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ABSTRACT

Mobile phones adoption and diffusion is a practical issue that has significant implications for e-commerce and m-commerce development. Examining the adoption of mobile phones from the well-developed theoretical foundation of innovation diffusion theory may clarify some significant factors that affect the adoption decision. Moreover, with the understanding of the influence sources of mobile phones adoption, the businesses can evaluate the number of mobile devices that can support the mobile commerce, plan the wireless capacity, formulate mobile commercial strategies, design more sophisticated applications, and launch more innovative wireless services.

In this research, we explore the sources of influence in the adoption of mobile phones in Taiwan, which mobile phone penetration ranks No.1 worldwide. We test adoption and diffusion pattern using three classical models: internal influence, external influence, and mixed influence models. Our findings suggest that mixed influence is the dominant influence factor in the diffusion of mobile phones. That is, the decision to become a new adopter of mobile phones is mainly determined by the positive influence of existing adopters and mass media channels.

Keywords: Innovation, Diffusion, Mobile Phone

1. INTRODUCITON

Explosive growth of the mobile phones over the past decade has greatly increased interest in its potential use of mobile commerce, especially as a vehicle for transactions. Plenty of mobile phones have provided consumers to perform various mobile commerce-related tasks without regarding to time and location. Therefore, tracking the adoption and diffusion pattern of mobile phones from the well-developed theoretical foundation of innovation diffusion theory is an increasingly important task, especially for mobile commerce planners. Examining the adoption of mobile phones from the well-developed theoretical foundation of innovation diffusion theory may clarify some significant factors that affect the adoption decision. With the understanding of the influence sources of mobile phones adoption and tracking the diffusion process, the businesses can evaluate the number of mobile devices that can support the mobile commerce's future use, plan the wireless capacity, formulate mobile commercial strategies, design more sophisticated applications, and launch more innovative wireless services.

Several behavioral models, such as Technology Acceptance Model, Theory of Reasoned Action, and Theory of Planned Behavior, for explaining and predicting the adoption and usage of technology have been proposed in the information systems literature. These studies primarily focused on surveys of individuals' perceptions but do not explore the sources of influence in the adoption of innovation within a social system. In this paper, we investigate the adoption process of mobile phones in Taiwan, which mobile phone penetration ranks No.1 worldwide, with well-developed theoretical foundation of innovation diffusion theory. By means of the mathematical diffusion models, the process by which the innovation (mobile phones) is communicated through certain channels over time among the members of a social system can be analyzed. Three classical diffusion models [Loh et. al., 1992; Venkatrman, 1994; Hu et al., 1997], external influence model, internal influence model, and mixed influence model, are applied to depict the successive increase in the number of mobile phone adopters over time. The validation consequences will show us which factors influence the speed and specific course of mobile phone diffusion processes and may clarify some significant factors that affect the adoption decision. The research results will also allow us to have better understanding of the mobile phone growth, explore the sources of influence in the adoption of mobile phones, and illustrate possible implications on mobile commerce.

The rest of the paper is organized as follows: Firstly, we would like to briefly outline the current status of mobile communications in Taiwan. Then we will review the literature related to diffusion of innovation theory. Secondly, we would like to discuss the classical mathematical models of the diffusion of an innovation as developed by Mahajan and Peterson [1978, 1979, 1985]. At length, we will present the research results with longitudinal statistics and discuss their implications.

2. RESERARCH BACKGROUND

2.1. Mobile Phone Telephony

A mobile phone is a portable telephone which receives or

sends messages through base station network. Each base station overlaps other stations and has a range of 6-9 kilometers. Most people use the term "cellular phones" to mean all mobile phones using cellular technology, including GSM (Global System for Mobiles), CDMA (Code Division Multiple Access), DECT (Digital Enhanced Cordless Telecommunications), and traditional analog mobile technology. In a mobile phone network, users can roam with their mobile device and be handed off from one base station to the other. Mobile phones not only support voice calls, but send and receive data such as text, pictures, and short messages. Newer models also allow for accessing WAP (Wireless Application Protocol) services, have a built-in digital camera, and have some applications and entertainment programs integrated into them. At the present, mobile phones are changing to include the ability to access the World Wide Web and providing e-mail capability. They offer full Internet access using technologies such as GPRS (General Packet Radio Service).

2.2. The Status of Mobile Communications in Taiwan

The past decade has seen tremendous growth in the mobile sector in Taiwan. According to ITU (International Telecommunication Union) World Telecommunication Indicator Database, the number of mobile phone subscribers makes Taiwan to take the top seat in Asian mobile phone penetration ranking in 2000 and the 1st place in worldwide level in June of 2002. Relatively cheap rates, variety services, and aggressive operator subsidization programs have all contributed to Taiwan's mobile growth. With a population of about 23m, Taiwan is one of Asia's most dynamic markets. Figure 1 portrays the critical events and historical growth trend of mobile phone subscribers in Taiwan.

The high growth rate also means that service providers are facing a quickly maturing market. Despite aggressive marketing campaigns, operators are discovering that the pace of growth cannot be maintained. The market is quickly shifting from one focused on customer acquisition to one that is examining how to increase revenue with new service. The operators in Taiwan have begun to concentrate on improving earning ability base on its existing customer. At the present, the mobile commerce, mobile internet, short message service, WAP service, entertainment programs, and data/value-added services have been regarded as the major revenue sources of Taiwan's mobile phone operators. For example, data/value-added services usages last year grew 426% and 284% respectively. Moreover, personalization, such as interchangeable covers and user defined ring tones, has also helped in the uptake by the teen's market.

2.3. Diffusion of Innovation Theory and Diffusion Models

The diffusion of innovation theory provides an explanation of how innovations diffuse through a social system. Diffusion is defined as the process by which an innovation is communicated through certain channels over a period of time among the members of a social system [Rogers, 1995]. Four key elements determine the characteristics of diffusion process of an innovation: innovation, time, social system, and communication channels. Rogers [1995] describe innovation as "any idea, object or practice that is perceived as new by the members of a social system…Time relates to the rate at which the innovation is diffused or the relative speed with which it is adopted by members of the social system…Social system consists of individuals, organizations, or agency … are potential adopters of innovation…Communication channels are means by which information is transmitted to or within the social system". As described above, communication channels have a significant effect on the diffusion pattern. Bass [1969] has categorized communication channels as either mass media messages or interpersonal communication channels. Mass media employ radio, television, newspapers, or other channels which enable a source of one or a few members within a social system to reach an audience of many. In contrast, interpersonal communication channels transmit an innovation to members within a social system via face to face communication between two or more individuals [Rogers, 1995]. Traditionally, the distribution of adopters over time is expected to be a bell-shaped curve. Adopters can be categorized into five categories by the different standard deviation from the mean: innovators, early adopters, early majority, late majority and laggards [Rogers, 1995].

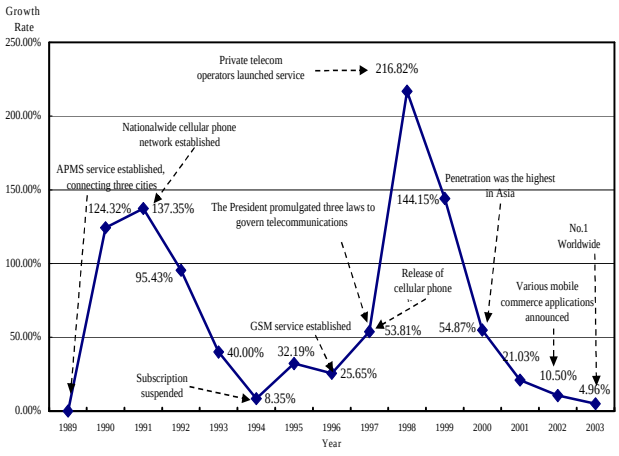

Figure 1. Historical Growth Rates

Since diffusion is the adopting process of the users among a social system, diffusion pattern, a line that is often a nonlinear curve, can describe the successive increase in the number of adopters or adopting units over time. Diffusion models are mathematical models that can be applied to depict the diffusion pattern, predict future distribution of an innovative technology, illustrate possible effect of a policy, or marketing of a new product. Mahajan and Peterson [1985] indicated three general

diffusion models: the external influence model, internal influence model and the mixed influence model. External influence model means the diffusion rate is affected by the mass media. The coefficient of diffusion is a constant, and the diffusion model was expressed as equation (1). Internal influence model hypothesize that the diffusion rate is affected by the interpersonal communication. Earlier adopters influenced the later adopters. The coefficient of diffusion is a function of the cumulative number of adopters, and the diffusion model was expressed as the equation (2). Mix influence model, equation (3), combined the effect of external and internal influence. All three general diffusion models are in the following:

$$N(t) = m(1-\exp(-pt)) \quad \text{----- (1)}$$

$$N(t) = \frac{m}{1+\frac{m-m_0}{m_0}\exp(-qmt)} \quad \text{-----(2)}$$

$$N(t) = \frac{m-\frac{p(m-m_0)}{p+qm_0}\exp(-(p+qm)t)}{1+\frac{q(m-m_0)}{p+qm_0}\exp(-(p+qm)t)} \quad \text{----- (3)}$$

Where: N(t) is the cumulative number of adopters, $N(t) = \int_{t_0}^{t} n(t)dt$;

$N(t= t_0) = m_0$, the initial number of adopters in a social system;

$\frac{dN(t)}{dt}$ = diffusion rate at time t;

m = total number of potential adopters in a social system.

In addition to three classical diffusion models, a rich body of studies adopt Exponential model to fit the diffusion pattern. Gurbaxani [1990] describes that an S-curve specification can be approximated by an exponential curve and characterized by a constant ratio of change when an innovation is in its early stages. Moreover, parameters of the diffusion models can be estimated in nonlinear estimation procedures [Srinivasan, 1986] or maximum likelihood estimation procedures [Schmittlein, 1982].

Diffusion models are built under some kind of patterns rather than random process. Therefore, it is necessary to verify the distribution of diffusion patterns after calculating the parameters. Mahajan et al. [1988] propose the White-Noise model, equation (4), to be the null hypothesis in order to test the validity of diffusion model. It means that diffusion model is useful when it can explain better than the White-Noise model on the innovation adoption process.

$X(t)=x(t-1)+e(t)$ ----- (4)

Where: x(t) is the number of adopters at time t;

e(t) is assumed to be $N(0,s^2)$

We adopt J-test [Davidson and Mackinnon, 1981] to test each influence model against White-Noise model, because White-Noise model is suitable for linear problems and J-test was designed to test the specification of an econometric model in the presence of an alternative model that purport to explain the same phenomenon.

2.4. Studies of Innovation Diffusion

A rich body of studies has discussed innovation diffusion. For instance, Chaddha and Chitgopekar [1971] used a logistic formulation in estimating the demand for Bell System residence main telephones over the period 1966-1991. Wang and Kettinger [1995] applied a logistic model to survey the diffusion of number of subscribers and number of cell sites in the United States. The data they used covered the period from December 1984 to June 1994. The result shows that the logistic fit for number of cellular subscribers and the number of subscribers starts flatting out in year 2015 with 78,242,205 subscribers. The logistic model fit for number of cells as for the subscribers. The model also points out that a saturation point is reached at year 2020, with 33,248 cell sites.

Since the Internet is an example of a technology cluster innovation [Prescott, 1996], the prior researchers have done many investigations related to Internet diffusion. For example, Goodman et al. [1994] argued that most of the barriers to the wider distribution of networking tend to fall into three categories: government relative policies, technical impediments, and cultural factors. In addition to qualitative discussions, the quantitative methodology-mathematical diffusion models- are adopted to track the diffusion process of Internet hosts. For example, Gurbaxani [1990] found the pattern of diffusion in the case of BITNET is S-shaped and is consistent with a logistic curve, which describes a symmetrical growth process. Rai et al. [1998] adopted logistic, Gompertz and exponential models to forecast future development of Internet. They used nonlinear regression with data from August 1981 to January 1994 to estimate parameters for each of the three models. The result shows that the Exponential model provided a better fit than others in the initial growth stage of Internet. Moreover, Kauffman and Techatassanasoontorn [2004] used a modified Bass model and a coupled-hazard survival model to test the effects of country environmental factors, digital and analog wireless phone industry environmental factors, and technology policy factors on the speed of diffusion. They found that multiple standards and high prices slow down the digital wireless phone diffusion process from the Introduction state to the Partial Diffusion state. Competition in both analog and digital wireless phone industry also shapes the growth of digital wireless phone diffusion.

3. MODEL EXAMINATION

Mobile phone is an innovation of communication technology for people to communicate with each other. Therefore the number of mobile phone subscribers is influenced by both the number of existing subscribers

and the number of potential future subscribers. This section would explore the sources of influence in the adoption of mobile phones in Taiwan. We will test adoption and diffusion pattern of source influence using three classical models: internal influence, external influence, and mixed influence models.

3.1 Data

In order to estimate the parameters of diffusion model, we collected longitudinal statistics of mobile phone subscribers form 1989 to 2004 in Taiwan. The data source is ITU World Telecommunication Indicator Database. Table 1 shows the historical data of mobile phone subscribers in Taiwan. We use the data between 1989 and 2001 to estimate the parameters of three classical models and the data between 2002 and 2004 for checking sum of squares of the difference.

Table 1. The Historical Data of Mobile phone Subscribers in Taiwan

Year	Number of Subscribers	Year	Number of Subscribers
1989	37,000	1997	1,492,000
1990	83,000	1998	4,727,000
1991	197,000	1999	11,541,000
1992	385,000	2000	17,874,000
1993	539,000	2001	21,633,000
1994	584,000	2002	23,905,000
1995	772,000	2003	25,090,000
1996	970,000	2004	25,207,000

3.2. Testing Methods

In this section, we conduct two types of statistic tests to determine which model best fits the observations of mobile diffusion. Firstly, we estimate the model parameters of all three diffusion models with the nonlinear least squares regression method. Then we determine the true model among the three alternatives using the J-test. Finally we calculate the sum of the squares of the difference between predictive value and actual subscriber numbers.

NLIN, a nonlinear regression procedure of the SAS software package, is used to estimate the parameters in the three diffusion models. Table 2 summarizes the parameter estimation and the model fit for the three models. As Table 2 illustrates, the internal model has an adjusted R^2 of 0.9833 which is the proportion of variance explained by this model. The mixed model has an adjusted R^2 of 0.9800 and the external model just has an adjusted R^2 of 0.6687. That is, the adjusted R^2 of internal model is almost exactly the same as the adjusted R^2 of mixed model. Both of them are significantly higher than the R^2-adjusted value of external model. Thus, the overall predictive fit of external model is the worst.

Table 2. Parameter Estimation and Model Fit

Parameter	Internal Influence	Mixed Influence	External Influence
m	47,433	35,134	266,620
m_0	37	37	37
p		6.54E-21	0.0038
q	1.2433E-05	1.73683E-05	
R^2	**0.9833**	**0.9800**	**0.6687**
NOTE: 1.Unit: 1,000 subscribers			

After the model parameters are estimated, the J-test is conducted to use each model in turn as the null hypothesis and the rest as the alternative hypotheses. Table 3 presents the results of comparisons of the alternative specifications with the White-Noise model with the J-test.

Table 3 J-test Model Comparisons: t Values with Probabilities

Null Model	Alternative Models		
White Noise	Internal Influence	Mixed Influence	External Influence
t statistic	8.3669	7.8965	0.7924
p-value	0.0000****	0.0000****	0.4449
**** p<0.001			

As table 3 shows, the J-test result rejects the null hypothesis that the adoption pattern of mobile phone is a random process. The alternative models can reject the White-Noise model at the significance level of $p<0.001$ or better. Thus we come to a conclusion that the diffusion of mobile phones is not a random process. However, table 3 also indicates that the J-test result can't reject the null hypothesis while alternative model is external-influence. That is, the external model is not suitable for predicting the diffusion process of mobile phones. This also confirms the parameter estimation and model fit results described in Table 2. Accordingly, we don't analyze the external model any more in next section.

3.3. Best Model and Discussions

Figure 2 presents the curve of actual numbers of mobile phone subscribers and model forecasts. In order to examine the predictive validity of internal model and mixed model, we calculate the sum of squares of the differences between actual and predicted number of subscribers with the data from 2002 to 2004.

Table 4 summarizes the actual and predicted number of subscribers and sum of squares error for each model. As table 4 shows, the mixed model performs better than another one. Our research result clearly indicates that the mixed model best describes the diffusion process of mobile phones adoption. That is, the mixed influence is the dominant influence factor in the diffusion of mobile phones adoption. Hence, the decision to become a new adopter of mobile phones is mainly determined both by the positive influence of existing adopters and mass media messages. Therefore, mass media play a critical role in the earlier diffusion stage. These mass media publicize the advantage about using mobile phones widely in several years ago. However, the effect of mass media is not the only outstanding factor in the adoption process.

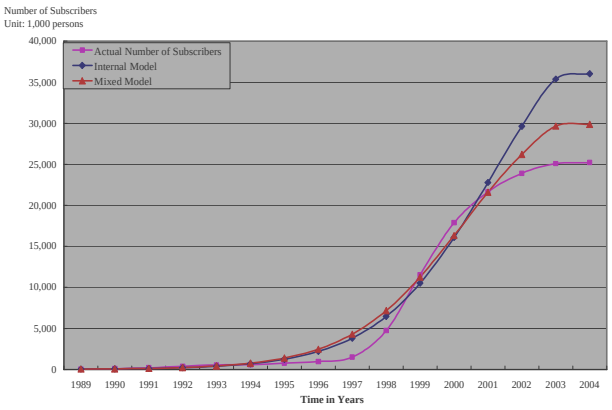

Figure 2. Actual Numbers of Mobile phone Subscribers V.S. Model Forecasts

Mahajan and Peterson [1985; p.18] noted that the internal influence perspective is "most appropriate when an innovation is … socially visible, and not adopting it places social system members at a disadvantage". With the rapid development of mobile technology, the mobile phone offers services independent of time and space. These benefits are perceived by users and are communicated to potential adopters. Even individuals will ask their friends, colleagues, or staffs to adopt mobile phones for communicating to each others more efficient. Besides, many individuals adopted mobile phones for the purpose of imitation. Factors which may motivate people to imitate buying mobile phones vary. For instance, factors considered in prior researches include perceptions that a user who adopts the mobile phone will be taken professional image, that a mobile phone makes me feel efficient, that it makes the user appear contemporary, dynamic and innovative.

Table 4. Model Forecasts vs. Actual Number of Subscribers

Year	Actual Subscribers	Internal Influence	Mixed Influence
1989	37	37	37
1990	83	67	68
1991	197	120	125
1992	385	216	230
1993	539	389	420
1994	584	696	766
1995	772	1,241	1,384
1996	970	2,192	2,467
1997	1,492	3,811	4,288
1998	4,727	6,457	7,159
1999	11,541	10,496	11,251
2000	17,874	16,072	16,317
2001	21,633	22,783	21,601
2002	23,905	29,647	26,213
2003	25,090	35,593	29,652
2004	25,207	36,024	29,883
Sum of squares of the difference		260,291,062	48,003,684

Furthermore, the pre-adopters may require friends of their social network to use mobile phones, especially the mobile phone has become a popular communication tool for most people. This is a strongly relationship for communication mechanisms where the value of the mobile phones increase with an increase in the number of users it connects. The mobile phone adoption is communicated among the members within the social system via interpersonal channels.

4. CONCLUSION

Mobile phone is one of the most important innovations over the last decade of the 20th century: with which communications become available anytime and any place. Accessibility, convenience, localization, and confidence make mobile services so unique. Mobility changes not only the life style of people but the enterprise's business model. Who, then, pushes the growth of the mobile phones? Our study addresses this issue with the diffusion of innovation perspective. The research results show that mixed model, which assumes that the decision to become a new adopter is mainly determined by the positive influence of existing adopters and mass media channels, has better predictive validity. This leads us to conclude that it is the combined effects of external media, interpersonal pressure, and internal communications at the personal level that significantly influence the decision to adopt mobile phones. Moreover, network externalities might also offer a good explanation [Gurbaxani, 1990]. That is to say, the value of the mobile phones increases with an increase in the number of users it connects. Another explanation is that imitation within social system is a very popular phenomenon. The potential adopters perceive the value from early adopters and then decide to buy mobile

phones. While this study provides empirical result of diffusion process of mobile phones adoptions in Taiwan, future research can examine diffusion models with different country's data or apply the different model to have better understanding of mobile phones diffusion.

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