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Identifying the determinants of broadband adoption by diffusion stage in OECD countries

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ABSTRACT

Governments worldwide actively promote broadband development, owing to its positive impact on economic growth. Although many studies have identified the determinants of broadband adoption, this study re-examines the determinants by applying Arellano–Bond GMM dynamic panel data estimation with more complete panel data for OECD countries. The estimation can not only closely capture the dynamics of broadband diffusion but also solve an endogeneity problem existing in the estimations of previous studies. The estimation results indicate that content is also a significant factor, in addition to previous broadband penetration and platform competition, as commonly identified in previous studies. This study further examines and compares determinants in different stages segmented by adopter categories proposed by Rogers. The results reveal different determinants in different stages. The key determinants are income, education, and content in the innovator and early adopter stage; platform competition and previous broadband penetration in the early majority stage; and broadband price in the late majority and laggard stage. Governments should thus devise and implement appropriate strategies for the major potential adopters in each stage instead of adopting a one-size-fits-all strategy. The results of this study provide a valuable reference for countries in early stages of broadband development or for those planning or reviewing their strategies.

1. Introduction

Broadband, defined as an always-on Internet access with transmission speeds equaling to or exceeding 256 Kbps for downstream connections and 64 Kbps for upstream connections (OECD, 2001), is currently the most common mode of Internet access. Broadband is widely recognized as a critical enabler of economic activity because it directly or indirectly enhances innovation, productivity, employment, economic growth, and, ultimately, national competitiveness (ITU, 2011a). Therefore, many governments have established ambitious targets, strategies, and measures for facilitating its development (ITU, 2011a; OECD, 2011a). Nevertheless, the 8% global penetration rate for fixed broadband subscriptions in 2010 (ITU, 2011a) reflects that many countries are still in the early development stages, so their governments are actively devising or implementing their policies and strategies to accelerate broadband development.

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Many studies have attempted to identify key factors in broadband adoption in order to provide policy and management guidance for governments or service providers. Early studies were mainly case studies that compared the circumstances among several countries and found the patterns of broadband development (e.g., Aizu, 2002; Frieden, 2005; OECD, 2001; Wu, 2004). Recently, a growing number of empirical studies have examined the factors that explain broadband penetration (e.g., Bauer, Kim, & Wildman, 2003; Bouckaert, Van Dijk, & Verboven, 2010; Cava-Ferreruela & Alabau-Muñoz, 2006; Distaso, Lupi, & Maneti, 2006; Garcia-Murillo, 2005; Lee & Lee, 2010; Trkman, Blazic, & Turk, 2008). These studies have adopted models derived either from supply and demand relationships or from innovation diffusion equations to analyze broadband adoption practices in OECD, EU, or ITU countries via various statistical methods such as cross-sectional OLS regression, factor analysis, and panel regression. Factors that reportedly may affect broadband adoption include previous penetration, platform competition, broadband price, income, population density, education, content, and local loop unbundling (LLU). Although the above studies have provided some insight into broadband development, the common significant factors for the development are not completely the same, probably due to different country-level data, models, statistic methods, or analysis durations adopted in those studies.

As broadband develops to a more mature stage, more panel data and advanced statistic methods are available. Therefore, this study re-examines the determinants mainly identified in previous studies by applying the Arellano–Bond generalized methods of moments (GMM) dynamic panel-data estimation with a more complete period from 1997 to 2009, by using a Gompertz diffusion model. In addition to closely capturing the dynamics of broadband development, the Arellano–Bond GMM estimation solves an endogenous problem[1] (See Wooldridge, 2002). The Arellano–Bond GMM estimation has been used in a study on broadband diffusion in the USA (Denni & Gruber, 2007) and in a cross-country analysis of Internet diffusion (Andres, Cuberes, Diouf, & Serebrisky, 2010), but has not been applied in the cross-country broadband studies surveyed by the authors. Therefore, the estimation results in this study should be more precise than those reported in previous studies.

Moreover, previous studies examined the factors without considering the influence of different adopter attributes in different stages of broadband development, so the determinants are the same in each stage. However, Rogers (2003) proposed that innovation adoption depicts an S-curve when plotted over time. He also accordingly identifies five categories of adopters: innovators, early adopters, early majority, late majority, and laggards. Different adopters have different attributes. Earlier adopters are usually wealthier, more educated, more cosmopolitan, and better at coping with uncertainty and risk than later adopters are. Therefore, different attributes may result in different determinants of broadband adoption in different stages, so the analytical results of previous studies are very probably less precise than previously thought.

This study also segments the diffusion process into three stages according to adopter categories proposed by Rogers. The objective is to examine the determinants of broadband development in different stages based on data for OECD countries in the years 1997–2009. This study focuses on OECD countries because their data are more readily available and because they have a much higher broadband penetration compared with other countries (21.81% in 2009 according to OECD (2011a) versus 7.13% worldwide according to ITU (2011b)). Instead of being the same for the overall diffusion, the determinants identified in each stage may provide valuable insights and implications for developing countries, especially for those in which broadband development is still in the early stages.

The rest of this paper is organized as follows. Section 2 presents related studies and the theoretical context of the study. Section 3 then describes the research method used for the empirical analysis. Section 4 discusses the analysis results and their implications. Conclusions are finally drawn in Section 5, along with recommendations for future research.

2. Related studies and theoretical context

2.1. Related cross-country empirical studies

Mainly due to data limitation, most early studies performed multivariate Ordinary Least Square (OLS) regression analyses with data for one or several time series. Various determinants have been reported, but few conclusive common factors have been identified. An analysis of 2001 broadband data for OECD countries in Kim, Bauer, and Wildman (2003) showed that national preparedness and population density are the key factors in broadband development. In another study based on data 2000 to 2002 for OECD countries, Cava-Ferreruela and Alabau-Muñoz (2006) suggested that technological competition and the low cost of deploying infrastructures are the key factors for broadband development. Additionally, in an analysis of 2001 data for ITU countries, Garcia-Murillo (2005) showed that GDP per capita, population density, broadband price, competition, Internet access, and Internet content have positive effects on broadband subscription. Finally, in analysis of data for ITU countries for the years 2002–2005, Lee and Brown (2008) showed that platform competition, LLU, broadband speed, information and communication technology use, and Internet content contribute to broadband adoption.

[1] The endogenous problem occurs because the lagged dependent variable is included as one of the independent variables in a panel regression model to capture the effect of previous broadband penetration. Due to the correlation between the independent variable and the error term of the regression in some periods, the strict exogeneity assumption fail to hold, so the standard panel estimation (e.g., fixed effect estimation) is not consistent (See Wooldridge, 2002).

However, the above studies obtained their results mainly by cross-sectional estimation, which may be biased by unobserved heterogeneity and which may not reveal the dynamics of broadband diffusion (see Wooldridge, 2002). More time series data was available as broadband further developed. Thus, recent studies have begun to apply panel regression models. Determinants commonly identified in these models include platform competition and previous broadband penetration. Distaso et al. (2006) used panel regressions with fixed effects, random effects, and instrumental variables based on 2000–2004 data for EU countries and showed that platform competition and LLU price affect broadband adoption. However, competition in the DSL market revealed no significant role. Bouckaert et al. (2010) adopted a panel regression with random effect based on 2003–2008 data for OECD countries, and found that inter-platform competition is a key driver of broadband penetration. Their regression analysis also showed that per capita GDP, population density, and previous broadband penetration also influence broadband penetration. Finally, Lee and Lee (2010) applied a Gompertz diffusion model and a panel regression based on 2000–2007 for OECD countries and showed that fixed and mobile network competition (platform competition), Internet access, and network effect (the penetration of previous year) are the significant factors.

Although recent studies applying panel regressions may provide better results than the earlier studies only applying cross-sectional estimations, their estimation may be not statistically consistent because they ignored the endogeneity problem caused by the lagged value of the dependent variable (see Wooldridge, 2002), which is the previous penetration. An instrumental variables procedure proposed by Arellano and Bond (1991) avoids this problem by using the lagged values of the dependent variable as instruments. Based on a panel data of 214 countries during the years 1990–2004, Andres et al. (2010) adopted this method in a Gompertz diffusion model to examine factors affecting Internet diffusion. Their estimation results indicated that previous penetration and competition are the determinants. Additionally, Denni and Gruber (2007) also applied this method in a logistic diffusion model to analyze the USA data for broadband diffusion in the years 1999–2004 and found that both intra- and inter-platform competition contribute to broadband diffusion, but the latter is a much more important driver of the diffusion rate. Nevertheless, the Arellano–Bond GMM estimation was not applied in the cross-country broadband studies surveyed by the authors. Therefore, this study applies this estimation method to re-examine the determinants of broadband adoption in OECD countries with a more complete panel data from 1997 to 2009.

2.2. Adopter attributes and appropriate policies in different diffusion stages

Although broadband is widely recognized as a critical enabler of economic activity, precisely understanding why broadband adoption tends to have an inconsistent diffusion across countries constitutes a challenging issue for policy-makers (Cambini, Hoernig, & Bohlin, 2012). Cambini et al. (2012) also suggested that precisely identifying the relevant determinants of broadband diffusion and then implementing appropriate policies according to these determinants appears to be an important way for governments to stimulate employment and economic growth. Hence, this study aims to identify these determinants based on Diffusion of Innovations Theory proposed by Rogers (2003).

Potential adopters do not simultaneously accept a new product or service. According to Rogers (2003), innovation adoption depicts a normal distribution over time. By using the mean and standard deviation of this distribution in a segmentation method, Rogers identified five adopter categories: innovators, early adopters, early majority, late majority, and laggards. The main characteristics of each category are as follows:

1. Venturesome and tending to be risk-takers, **innovators** usually belong to the highest social class, as well as have the most financial capacity, closest contact with scientific sources, and the most exposure to mass media communication channels or interpersonal communication channels.
2. Respected and often holding the highest opinion leadership among the adopter categories, **early adopters** are typically less conservative, as well as have a higher social status, financial capacity, or educational level than the later adopters.
3. Deliberate and tending to have above average social status and educational level, **early majority** seldom hold positions of opinion leadership.
4. Skeptical and tending to have below average social status and financial capacity, **late majority** hold very little opinion leadership.
5. Traditional and tending to have the lowest social status, educational level, and financial capacity, **laggards** have the least exposure to mass media communication channels or interpersonal communication channels.

The attributes in the above categories vary widely. Therefore, categorizing adopters is important, because it can help governments or service providers to develop targets for the diffusion of a new product or service, formulate corresponding marketing strategies for each category, and predict the continuous acceptance (Mahajan, Muller, & Srivastava, 1990). More precisely, after categorizing adopters, the factors affecting broadband adoption can be identified based on the categorized adopters, so dedicated and effective targets, strategies, and predictions can be accordingly made.

However, no broadband studies surveyed by the authors have identified the determinants of broadband adoption based on adopter categories; in fact, most studies examined the determinants by a single process. An Internet study by Andres et al. (2010), however, considered and compared two phases of Internet adoption: early and late. Their analysis results indicated that although both income and network effect (the penetration of previous year) are the significant factors, the effect of the former in the early phase is higher than the effect in the late phase, whereas the effect of the latter is lower in the early phase. The distinct effects of income and network effect in different phases are very probably caused by the different adopter attributes in each phase. Nevertheless, Andres et al. (2010) did not address or mention the relationship between adopter attributes and the effects of those determinants.

As for broadband studies, adopting panel regressions based on a new and unique dataset covering 30 OECD countries (Rossi, 2010), Belloc, Nicita, and Alessandra Rossi (2012) revealed that, while both supply- and demand-side policies have a positive effect on wired broadband penetration, their relative impact depends on the actual stage of broadband diffusion—only demand-side policies have a significant positive effect in an advanced stage. Moreover, Inderst and Peitz (2012) applied a standard duopoly model to theoretically explore the interplay of ex-ante and ex-post access contracts as well as access regulation with competition and investment incentives in the context of next generation access network. Both studies implied that implementing the same policies in different diffusion stages or timings may cause different effects or impacts. Consequently, precisely devising appropriate strategies or measures is very important. However, both studies adopted very different research approaches—such as models, variables, or database—from the cross-country empirical studies reviewed in Section 2.1, making it difficult to compare the results of these two studies with those of the previous ones. Furthermore, both studies did not address the effects of policy strategies or measures based on adopter attributes proposed by Rogers (2003).

Therefore, besides using the Arellano–Bond GMM estimation as described in Section 2.1, this study further examines the factors in different stages of broadband diffusion segmented by adopter categories to more precisely identify the determinants of broadband adoption and then propose appropriate policy strategies or measures.

3. Research method

3.1. Empirical model

The Gompertz and logistic models are the most common functional forms used for describing an S-curve of innovation diffusion (Lee & Lee, 2010). This study applies the Gompertz model, because the logistic model estimation has to decide the total number of potential adopters at time t in country i, a number which is hard to estimate if a diffusion is still in early stage or if heterogeneity exists among different countries (Gruber and Verboven, 2001). Unlike the logistic model, the Gompertz model estimation need not directly decide the number because it may assume that the number is a function of demand-side variables and supply-side variables as shown in the following Eq. (2), which is finally merged into the following Eq. (4) for a regression. The Gompertz model has also been widely applied to estimate the diffusion of new communication technologies or services, such as personal computers, Internet access, mobile phones, and broadband access (e.g., Andres et al., 2010; Estache, Manacorda, & Valletti, 2002; Kiiski & Pohjola, 2002; Lee & Lee, 2010; Singh, 2008; Stoneman, 1983; Trappey & Wu, 2008).

In the Gompertz model, the change in the number of adopters from the current period to the next is expressed as a fraction of the gap between the number of adopters in equilibrium and the number of current adopters. Let BP_{it} represent the total number of fixed broadband subscribers per 100 inhabitants in country i in year t, and let BP_i^* be its equilibrium level, or the total number of potential adopters. Therefore, the formula for broadband diffusion in the Gompertz model is:

$$\ln BP_{it} - \ln BP_{it-1} = \alpha_i(\ln BP_i^* - \ln BP_{it-1}) \tag{1}$$

where α_i is the speed of adjustment. Assume that the equilibrium level BP_i^* is a function of demand-side variables (e.g., income level I_{it} and broadband price P_{it}) and supply-side variables. Given that the variables change over time, $\ln BP_i^*$ is assumed to be time-dependent, and can be further expressed as:

$$\ln BP_{it}^* = \beta_{i0} + \beta_{i1}\ln I_{it} + \beta_{i2}\ln P_{it} + \gamma_i' Z_{it} \tag{2}$$

where Z_{it} is the vector of other possible explanatory variables describing the demand and supply conditions in country i in year t. An estimation equation is obtained by inserting Eq. (2) into Eq. (1):

$$\ln BP_{it} = \alpha_i\beta_{i0} + \alpha_i\beta_{i1} - \ln I_{it} + \alpha_i\beta_{i2}\ln P_{it} + \alpha_i\gamma_i' Z_{it} + (1-\alpha_i)\ln BP_{it-1} \tag{3}$$

To run a panel regression, Eq. (3) can be further simplified as follows:

$$\ln BP_{it} = a_0 + \beta_1\ln I_{it} + \beta_2\ln P_{it} + \gamma_3' Z_{it} + B_4\ln BP_{it-1} + \mu_{it} \tag{4}$$

where $\ln BP_{it-1}$ is the log value of total number of broadband subscribers per 100 inhabitants in the previous year; μ_{it} is the error term for the panel regression. Eq. (4) is the empirical model in this study, and its definitions and measurements of variables are described below.

3.2. Variables and data

Table 1 shows the definitions and data sources of the variables in this analysis. The dependent variable is broadband penetration, measured as total fixed broadband subscribers per 100 inhabitants, and the broadband technologies adopted

Table 1
Variable, measurement and data source for the analysis.

Type	Variable	Measurement	Source
Dependent variable	Broadband penetration	Total fixed broadband subscribers per 100 inhabitants	OECD (2011a)
Independent variables	Income	GDP per capita (USD, PPP)	World Bank (2011)
	Education	Gross enrolment ratio in secondary and tertiary level institutions multiplied by 100	UNESCO (2011)
	Broadband price	Monthly fee per Mbps at download speed (USD, PPP)	OECD (2011a, 2011b)
	Platform competition	HHI (Herfindahl-Hirschman Index) for DSL and other broadband platforms	OECD (2011a, 2011b)
	Content	Number of Internet hosts per 1 million people	OECD (2011a)
	Previous broadband penetration	Total fixed broadband subscribers per 100 inhabitants in the previous year	OECD (2011a)

by the subscribers include DSL, cable, fibre, satellite, and fixed wireless (OECD, 2011a). Independent variables include six key factors: income, education, broadband price, platform competition, content, and previous broadband penetration, which are further described in the following subsections.

Chosen mainly from the determinants identified by previous cross-country studies, the variables are measured by using country-level data. Although not the same as the individual-level attribute data in the adopter categories proposed by Rogers (2003), the variable data can still be applied for the analysis. First, this is owing to that the different adopter attributes in each category very probably cause the determinants to differ by diffusion stage, explaining why segmenting the stages of broadband diffusion for analysis is reasonable. Country-level data are applied both to compare the determinants found in this study with the findings of previous studies and to compare the determinants between different stages. Second, this is also owing to that country-level data are calculated based on individual-level data, so they are correlated. For example, a high-income or high-educational level country normally has more individuals with high financial capacity or high educational level; the country thus has more innovators and early adopters. Consequently, broadband development in that country is usually earlier and faster.

3.2.1. Income

Income is a key variable in the Gompertz model in Eq. (4). Garcia-Murillo (2005) and Bouckaert et al. (2010) found income (measured as per capita GDP) has a significant positive effect on broadband diffusion. Kiiski and Pohjola (2002) and Andres et al. (2010) also reported similar results in their studies of Internet diffusion. Moreover, Rogers (2003) identified that different categories of adopters have different financial capacity. To test the effect of income on broadband adoption, particularly the effects in different diffusion stages, this study similarly uses per capita GDP as the measurement, but further converts it by purchasing power parity (PPP) so as to take into account the relative cost of living and the inflation rates among the analyzed countries.

3.2.2. Education

Although several studies (Cava-Ferreruela & Alabau-Muñoz, 2006; Garcia-Murillo, 2005; Lee & Lee, 2010) have included education as an independent variable, none of them has revealed a significant effect of education on broadband adoption. However, Rogers (2003) identified that different adopter categories have different education levels. The above studies did not reveal a significant effect of education probably because they only examined education by a single stage without considering the adopter categories. If education is analyzed stage by stage according to the categories, its effects in different stages may reveal substantial differences. Thus, this study uses gross enrolment ratio in secondary and tertiary level institutions (GERSTLI) as the measurement to further test the effect by stage. A high GERSTLI indicates not only a high education level in a country, but also a high proportion of young inhabitants enrolled in schools. Compared with older population, students tend to be more venturesome and tend to have a higher demand for broadband services because they are more interested in Internet activities such as web browsing, on-line gaming, and social networking. Therefore, a higher GERSTLI very probably brings a higher broadband penetration.

3.2.3. Broadband price

According to economic theory, price is expected to negatively affect adoption, so broadband price is a key variable in the Gompertz model expressed by Eq. (4). However, although previous studies (Garcia-Murillo, 2005; Cava-Ferreruela & Alabau-Muñoz, 2006; Lee & Lee, 2010) have examined broadband price, only Garcia-Murillo (2005) has reported a significant effect on broadband adoption. The above studies did not reveal a conclusive significant effect of broadband price probably because they only examined it by a single stage. This study suggests that the effect differs by diffusion stage due to the differences in financial capacity between adopter categories. Therefore, this study is to further examine the effect by diffusion stage. Broadband price is measured as monthly fee per Mbps (PPP), which is calculated by dividing the monthly DSL service fee by its download speed and PPP (OECD (2011b).

3.2.4. Platform competition

Platform competition is the competition among different broadband technology platforms (that is, DSL, cable, fibre, satellite, and fixed wireless) to attract users. Competition may reduce prices, diversify services, and expand networks (ITU, 2003), and, consequently, increase penetration. Measuring it by Herfindahl–Hirschman Index (HHI), several studies (Bouckaert et al., 2010; Distaso et al., 2006; Lee & Lee, 2010) have agreed that it significantly affects broadband adoption. Likewise, this study applies HHI to test the effect of platform competition, especially in different stages of diffusion. A higher HHI reflects a more asymmetric market structure and implies a lower degree of platform competition. With 58.8% of the total fixed broadband subscribers in 2009, DSL is the main technology in OECD countries (OECD, 2011b). Therefore, this study calculates HHI by the squared DSL market share plus the squared non-DSL market share.

3.2.5. Content

The main motivation for adopting broadband services is to access Internet content. Thus, the inhabitants in a country with richer Internet content are expected to be more willing to subscribe to broadband services. By using the number of Internet hosts as a proxy, Garcia-Murillo (2005) found that content contributes to broadband adoption. Measuring it by Internet hosts per 100 inhabitants, Lee and Brown (2008) also reported a similar result. An Internet host, which is a computer possessing Internet Protocol (IP) address directly connected to the Internet, may provide various content and services, such as website storage and retrieval, email, and IP telephony, so the number of Internet hosts is an appropriate proxy of content. Therefore, this study uses number of Internet hosts per 1 million people as the measurement of content to test its effect.

3.2.6. Previous broadband penetration

Previous broadband penetration ($\ln BP_{it-1}$) is a key variable in Eq. (4), which is derived from the Gompertz model. Previous studies named it as lagged total penetration (Bouckaert et al., 2010) or previous broadband penetration (Lee & Lee, 2010) and explained it in different aspects. The former study suggested that the variable reflects the extent of persistence of the penetration over time, because a higher penetration in the previous time normally causes a higher current penetration. The latter one suggested that the variable captures network effect. Network effect means that the number of users of a good or service has effect on the value of that product or service to the users. In other words, whether consumers adopt a product or service depends on not only its relative characteristics and price, but also on its network size (Church & Gandal, 2005). Therefore, if the effect is apparent in the broadband market, the number of current broadband subscribers affects the adoption decisions of potential broadband subscribers.

Both Bouckaert et al. (2010) and Lee and Lee (2010) found that the penetration in the previous time period significantly and positively affects current broadband penetration. Andres et al. (2010) also reported similar results in the studies of the Internet diffusion. Likewise, this study uses broadband penetration in the previous year as a measurement for the variable. The study also suggests that this variable may contain both effects suggested by previous studies, because network effect may further accelerate the diffusion in addition to the natural persistence.

3.3. Segmenting the stages of broadband diffusion

This study is to explore the determinants of broadband adoption in different stages based on the adopter categories proposed by Rogers. Ziemer (1985) and Mahajan et al. (1990) suggested that the categories can be obtained by examining trends in both the noncumulative adopter distribution, $bp(t)$, and its rate of change, $bp'(t)$. The $bp(t)$ and $bp'(t)$ are derived from the cumulative distribution $BP(t)$, which is the total fixed broadband subscribers per 100 inhabitants in this study.

Table 2 lists the value of $BP(t)$, $bp(t)$, and $bp'(t)$ of OECD countries, which includes 34 countries, while Fig. 1 displays the corresponding curves. The curve of $BP(t)$ closely resembles the S curve proposed by Rogers (2003). According to Ziemer (1985) and Mahajan et al. (1990), before the maximum of $bp'(t)$, with $BP(t)$ at 2.93, most adopters are innovators and early adopters; between the maximum of $bp'(t)$ and the maximum of $bp(t)$, with $BP(t)$ at 13.78, most adopters are early majority; and after the maximum of $bp(t)$, most adopters are late majority and laggards.

Table 2
Segments of broadband diffusion in OECD countries.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
BP(t)	0.01	0.06	0.30	1.21	2.93	4.87	7.28	10.34	13.78	16.79	19.65	21.81	23.10
bp(t)		0.05	0.24	0.91	1.72	1.95	2.41	3.06	3.45	3.00	2.86	2.16	1.29
bp′(t)			0.19	0.67	0.81	0.23	0.46	0.65	0.39	−0.44	−0.14	−0.70	−0.87
Adopters	Innovators and early adopters					Early majority				Late majority and laggards			
Stage	Stage 1					Stage 2				Stage 3			

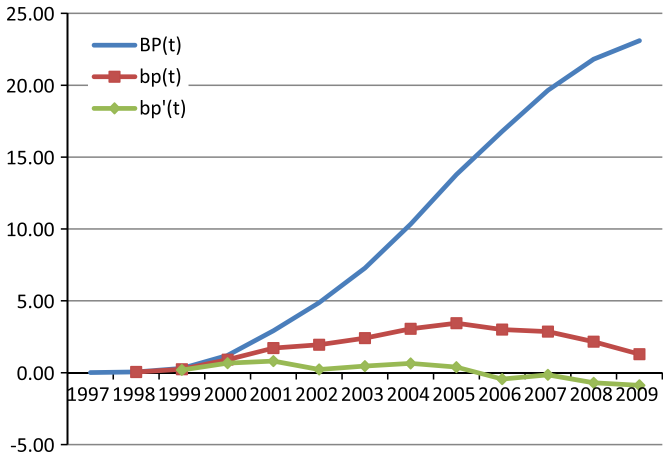

Fig. 1. Curves of broadband diffusion in OECD countries.

Although broadband development in each country may differ, this study assumes that the development pattern of each country resembles that of OECD countries, as shown in Table 2 and Fig. 1. Additionally, to have sufficient observations for regression in each stage, this study segments the diffusion into three stages[2] instead of the five stages proposed by Rogers. Therefore, this study decides the three stages of individual country by segmenting $BP(t)$ at 2.93 and 13.78 to ensure that the country data selected in each stage are consistent with the adopter categories proposed by Rogers.

According to OECD (2011a), in 2009, although the total number of fixed broadband subscribers per 100 inhabitants of either Denmark or Netherlands was more than 37, that same number of Poland, Slovak, Mexico, Chile or Mexico were below 13.78, which were still in Stage 2. Due to the difference among OECD countries and some missing data of $BP(t)$ in the earlier stages for Israel and Slovenia, the country list in each stage are different. Stage 1, 2, and 3 comprise 32, 33, and 29 countries, respectively (see Table A1 of Appendix).

4. Results and discussion

4.1. Regression results

Table 3 shows the panel regression results. Based on the date for 34 OECD countries (OECD, 2011a), 235 observations are analyzed. To follow Eq. (4) and reduce positively skewed problems, all variables were transformed by a logarithmic function. Four regressions are analyzed: the overall regression with all observations, Stage 1, Stage 2, and Stage 3. Variable data are missing for some years or for some counties in the data sources. Because list-wise deletion is adopted for the missing data, the number of countries for the regression differs in different stages, which is 28, 30, and 25 for Stage 1, 2, and 3, respectively (see Table A1 of Appendix).

To solve the endogenous problem from the lagged dependent variable, this study applies the Arellano–Bond linear dynamic panel-data estimation (Arellano & Bond, 1991). Arellano and Bond (1991) also developed one-step and two-step GMM estimators. Here, the one-step estimation rejects the null hypothesis of the Sargan test, which is that the over-identifying restrictions are valid; therefore, the two-step one is used. Arellano and Bond (1991) also reported serious bias in their robust two-step standard error, so the bias-corrected (WC) robust estimator, proposed by Windmeijer (2005), is used to estimate the standard error. Table 3 shows that the Arellano–Bond test, Wald test, and Sargan test for the four regressions confirm the validity of the models.

4.2. Discussion and implications

4.2.1. Determinants of the overall diffusion

The regression analysis of the overall data set indicates that platform competition, previous broadband penetration, and content are the significant factors of broadband adoption. The significance of platform competition, which is consistent with the results of panel regressions in previous works (Bouckaert et al., 2010; Distaso et al., 2006; Lee & Lee, 2010), indicates that penetration increases with increasing competition among different technologies. Therefore, governments should introduce and encourage market competition among new technologies because it can lower prices, increase innovation, and expand networks (ITU, 2003), and, consequently, increase penetration.

[2] Segmenting the diffusion into three stages is owing to the following reasons: (1) The percentage of innovators is slight (that is, only 2.5%, according to Rogers) and most broadband-related data in this period are missing. Therefore, innovators are combined with early adopters in Stage 1; (2) Most countries have not yet reached laggards stage, so laggards are combined with late majority in Stage 3.

Table 3
Results of regressions.

	Overall	Stage 1	Stage 2	Stage 3
Income	−0.043	6.009**	0.523	0.478*
(WC robust standard error)	(0.419)	(2.798)	(0.545)	(0.245)
(*P* value)	(0.918)	(0.032)	(0.337)	(0.051)
Education	0.144	5.355*	2.046*	−0.111
(WC robust standard error)	(0.927)	(3.142)	(1.173)	(0.182)
(*P* value)	(0.876)	(0.088)	(0.081)	(0.543)
Broadband price	−0.002	0.246*	−0.037	−0.035**
(WC robust standard error)	(0.021)	(0.145)	(0.051)	(0.017)
(*P* value)	(0.941)	(0.090)	(0.459)	(0.036)
Platform competition	−0.432**	−0.101	−0.670***	−0.118
(WC robust standard error)	(0.203)	(0.272)	(0.085)	(0.164)
(*P* value)	(0.034)	(0.710)	(0.)	(0.472)
Content	0.287**	0.986**	0.177	0.266***
(WC robust standard error)	(0.146)	(0.495)	(0.231)	(0.052)
(*P* value)	(0.050)	(0.046)	(0.443)	(0.)
Previous broadband penetration	0.536***	0.248*	0.495***	0.343***
(WC robust standard error)	(0.087)	(0.130)	(0.117)	(0.046)
(*P* value)	(0.)	(0.056)	(0.)	(0.)
Arellano–Bond test AR(2)	1.026	1.204	−1.385	−0.118
(*P* value)	(0.305)	(0.229)	(0.166)	(0.906)
Wald test	831.58	233.35	697.56	704.7
(*P* value)	(0)	(0)	(0)	(0)
Sargan test	12.651	5.168	6.511	12.891
(*P* value)	(0.179)	(0.523)	(0.688)	(0.116)
No. of observations	235	39	83	113

*,**, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Additionally, the positive significant effect of previous broadband penetration is consistent with the panel regression results of studies examined by Bouckaert et al. (2010) and Lee and Lee (2010). The former study suggested that the result verifies the positive persistence of the penetration over time, while the latter one suggested that it is positive network effect, indicating that a higher current subscriber number attracts more subscribers in the future. No matter what the explanation is, the positive significant effect of previous broadband penetration reveals that a higher penetration in the current year results in a higher penetration in the next year.

Finally, although the significance of content is consistent with the finding of the OLS regressions conducted by Garcia-Murillo (2005) and Lee and Brown (2008), previous studies using panel regressions have not observed this result. The significant effects of content observed in this study may be caused by the use of Arellano–Bond GMM estimation. The estimation result indicates that as the richness of Internet content increases, the willingness of inhabitants to subscribe to a broadband service increases. This finding implies that governments should also promote the development of Internet content to increase the demand for a broadband service.

4.2.2. Determinants in different stages

Although the above results are generally consistent with the literature and provide some valuable insights and implications, they are obtained by only treating the overall broadband diffusion as a single process. Table 3 also shows the determinants and significance observed after examining the variables in each stage. The significant factors for each stage are as follows: income, education, broadband price, content, and previous broadband penetration in Stage 1; education, and platform competition, and previous broadband penetration in Stage 2; income, broadband price, and content, and previous broadband penetration in Stage 3. Therefore, different stages do have different determinants. Examining them stage by stage enables accurate identification of specific determinants in each stage. The results also imply that governments should tailor strategies for promoting broadband development to specific stages rather than implementing the same strategies for the overall diffusion process.

Furthermore, the different significance of determinants in different stages also reflects the influence of adopter attributes. For example, previous broadband penetration has the lowest coefficient and significance in Stage 1. This variable may capture both the persistence of the penetration over time and network effect. As the persistence is normally similar in each stage, the difference is caused mainly by network effect. Because the adopters in stage 1 tend to be venturesome opinion leaders, they are less affected by others, so the network effect tends to be lower than in other stages. On the other hand, the potential adopters in Stage 2 and Stage 3 are mostly followers, so network effect is higher. Hence, because of the higher network effect, governments may implement more advertising campaigns and promotions to publicize the advantages of broadband services in these two stages, especially in Stage 2 due to its highest coefficient. Therefore, more potential adopters may follow the existing adopters to subscribe to the services.

Table 4
Key determinants and strategies to promote broadband development.

Main adopters	Key determinants	Key strategies
Stage1 BP $\leq$ *2.93*		
• Innovators • Early adopters	• Income and education • Content	• Target wealthier or more educated people for broadband services. • Promote Internet content, especially the content demanded by innovators and early adopters.
Stage2 2.93 $<$ *BP* $\leq$ *23.78*		
Early majority	• Platform competition • Previous broadband penetration	• Ensure various technology platforms to effectively compete in the broadband market. • Implement advertising and promotions and to inform the public of the advantages of broadband services.
Stage3 BP $>$ *13.78*		
• Late majority • Laggards	• Broadband price	• Ensure that prices are affordable for late majority and laggards.

In Stage 1, income, education, broadband price and content have the highest significant coefficients among the stages. These findings are also consistent with the adopter attributes in Stage 1, who tend to be wealthier, more educated, and more likely to contact more sources of scientific information or communication channels. Furthermore, the positive significant coefficient of broadband price unexpectedly shows that broadband service is a conspicuous good due to the positive price elasticity of demand. This finding is consistent with that of Garcia-Murillo (2005), who applied the data for ITU countries in an early year, that is, 2001. Although the conclusion requires a further verification because the observation number is only 39 and its significance is at 9%, the finding at least revels that a higher broadband price does not appear to lower the demand of broadband services in this stage. Finally, platform competition shows no significance, which indicates that introducing competition is not so important in Stage1, but targeting innovators and early adopters to provide broadband services is an effective strategy.

In Stage 2, the diffusion takes off, so previous broadband penetration has the highest effect. Platform competition also has an influential effect. Higher platform competition may bring lower price, more innovation, and more supplies to meet the high demand of early majority in this stage. Therefore, in addition to promotions and advertising to expand network in this stage, governments should simultaneously ensure different technology platforms to effectively compete in the broadband market to supply sufficient services.

In Stage 3, most potential adopters are late majority and laggards, who are mostly below average social status and who tend to have less opinion leadership and financial capacity. The estimation result reveals that broadband price has a negative significant effect on broadband adoption, while platform competition has no significant effect. Therefore, ensuring that prices are affordable for late majority and laggards is much more important than ensuring platform competition. Again, the adopter attributes affect the determinants, so governments should target the potential adopters in this stage to implement appropriate strategies. Finally, similar to Stage 1, content is also a significant factor, so governments should continue to enrich the Internet content in this stage.

4.3. *Dynamic strategies to promote broadband development*

Based on the diffusion stages segmented by adopter categories proposed by Rogers, this study shows determinants differs by diffusion stage. According to Section 4.2, for efficient promotion of broadband development, governments should focus on the attributes of the main potential adopters in each stage to dynamically devise and implement corresponding strategies instead of adopting one-size-fits-all strategies. Table 4 summarizes the key determinants of broadband adoption and the corresponding strategies for governments. Except for broadband price, a key determinant is a significant variable whose coefficient is the highest among the three stages. Broadband price is chosen in Stage 3 rather than Stage 1, because its negative significant coefficient in Stage 3 is more reasonable for governments to implement appropriate strategies.

5. Conclusions

Although previous studies have adopted various country-level data, models, statistic methods, or analysis durations to examine the determinants of broadband adoption and have provided some insight into broadband adoption, this study further applies the Arellano–Bond GMM dynamic panel estimation with a more complete duration (from 1997–2009) based on a Gompertz diffusion model to re-examine the determinants mainly reported in previous studies. In addition to closely reflecting the dynamics of broadband diffusion, the Arellano–Bond GMM estimation solves an endogeneity problem incurred in the estimation of previous panel data studies. The estimation results indicate that besides previous broadband penetration and platform competition, which have been commonly identified by the previous panel data studies, content is also a significant factor in the overall diffusion. Therefore, governments should also promote the development of Internet content to increase the demand for broadband services.

This study further examines the determinants of broadband adoption in different stages based on the adopter categories proposed by Rogers (2003), an analysis which has not been used in the previous studies of broadband adoption. The estimation results indicate that the determinants do differ by diffusion stage. Table 4 shows the key determinants and the corresponding strategies suggested for governments. Therefore, in order to efficiently promote broadband development, governments should focus on the main potential adopters in each stage to implement appropriate strategies rather than adopting one-sizes-fits-all strategies.

As OECD countries have much higher broadband penetration and have more complete data for the variables than other countries, they can better serve for the complete staged analysis. Moreover, the determinants in each stage may provide valuable implications for a country to plan or review its broadband strategies according to the stage which it finds itself in.

However, due to the incomplete data sources, the number of observations for the regression is limited, especially in Stage 1, so only six key independent variables are included. Therefore, future studies may include more independent variables and more countries as their data become available in order to more generally examine the key factors of broadband adoption.

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Table A1
Country list for each stage.

Stage *BP(t)*	**Stage 1** $BP(t) <= 2.93$	**Stage 2** $2.93 < BP(t) <= 13.78$	**Stage 3** $13.78 < BP(t)$
Countries	Australia	Australia	Australia
	Austria	Austria	Austria
	Belgium	Belgium	Belgium
	Canada	Canada	Canada
	Chile[a]	Chile[a]	Czech
	Czech	Czech	Denmark
	Denmark	Denmark	Estonia[a]
	Estonia[a]	Estonia[a]	Finland
	Finland	Finland	France
	France	France	Germany
	Germany	Germany	Greece[a]
	Greece	Greece	Hungary
	Hungary	Hungary	Iceland
	Iceland[a]	Iceland	Ireland
	Ireland	Ireland	Israel[a]
	Italy	Italy	Italy
	Japan	Japan	Japan
	South Korea[a]	South Korea	South Korea
	Luxembourg	Luxembourg	Luxembourg
	Mexico	Mexico	Netherlands
	Netherlands	Netherlands	New Zealand
	New Zealand	New Zealand	Norway
	Norway	Norway	Portugal
	Poland	Poland	Slovenia[a]
	Portugal	Portugal	Spain
	Slovak	Slovak	Sweden
	Spain	Slovenia[a]	Switzerland
	Sweden	Spain	United Kingdom
	Switzerland	Sweden	United States
	Turkey	Switzerland	
	United Kingdom	Turkey	
	United States	United Kingdom	
		United States	
Number of countries	32	33	29
Number of countries after list-wise deletion	28	30	25

[a] Countries excluded by list-wise deletion.

Appendix

See Table A1.

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