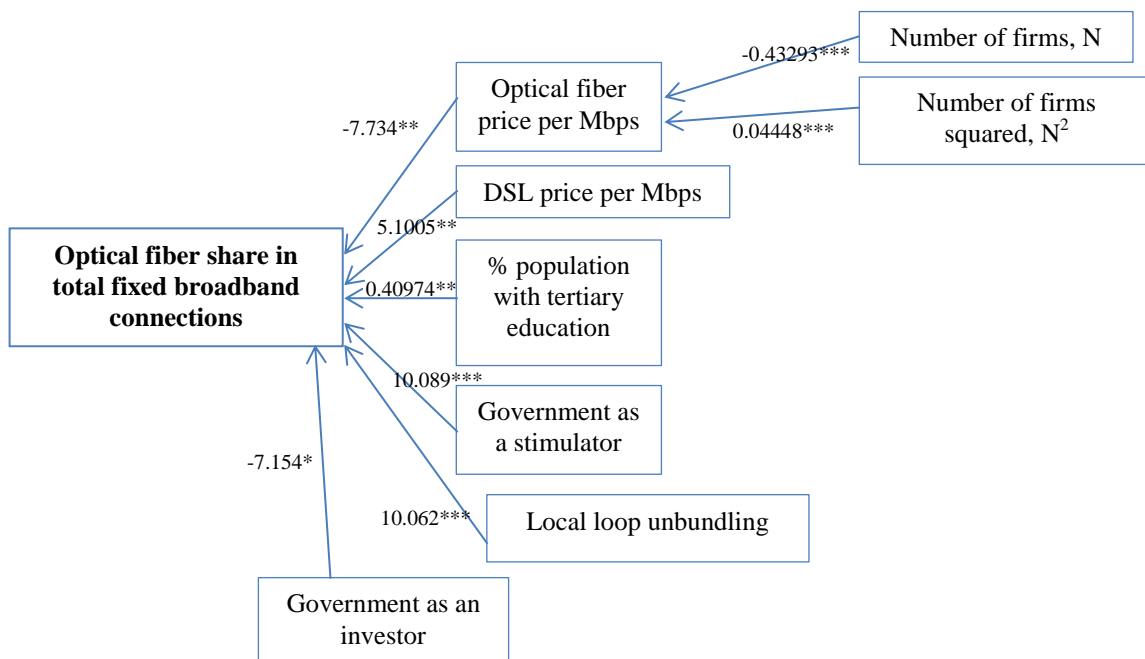


Figure 4: Summary of the determinants of optical fiber share and the optical fiber unit price

Many interesting points arise by these results. First, the significance of the unit price of optical fiber reveals that the customers are aware of the comparison between absolute price and speed of the internet. Once the price rises but along with the higher speed, the customers can accept to use optical fiber more as long as its unit price drops. Second, optical fiber and DSL are clear substitutes. Customers always compare their unit prices and choose the more competitive one. Third, digital literacy gained by tertiary education is a must to make people use the high-speed internet. The education does not only teach people how to use high-speed internet but also make them addict to it. Fourth, the role of government as a stimulator clearly promotes the use of optical fiber.

Fifth, local loop unbundling which represents the role of government as the regulator positively affects the optical fiber share. This result supports the work of Tsuji, Shinohara, & Akematsu (2012). Moreover, it also supports Mitomo (2014) that the local loop unbundling is one of key success factors for the entry into optical fiber market which leads to the growth of the industry. This measure will lead to the open access of the infrastructure such that new entrants can reduce its cost of entry to the industry.

Last, the negative effect on the share of optical fiber in total fixed broadband connections raised by the role of government as an investor may be explained by these following reasons:

- (1) The government invests in the Next Generation Access (NGAs) system that consists of fiber optic as a part of the system. The system uses other broadband technologies too. The target of the provision of NGAs system is at 100 Megabit per second. Many technologies are possible to provide this speed; DSL is a major technology that dominates the provision of the service. Therefore, governments in many countries may find themselves comfortable to use DSL as a major technology for their NGAs system. Consequently, as long as the growth of the optical fiber cannot exceed that of DSL or other platforms, the share of optical fiber drops.
- (2) The government investment may suffer from the inefficiency of state enterprises. When the government initiates the investment in fiber optic while private enterprises invest in DSL platform, then the growth of optical fiber is less than that of DSL.
- (3) The government investment in optical fiber may take effects some years after the investment because of the time lags of people perception and adoption of the optical fiber technology.

However, these explanations are still the new hypotheses that should be answered clearer probably by the series of research works in the future.

9. Conclusion

The digital economy benefits from fixed broadband in terms of economic growth and job creation. The speed of fixed broadband especially fiber-optic to the X (FTTx) surpasses other broadband technologies. It is possible to provide the ultra-high speed internet by the optical fiber network. Its capability and stability in the last mile of the network make its penetration grow at the moment that fixed broadband market is unlikely to grow much further.

This study analyzes the determinants of optical fiber share in total broadband connections in OECD countries. It focuses on the demand-driven factors and the government roles as the stimulator, the regulator and the investor in the optical fiber sector. It uses the data during

2012-2014 to construct a panel data set and then estimate the fixed and random effects model with the judgment of the best model by Hausman test.

The results reveal that the share of optical fiber follows the demand theory such that it rises along with the drop of unit price of optical fiber and the increase of unit price of DSL. Tertiary education plays an important role to produce more educated people who are highly potential to be customers of the optical fiber. The government roles also enhance the growing share of optical fiber; i.e. the role of stimulator and the regulation of local loop unbundling empower the growth of optical fiber deployment and adoption. However, the government role as the investor negatively impacts the share of optical fiber in total broadband connections. The reasons may lie into 3 explanations which are the dominance of DSL in the Next Generation Access (NGA) system, the inefficiency of state enterprises, or the time lags of perception and adoption by individuals for the optical fiber broadband.

Another result from the study is on the effects of government roles on the unit price of optical fiber. The panel data analysis reveals that at the beginning the increasing number of operators forces the unit price to drop due to their competition. Later it seems that the incumbent firms grow to significant sizes that can control the market power and prices. At that stage, the new comers seem to be smaller in sizes and are unable to drive the prices down. Then the unit price of optical fiber broadband rises along with the larger market power of the incumbent firms.

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