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Yi-Wun Lu
National Sun Yat-Sen University

Yi-Cheng Ku
Fortune Institute of Technology

Hsin-Hui Lin
National Sun Yat-Sen University

Diffusion of Contingent Innovation: An Analysis of Interrelated Process between the Internet and DSL[1]

Yi-Wun Lu[a], Yi-Cheng Ku[a,b] and Hsin-Hui Lin[c]

[a] Department of Information Management, National Sun Yat-sen University
No.70, Lien-hai Rd., Kaohsiung, Taiwan 804, R.O.C.
d8842806@student.nsysu.edu.tw

[b] Department of Information Management, Fortune Institute of Technology
No.125-8, Chiwen Rd., Chishan Jen, Kaohsiung County, Taiwan 842, R.O.C.
ycku@center.fjtc.edu.tw

[c] Department of Information Management, National Sun Yat-sen University
No.70, Lien-hai Rd., Kaohsiung, Taiwan 804, R.O.C.
hhlin@mis.nsysu.edu.tw

Abstract

The purpose of this study is to explore the extent to which the diffusion of the Internet-related product could be adequately described by dynamic diffusion models. Three diffusion models, Bass model, Logistic model, and Dynamic model, are applied to examine the DSL adoption pattern in Taiwan. The research results demonstrate that the dynamic model best describes the diffusion pattern of DSL users. It indicates that potential adopters of innovations emerging upon using the Internet are not static. The user increases along with the growth of Internet users. In order to analyse the interrelated process between Internet and DSL, a cumulative measure of the potential adopters of three models is quantified and discussed.

Keywords

Innovation Diffusion, Diffusion Model, Contingent Product

Introduction

The pervasion of Internet has been witnessed practically and theoretically. Its success has induced many innovations, such as new computer and communication technologies, new business models, and creative applications. These innovations do not pervade independently. Instead, they are interrelated with the diffusion of Internet. Adopting an Internet-related innovation is also adopting the Internet, either concurrently or consecutively. Therefore, in order to accurately portrait the diffusion of Internet-related innovation, we have to take the diffusion of Internet into consideration. The phenomenon fits into the concept of *technology cluster* (Rogers 1995, p. 235):

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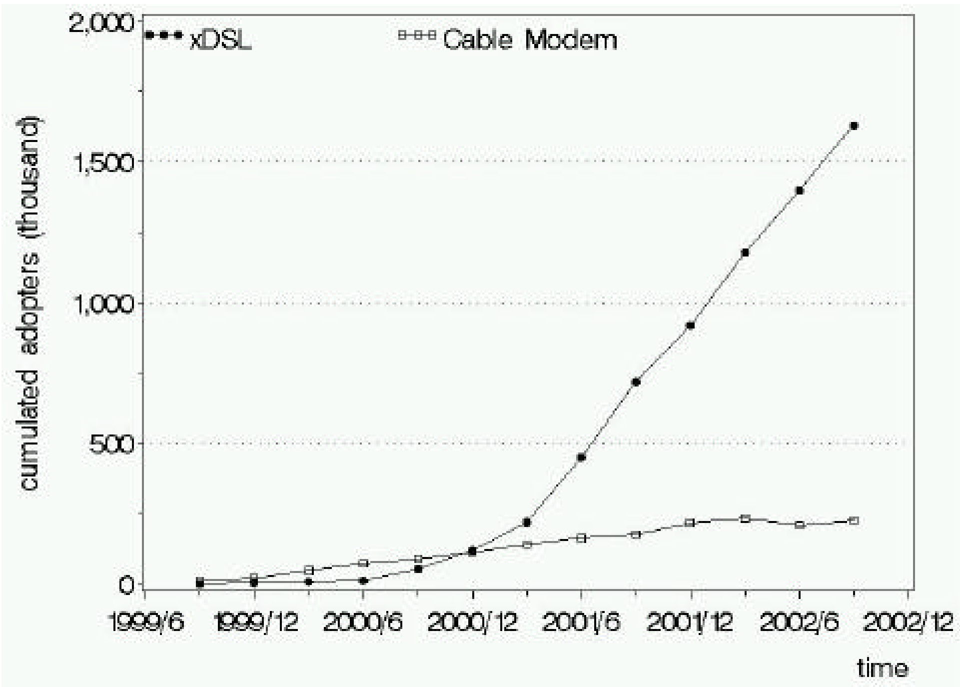
> *"Innovations often are not viewed singularly by individuals. They may be perceived as an interrelated bundle of new ideas. The adoption of one new idea may trigger the adoption of several others. A technology cluster consists of one or more distinguishable elements of technology that are perceived as being interrelated."*

The adoption of Internet-related innovation is conditional upon the adoption of Internet. In other words, the diffusion of Internet-interrelated innovation is directly contingent upon the diffusion of Internet. The diffusion model of Internet itself as an innovation has been studied (Gurbaxani 1990, Goodman, Press, Ruth and Rutkowski 1994, Rai, Ravichandran, and Samaddar 1998). However, little researches have focused on the contingent diffusion of Internet-interrelated innovation.

Among various Internet-interrelated innovations, digital subscriber line (DSL) is our choice for further investigation. DSL is a high-speed broadband communication technology, which includes many protocols, such as ADSL, RADSL, HDSL, SDSL, and VDSL, which may be referred as xDSL. For simplicity, they are called DSL in this paper.

From the Internet user's point of view, DSL is an Internet access service provided by Internet Service Provider (ISP). DSL was introduced in Taiwan in the mid year of 1999 and beat its competitor, Cable Modem, to become the number one broadband access service in 2001. Figure 1 shows the cumulated adopter in the past three years. A latest report[2] in 2002 indicates that DSL has dominated the Internet access market in Taiwan, and the total number of DSL subscribers in Taiwan is ranked number six worldwide.



Source: E-Commerce Resources Center of Institute for Information Industry, Taiwan.

Figure 1. Cumulated Numbers of DSL and Cable Modem Adopters in Taiwan

[2] E-Commerce Resources Center (ECRC) of Institute for Information Industry in Taiwan.

The remainder of this paper is organized as follows. Diffusion theory and the general models are reviewed in section 2. Mathematical diffusion models are illustrated mainly in sections 3, followed by parameter estimation and comparison in section 4. Finally, conclusions are provided in section 5.

Diffusion Theory

Diffusion is defined as the process by which an innovation is communicated through certain channels over a period of time among the numbers of a social system (Rogers 1995). Four critical elements that affect the diffusion pattern in the process are innovation, communication channels, time and social system. Since the diffusion of innovation is a growth process, it is often described by mathematical formulae, called diffusion models. Diffusion models are used to depict the successive increase in the number of adopters or adopting units over time (Mahajan and Peterson 1985). Therefore, they can be used to portray the diffusion pattern, predict future distribution of an innovative technology, and illustrate possible effects of a policy or marketing of a new product. The basic diffusion model can be expressed as equation (1), where *N(t)* stands for the cumulated number of adopters, *m* is the ultimate ceiling of potential adopters. Equation (1) conveys that the diffusion rate is a function of the potential adopters who have not adopted the technology yet. The function of time, *g(t)*, is the probability that potential adopters will adopt the innovation at time t.

$$\frac{dN(t)}{dt} = g(t)[m - N(t)]. \qquad (1)$$

Mahajan and Peterson (1985) proposed three general diffusion models: the external-influence model, internal-influence model and the mixed-influence model. External-influence model implies the diffusion rate is affected by factors outside the system, such as the mass media. In this model, the coefficient of diffusion *g(t)* is a constant *p*. The internal-influence model assumes that the interpersonal communication within the system has a great influence on the diffusion rate. Earlier adopters influenced the later adopters. The coefficient of diffusion *g(t)* is $q \cdot N(t)$. The mix-influence model combines the effects of external and internal influence. The coefficient of diffusion *g(t)* is $p+q \cdot N(t)$

Contingent Diffusion

Diffusion model can be used to forecast the growth of a new product. However, this application is limited when the growth is affected by other new or existing products. In order to draw the relationship between two or more products, four multi-product growth models have been developed: independent Products, complementary products, contingent products and substitute products (Peterson and Mahajan 1978). Contingent product model implies that buyers who have previously purchased a given product will be potential purchasers of a related product; and the success of one product is directly contingent upon the success of a related product (Peterson and Mahajan 1978). The contingent model can be described as the diffusion of depended and depending products in two equations. Equation (2), which is a normal mixed-influence model, conveys the diffusion of depended product. Equation (3) illustrates the diffusion of depending product, which is a mixed-model with $F_1(t)$ to be its ultimate ceiling of potential adopters.

$$\frac{dF_1(t)}{dt} = (a_1 + b_1 F_1(t))(\overline{F_1} - F_1(t)) \quad \text{...(2)}$$

$$\frac{dF_2(t)}{dt} = (a_2 + b_2 F_2(t))(F_1(t) - F_2(t)) \quad \text{...(3)}$$

Since the adoption of DSL is conditioned by their prior adoption of Internet, the general model of contingent products is suitable for analysing its diffusion behavior.

The Research Model

Since the external-influence model and the internal-influence model can be regarded as a special case of the mixed-influence model, this research uses the mixed-influence model by Mahajan and Peterson (1985) as the basis for analysis. One of the best-known applications of the mixed-influence model was done by Bass (1969), which derives from a hazard function of probability in equation (4), given that an adoption will occur at time t for non-adopters.

$$\frac{f(t)}{(1 - F(t))} = p + qF(t) \quad \text{..(4)}$$

where *f(t)* is the probability density function of adoption at time t

F(t) is the cumulated density function of adoption at time t

When *m* is defined as the potential number of ultimate adopters, then n(t) and N(t) can be defined as:

n(t) = mf(t) is the number of adopters at time t.

N(t) = mF(t) is the cumulated number of adopters at time t.

Thus, equation (1) becomes equation (5).

$$n(t) = \frac{dN(t)}{dt} = [p + \frac{q}{m} N(t)][m - N(t)] \quad \text{.......................................(5)}$$

With the assumption that the potential adopter *m* is a constant, equation (5) is a first-order differential equation, and can be integrated to yield the cumulated adopters distribution *N(t)* in equation (6). This model is referred as the Bass model. Three parameters (*p, q, m*) need to be estimated in the model. The solution of the Bass model is listed below in equation (6).

$$N(t) = \frac{m - \dfrac{p(m - N_0)}{p + \frac{q}{m} N_0} e^{-(p+q)t}}{1 + \dfrac{\frac{q}{m}(m - N_0)}{p + \frac{q}{m} N_0} e^{-(p+q)t}} \quad \text{...(6)}$$

where, $N(t = 0) = N_0$

In a special case where the coefficient *p* is zero, the Bass model in equation (5) becomes equation (7).

$$n(t) = \frac{dN(t)}{dt} = \frac{q}{m} N(t)[m - N(t)] \quad \text{......(7)}$$

Equation (7) is similar to the internal-influence model of Mahajan and Peterson, except that the coefficient of internal influence is divided by *m*. The model is referred as the Logistic model, and two parameters (*q*, *m*) need to be estimated. The solution of Logistic model is as follows in equation (8):

$$N(t) = \frac{m}{1 + \frac{(m - N_0)}{N_0} e^{-qt}} \quad \text{......(8)}$$

where $N(t = 0) = N_0$

Both the Bass model and the Logistic model give S-shaped patterns, which are similar to the shape of DSL growth in Figure-1. Typically, the S-shape diffusion starts at an increasing rate, the cumulated number of adopters increases over time. As time goes by, the curve reaches a point of inflection, and the adoption rate starts to decrease. Finally, the diffusion reaches a saturation level. Unlike the S-shaped pattern, another special case of the Bass model with the zero coefficient *q* is illustrated as a decaying exponential curve for that the cumulated number of adopters increases at a (constant) decreasing rate. Due to the dissimilarity to the actual data, this research does not consider this special case.

Since the adoption of DSL is also adopting the Internet at the same time, the diffusion of DSL is directly contingent upon the diffusion of the Internet. Given that the group of Internet users is the potential population of the DSL subscribers, and the number of Internet users are growing at its own rate, it is necessary to redefine the potential adopters *m* in equation (5) as a function of time *m(t)* for the diffusion model. Thus, equation (5) becomes equation (9) in the following:

$$\frac{dN(t)}{dt} = [p + \frac{q}{m(t)} N(t)][m(t) - N(t)] \quad \text{......(9)}$$

Here, *m(t)* is interrelated with the growth of Internet users. However, it is very difficult to obtain the accurate number of Internet users for various reasons. For example, the number may be counted redundantly for that one user may access Internet through many ISPs or several users may share one Internet account. Therefore, a general exponential form in equation (10) was used in this research to represent the time-variant effect caused by the Internet user growth. The justification of the exponential growth was supported by the research of Rai et al. (1998). Their result showed that Exponential model was better than the other two in predicting the growth of Internet.

$$m(t) = m_0 e^{gt} \quad \text{......(10)}$$

where $m_0 = m(t = t_0)$

The model is referred as the Dynamic model in this research, and four parameters (p, q, g, m_0) must be estimated. The equations (9) and (10) have been solved by Sharif and Ramannathan (1981), and the solution is listed below.

$$N(t) = m_0 e^{gt}\left(\frac{\left(\frac{f_1 - f_2}{2}\right) - f_3\left(\frac{f_1 + f_2}{2}\right)e^{-f_1 t}}{q + q f_3 e^{-f_1 t}}\right)$$

$$f_1 = \sqrt{(g + p - q)^2 + 4pq}$$

$$f_2 = (g + p - q)$$

$$f_3 = \frac{\left(\frac{f_1 - f_2}{2}\right) - \frac{qN_0}{m_0}}{\left(\frac{f_1 + f_2}{2}\right) + \frac{qN_0}{m_0}}$$

$$0 < N(t=0) = N_0 \le m(t=0) = m_0$$

Table 1 summarizes the models used for the research. Nonlinear regression analysis is applied to estimate parameters of the models.

Model	Mathematical Form	Parameter
Bass Model	$\frac{dN(t)}{dt} = [p + \frac{q}{m}N(t)][m - N(t)]$	p, q, m
Logistic Model	$\frac{dN(t)}{dt} = \frac{q}{m}N(t)[m - N(t)]$	q, m
Dynamic Model	$\frac{dN(t)}{dt} = [p + \frac{q}{m(t)}N(t)][m(t) - N(t)]$ $m(t) = m_0 e^{gt}$	p, q, g, m_0

Table 1. Research Models

Parameter Estimation and Comparison

The number of DSL adopters, as shown in Table 2 was used to fit the model. The data was obtained from the E-Commerce Resources Center (ECRC) of Institute for Information Industry, as published on their website (http://www.find.org.tw) as the result from the grant sponsored by the Department of Industrial Technology, Ministry of Economic Affairs of Taiwan.

Observation	Time	DSL (thousand)
1	1999/09	2
2	1999/12	5
3	2000/03	9
4	2000/06	13
5	2000/09	54
6	2000/12	120
7	2001/03	220
8	2001/06	450
9	2001/09	720
10	2001/12	920
11	2002/03	1,180
12	2002/06	1,400
13	2002/09	1,630

Table 2. Quarterly Data of Cumulated DSL Adopters

Bass Model and Logistic Model

First, Bass model and Logistic model are compared because both models have embedded the assumption of static potential adopters. The resulting model parameters are summarized in Table 3. The Bass model gives a satisfactory result except the parameter *p*, which is 0.001867 (p=0.0144) and is less significant than the other two parameters (p<0.0001). Although the result shows that the parameters of the Logistic model are all highly significant (p<0.0001), the residual sum of squares (27,314.00) and the adjusted R-square (0.9928) are worse than the Bass model (11,200.0 and 0.9968). In addition, the potential adopter *m* (1,644.829) of the Logistic model is very close to the actual cumulated adopter (1,630) in 2002/09. It implies that the next actual number would exceed the saturation level *m*, and that is unreasonable in explaining the diffusion of innovation. The graphs of both models, plotted in Figure-3 and Figure-4 respectively, show that the Bass model fits better than the Logistic model. Therefore, the Bass model is superior to Logistic model in describing the diffusion of DSL.

Model	**Parameter Estimates**				**Residual Sum of Squares**	**Adjusted R^2**
	Parameter	**Value**	**t Value**	**Approx Pr > |t|**		
Bass (1969)	p	0.001867*	2.96	0.0144	**11,200.0**	**0.9968**
	q	0.611777***	14.16	<.0001		
	m	1,839.417***	22.09	<.0001		
Logistic	q	0.786924***	74.29	<.0001	**27,314.0**	**0.9928**
	m	1,644.829***	32.42	<.0001		
* p<0.05 ** p<0.01 *** p<0.001						

Table 3. Parameters of Models with Static Potential Adopters

Dynamic Model

As discussed in the previous section, DSL is not an independent innovation. Instead, it is contingent upon the Internet. Its potential adopters would vary when Internet users increase over time. The resulting parameters estimated from the data are shown in Table 4. The parameter *p*=0.059 (<0.1) is not significant compared to other parameters, but the residual sum of squares (1,733.1) and adjusted R-square (0.9994) are better than the Bass model and the Logistic model. Figure-4 demonstrates the better fit of the model as well.

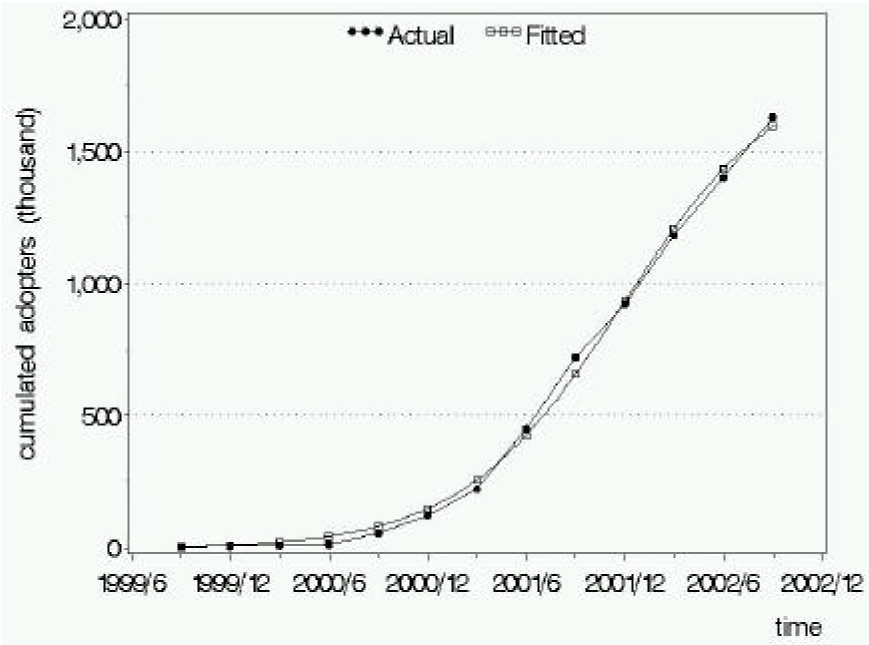


Figure 2. Bass Model Fit

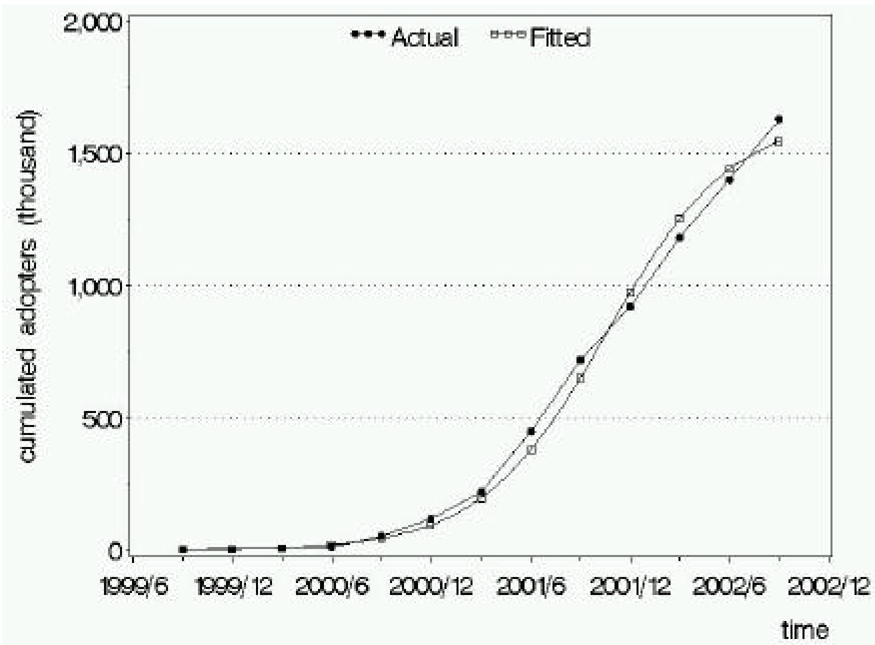


Figure 3. Logistic Model Fit

Model	Parameter Estimates				Residual Sum of Squares	Adjusted R^2
	Parameter	Value	t Value	Approx Pr > |t|		
Sharif and Ramanathan (1981)	p	-0.00323	-2.16	0.0590	**1,733.1**	**0.9994**
	q	1.031666***	13.44	<.0001		
	g	0.143089***	12.55	<.0001		
	m_0	343.8679***	7.49	<.0001		
* p<0.05 ** p<0.01 *** p<0.001						

Table 4. Parameters of the Model with Dynamic Potential Adopters

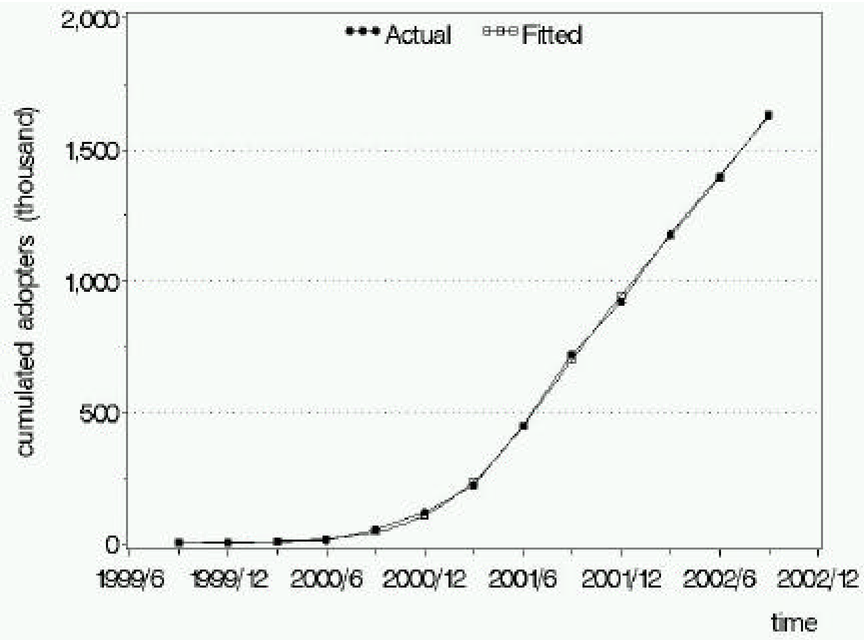


Figure 4. Dynamic Model Fit

Finally, the estimated potential adopters *m* of the three models are depicted in Figure-5. Two horizontal lines show that the Bass model and the Logistic model assume static potential adopters. The value of the Bass model (1,839,417) is higher than the value of Logistic model (1,644,829). However, if we look at the trend of the actual data of cumulated adopters, , the number of cumulated adopters in the next few quarters would exceed the ceilings estimated by both the Bass model and the Logistic model. Therefore, these two models do not seem to fit well. The Dynamic model is better. The increasing rate of *m(t)* that eliminates the possibility of intersecting with the actual value makes the Dynamic model to be the most appropriate model in estimating *m*. However, there is some shortcomings in equation (10). As the time goes infinitely, *m* will become infinitely large as well, which is not reasonable. The situation should work like that *m* would reach an inflection at some point and then approaches to a saturation level gradually. That means it should look like a S-shape. Consequently, the model should be enhanced in order to capture this property; we leave it in the next stage of the research.

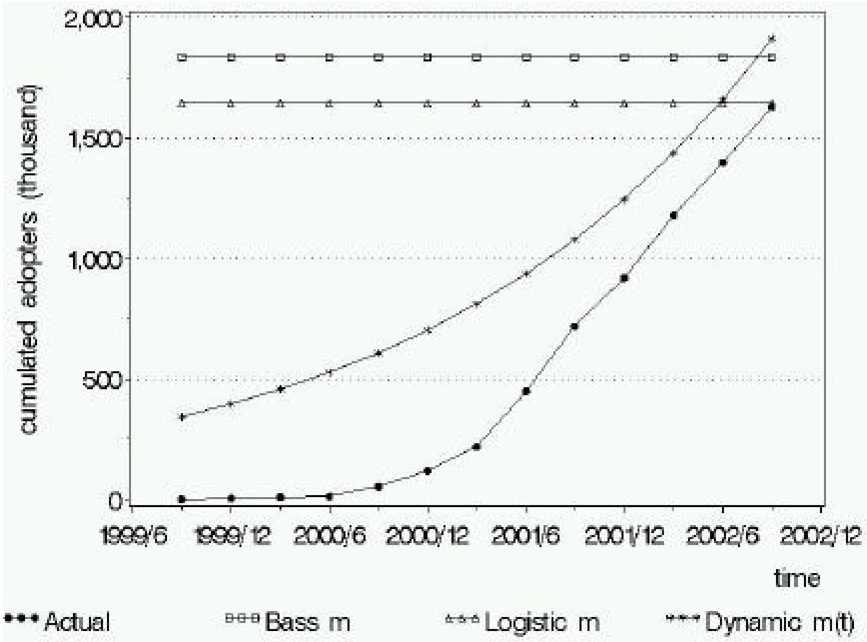


Figure 5. Comparison of the maximum number of Potential Adopters m

Conclusion

This research has analysed the application of three different contingent diffusion models to the DSL diffusion in Taiwan. The result indicates that the dynamic model outperforms the other two. The contribution of the research is two fold. First, it conveys the concept of contingent products in studying the diffusion of Internet-related innovation. We treat the Internet and its related innovations to be a technology cluster that must be examined together. The diffusion of the Internet-related innovation should not be modelled independently without including the diffusion of the Internet. Secondly, the diffusion rate of DSL shows an increasing demand of broadband services, which implies that the Internet infrastructure is improving and the Internet content providers have a good chance to promote multi-media services successfully.

Implications

This study highlights the diffusion of the Internet-related innovation should not be modelled independently without including the diffusion of the Internet. It implies that Bass model cannot be applied to describe contingent products without modification. This study provides theoretical evidence that the growth pattern of the product with dynamic potential adopters could be better described by dynamic diffusion model than general diffusion model. It is necessary to evaluate the assumptions cautiously while applying the general diffusion model in describing and forecasting the adoption pattern.

In addition to the theoretical implications, this study implies phenomena that are meaningful for practitioners. One important insight from this research is that it is indeed necessary to forecast the market potential not only on the focal product but also on its contingent product. For example, we cannot investigate automobile market without considering the number of driving licenses and the population. The companies that provide Internet-related products or service should always keep eyes on the diffusion of the Internet. Furthermore, the dynamic diffusion model provides a useful methodology in market investigations. Diffusion model can be used to explain the product life cycle, marketing channel and market penetration. This research suggests that in order to avoid making incorrect marketing decision, the traditional diffusion model cannot be applied directly. Instead, some modification with contingent modelling is indispensable.

Research issues in the future

Why has the diffusion of ADSL been so fast to dominate the broadband service in Taiwan? There are several factors that may affect the adoption rate: 1) the perceived attributes of innovations, 2) the type of innovation-decision, 3) the nature of communication channels, 4) the nature of the social system in which the innovation is diffused, and 5) the extent of change agents' promotion efforts (Rogers 1995, Abrahamson and Rosenkopf, 1997). It would be interesting to further investigate these factors and how they affect the dramatic adoption of DSL.

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