Deregulation and Network Externalities in an Accelerated Diffusion of Mobile Telephony

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Abstract

Taiwan is one of only two countries worldwide in which the penetration of mobile telephony exceeded 100% in 2002. This study identifies the drivers behind the accelerated growth of mobile telephony in Taiwan, in terms of the diffusion model and forces driving such diffusion. Various diffusion models are compared to identify the optimum one. Drivers for the diffusion rate of the model are then estimated. Empirical results, based on 1988–2007 data, indicate that the Logistic model performs the best in terms of the minimum root mean square error. Network externalities explain the dynamics and superiority of the Logistic model. Deregulation leads to market competition, making it the primary driver for diffusion. This empirical study also demonstrates that deregulation promotes the diffusion to the takeoff point, which is vital for success. Overall, network externalities are in conjunction with the deregulation to promote the rapid diffusion in Taiwan.

Keywords: Telecommunications management, mobile telephony, deregulation, network externalities

1. Introduction

The major issue of technological change is the diffusion process (Stoneman, 1981). Mobile telephony is an innovation in telecommunications technology owing to offering seamless and ubiquitous communication without time or location constraints. The diffusion of mobile telephony, similar to the diffusion of innovations (Rogers, 2003), is generally represented by an S-shaped (cumulative) curve. The curve rises gradually, accelerates after taking off (assuming that the service is adopted successfully), begins to level off following the inflection point and, finally, increases slowly to approach saturation. The number of mobile telephone subscribers reached 1.2 billion globally in 2002, exceeding the number of fixed-line telephone subscribers (1.1 billion) (ITU, 2008) and making mobile telephony the dominant telecommunications service globally.

The rapid diffusion of mobile telephony has attracted considerable attention. Stoneman and Battisti (1997) using firm level data tested the validity of different modeling techniques,
e.g., Gompertz and Logistic. According to their results, a distribution free equilibrium model might provide further insight into the diffusion process than the disequilibrium Logistic type of models. Gruber and Verboven (2001a) analyzed mobile diffusion in 15 EU countries by using the Logistic model. Their study demonstrated that while technology and competition are significant determinants of mobile diffusion, technology more significantly affects mobile diffusion than the competition does. While using the Bass model, Sundqvist et al. (2005) examined years of adoption of mobile communication in 25 countries, indicates that national wealth is positively associated with early adoption of mobile communications. That work also demonstrated that adopters of mobile technology attempting to avoid uncertainty have a large imitation coefficient. Rouvinen (2006) compared the diffusion speed in industrialized and developing countries using the Gompertz model. That study found that the two groups of countries do not differ in diffusion speed, even though later entrants experienced faster diffusion.

Above empirical works clearly indicate that applying a diffusion model analogy is the initial step in analyzing the diffusion of mobile telephony. However, the Logistic, Gompertz and Bass models have their own unique characteristics. Still, no strong arguments or principles have yet been developed for selecting a diffusion model. Moreover, although previous studies have found that late entrants enjoy rapid diffusion (Takada and Jain, 1991; Ganesh et al., 1997; Rouvinen, 2006), the speed of diffusion for the accelerated diffusion warrants further study.

While attempting to identify the drivers of accelerated diffusion in mobile telephony, this study analyzes the drivers of its diffusion by using Taiwan data as a sample. Taiwan introduced mobile telephony commercially in 1989. Taiwan was one of only two countries worldwide in which the penetration (subscribers per 100 inhabitants) of mobile telephony exceeded 100% in 2002. Taiwan is thus an appropriate site for such a study. Moreover, this study attempts to reduce uncertainty in selecting a diffusion model by comparing the performances of the Gompertz, Logistic and Bass models in terms of both fitting and forecasting in order to find the optimal model. The dynamics of the optimal model are also analyzed to understand why it excels in accelerating the diffusion of mobile telephony.

1.1 Mobile telephony in Taiwan

Telecom services in Taiwan initially operated under the regulations of the Directorate General of Telecommunications (DGT) of the Ministry of Transportation and Communications. However, under both domestic pressure to eradicate the monopoly and overseas pressure to liberalize the telecom market associated with WTO accession negotiations (WTO, 2004), the state-owned operator-Chunghwa Telecom (CHT), which functions separately from DGT, was established in July 1996 to manage the operations of telecom services. Consequently, the pure regulator-DGT assumed responsibility for introducing market competition by deregulating telecom services, i.e. inviting private operators in addition to CHT to enter the market. Among the various telecom services, Taiwan government prioritized mobile telephony for deregulation due to strong public calls to terminate the monopoly as an effective means of enhancing service quality. The mobile telephony market was subsequently deregulated in 1997, a year after the restructuring of DGT. Moreover, five additional mobile operators entered the market in 1998.

Moreover, as most mobile calls originate from or terminate at a fixed-line network when the market began to liberalize, interconnection fees with the fixed-line monopoly-CHT initially cost private mobile operators a significant amount. The interconnection arrangements
between mobile and fixed-line services can ensure or ruin the business plans of new mobile operators (ITU, 1999). Without regulation, private mobile operators lack negotiation power regarding the interconnection fees with the fixed-line monopoly-CHT. To further safeguard competition and prevent CHT from engaging in the anti-competitive pricing strategies, DGT stipulated regulations governing connections and implemented two compulsory reductions in interconnection fees between private mobile operators and CHT. Those fees were initially reduced in October 1998, when the interconnection fee was reduced to 1.15 TWD (Taiwan Dollar) per minute from 1.6 TWD per minute previously, amounting to a 28% reduction in fees. The second reduction of interconnection fees occurred in October 1999, when the interconnection fee was reduced again to 0.96 TWD per minute, from 1.15 TWD per minute previously, representing a 17% reduction in fees (DGT, 2000).

Deregulation of mobile telephony services and regulation of the interconnection fees affected price (i.e. total revenue/total traffic) reductions of mobile telephony in Taiwan. Figure 1 shows the price reductions related to mobile telephony in Taiwan from 1998–2007 (data are unavailable before 1998). Mobile telephony cost 225.37 TWD per minute in 1998 (the first year in which private operators entered the market). In 1999 (when the effect of the first reduction of interconnection fees in October 1998 was included), the price of mobile telephony was 105.82 TWD per minute, half the price of that in 1998. In 2000 (when the effect of the second reduction of interconnection fees in October 1999 was included), mobile telephony cost 9.87 TWD per minute, just one tenth the price of that in 1999.

Figure 1. Price of mobile telephony in Taiwan

Liberalization of the mobile telephony market in Taiwan continues to significantly accelerate the market competition. Market competition in mobile telephony is intense to the extent that mobile handsets are often free for customers subscribing an operator for a certain period and making a minimum usage payment. Among the numerous incentives that mobile operators offer include special discounts and customized usage plans to further increase mobile usage. Mobile penetration in Taiwan was 108% in 2002. Taiwan was one of only two
countries worldwide in which the penetration of mobile telephony exceeded 100% in 2002, with Luxembourg (the other country) having a penetration of 106%. Taiwan can thus be viewed as a fast follower in mobile communications.

The rest of this paper is organized as follows. Section 2 introduces pertinent empirical studies. Section 3 then presents the methodology of this study. Next, Section 4 summarizes the results, followed by a discussion. Section 5 gives the implications of our findings. Conclusions are finally drawn in Section 6, along with recommendations for future research.

2. Literature review

Although technological diffusion processes are generally denoted via S-shaped curves, models and reality differ in the precise shape of the individual curves. Technological diffusion has been analyzed using numerous approaches (Karshenas and Stoneman, 1995). While stressing the role of imitation in technical change, Mansfield (1968) asserted that the full economic impact of innovation occurs only when imitation is underway. Bass (1969) pioneered the renowned Bass model by combining the purchasing behaviors of innovators and imitators in the adoption of consumer durables. While viewing technological advances as a set of substitution processes, Fisher and Pry (1971) hypothesized that many technological advances can be considered as competitive substitutions to satisfy the requirements of another technology. Furthermore, “the fractional rate of fractional substitution of new for old is proportional to the remaining amount of the old left to be substituted.” Moreover, Geroski (2000) developed a mixed information source model for technology diffusion by assuming that broadcast and word-of-mouth communications are the major information sources for technology diffusion.

Applying a diffusion model analogy is the initial step in analyzing the diffusion of innovative telephony. While reviewing pertinent literature for modeling and forecasting innovation diffusion, Meade and Islam (2006) found that, despite the abundance of research, few research questions have been resolved. For instance, only de-selected models, which are clearly inferior, have been reported. Meade and Islam (2001) also asserted that a reasonable initial set of candidate models includes the Gompertz, Logistic and Bass models. These models are also extensively adopted in diffusion studies of mobile telephony. Each model has its own unique features. For instance, while studying the demand in the United States for computers, Chow (1967) indicated that the Gompertz model explained the demand better than the Logistic model did. Meanwhile, Griliches (1957) found that the Logistic model explained the adoption of hybrid corn in the United States. Bass (1969) developed a novel diffusion model, the Bass model, which accurately forecast the peak in color TV sales in 1968. The empirical results of Chow (1967), Griliches (1957) and Bass (1969) provide valuable references for studies adopting the Gompertz, Logistic, and Bass models, respectively.

Although the Logistic model is the most extensively adopted one for mobile telephony diffusion (Gruber and Verboven, 2001a; 2001b; Frank, 2004; Liikanen et al., 2004; Lee and Cho, 2007), the Bass model has been widely used (Dekimpe et al., 1998; Sundqvist et al., 2005), as well as the Gompertz model (Rouvinen, 2006).

Mobile telephony diffusion studies have largely focused on determinants of the growth rate of the diffusion, i.e. the diffusion rate, which includes technological innovation, deregulation/market competition, economic situation, and distinctions between substitutive and complementary services.
Most studies have identified deregulation/market competition as largely responsible for influencing the diffusion rate. Similarly, numerous studies have ranked the economic situation (based on GDP) as significant (Frank, 2004; Sundqvist et al., 2005; Lee and Cho, 2007), while a few have identified it as insignificant (Gruber and Verboven, 2001a). Notably, a few studies have determined the significance of digital technology/technological innovation (Gruber and Verboven, 2001a). The number of fixed telephone lines was the only significant factor with a negative coefficient for diffusion rate (Gruber and Verboven, 2001a; Lee and Cho, 2007), and identified as substitutive for mobile telephony rather than complementary. Moreover, Massini (2004) found that both the digital technology and a decreasing price of handsets has accelerated mobile telephony diffusion and increased the saturation level in Italy.

3. Methodology

Most data in this study for mobile telephone subscribers were obtained from the World Telecommunication/ICT Indicators 2007 published by the International Telecommunication Union (ITU). The population of mobile telephony is made up of individuals rather than households. Data for estimating the determinants, i.e. technology innovation, deregulation, operators, fixed-line telephony and pre-payment restriction, were obtained from the National Communications Commission, Taiwan. GDP data was obtained from the database of the International Monetary Fund. Since Taiwan did not have mobile telephone subscribers before 1989, this study was based on 20 observations from 1988-2007.

3.1 Diffusion model

Analyzing the diffusion of mobile telephony initially involves adopting the analogy of a growth model. Drivers of the diffusion rate and diffusion forecasting are estimated based on the chosen growth model. However, to our knowledge, no framework for model selection has been developed and, thus, the model selection becomes an ad hoc process. This study determines the most appropriate model for analyzing the diffusion of mobile telephony by comparing the performances of the three most popular models, i.e. Gompertz, Logistic and Bass. This study tests the model fitness, and then evaluates the forecasting ability of each model.

Equations (1), (2) and (3) list the equations of the Gompertz, Logistic and Bass models, respectively.

\[
N(t) = Ke^{-e^{rt(1-e)}} 
\]

\[
N(t) = \frac{K}{1+e^{rt(1-m)}} 
\]

\[
N(t) = K \frac{1-e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} 
\]

In these equations, \(N\) denotes the number of mobile telephone subscribers at time \(t\), \(r\) denotes the growth rate, and \(K\) denotes the number of mobile telephone subscribers at equilibrium, i.e. the maximum number of subscribers, where \(p\) represents the innovation coefficient and \(q\) represents the imitation coefficient.

Success of a model in fitting historical data demonstrates the basic structural soundness of a model and its effectiveness as a forecasting device for future growth (Heeler and Hustad,
The fitnesses of the Gompertz, Logistic and Bass models were estimated by adopting the nonlinear least squares procedure. Forecasting accuracy of each model was tested by applying input data (trained data) with various durations. Restated, some years at the end of the data set were omitted from the estimation procedure as the hold back samples. The remaining data were trained data, and the curves of the three models were extrapolated to forecast the subsequent values, which were then compared with the hold back (actual) data to evaluate their forecasting accuracy of diffusion. The forecast performances were compared by using 2-year forecasting accuracy. The measures of root mean square error (rmse) and mean absolute percentage error (mape) for assessing the model performance developed by Meade and Islam (1995) were adjusted as follows:

\[
rmse = \sqrt{\frac{2}{k-1} \sum_{k=1}^{2} (x_{\text{fit,year}+k} - E(x_{\text{fit,year}+k} | x_{\text{fit,year}}))^2},
\]

\[
mape = \frac{2}{k} \sum_{k=1}^{2} \frac{|x_{\text{fit,year}+k} - E(x_{\text{fit,year}+k} | x_{\text{fit,year}})|}{x_{\text{fit,year}+k}} \times 100
\]

The testing period lasted from 1992–2008. Whether the three models statistically differ in annual performance data was evaluated using Friedman’s non-parametric two-way analysis of variance (a randomized block design). The analysis of variance used the models as treatments and the time series as blocks. Rankings of both the fitted and forecasted performances of the three models by rmse were calculated. However, for forecasting the rmse performance, the mape of at least one model must not exceed 20; otherwise, the data for that year were deleted. The null hypothesis is that the treatments have identical effects. The null hypothesis is rejected at a \( p \)-value of 0.10 or less. In this study, both three-model and pairwise comparisons were performed to complement each other owing to the limited number of observations. The most appropriate diffusion model was that with the best fitness and forecasting accuracy in terms of minimum rmse.

### 3.2 Drivers of the diffusion rate

After the most appropriate diffusion model is identified, the next step involves estimating the determinants of the diffusion rate of the model. The diffusion rate of a model affects the slope of the S-shaped curve, i.e. the speed of diffusion. Since the Bass model lacks a diffusion rate parameter, it is not considered when estimating the determinants of the diffusion rate. This study adopts the 2-parameter model for estimating the growth rate developed by Frank (2004), in which the diffusion rates of the Gompertz and Logistic models are given by Eqs. (5a) and (5b), respectively, as follows:

\[
N_T = K_T e^{-e^{-r_T(T-m)}}
\]

\[
N_T = \frac{K_T}{1 + e^{-r_T(T-m)}}
\]

where \( N_T \) denotes the number of adopters at time \( T \); \( K_T \) denotes the maximum (or equilibrium) number of adopters; \( r_T \) denotes the growth (or diffusion) rate at time \( T \), and \( m \) represents the year of the inflection point in the growth curve, which is 1999 in Taiwan. Both \( K_T \) and \( r_T \) are time-variant. \( K_T \) is correlated with \( r_T \). A larger \( r_T \) implies a higher \( K_T \). The saturation level (i.e.
\( K_T \) over the entire population) is not limited to 100% as other technologies do. Examples can be found in Stoneman and Battisti (1997). If the most appropriate model is the Gompertz model, then use Equation (5a); if the most appropriate model is the Logistic model, then use Equation (5b).

Six items are selected as independent variables for linear regression, Equation (6), to determine their significance for the diffusion rate. These items are gross domestic product per capita (GDP), technology innovation/system digitalization (DIG), deregulation/market competition (DER), number of operators (OPR), fixed-line telephony (FIX) and pre-payment restrictions (PPR).

\[
\begin{align*}
 r_t &= \beta_0 + \beta_g \text{GDP}_t + \beta_d \text{DIG}_t + \beta_r \text{DER}_t + \beta_o \text{OPR}_t + \beta_f \text{FIX}_t + \beta_p \text{PPR}_t \\
(6)
\end{align*}
\]

The independent variables for the growth rate are defined below.

**Gross domestic product per capita (GDP)** GDP denotes gross domestic product per capita, which is used to reflect the national economic circumstances.

**Technology innovation/system digitalization (DIG)** The first invented mobile (cellular) telephone system utilized analog technology. The evolution of mobile systems from analog to digital technology is an important technology innovation. Introduced to Taiwan in 1989, the first analog mobile telephone system was the Advanced Mobile Phone System (AMPS). Since 1996, the Global System for Mobile (GSM) system, i.e. a digital system, has been implemented to replace AMPS in Taiwan. This study used DIG as a dummy variable indicating whether or not the analog (AMPS) or digital (GSM) system was used in Taiwan, i.e. identifying the use of digital technology. The value of DIG was 0 before 1996, i.e. introduction of the digital system-GSM, and 1 afterwards.

**Deregulation/market competition (DER)** Governments have largely attempted to speed up the diffusion of new technologies (Stoneman and David, 1986). The deregulation is largely the major means for mobile telephony diffusion. The deregulation examined in this study refers to governmental liberalization of the mobile telephone market to the private sector. The speed of diffusion is related to the number of operators in the market (Stoneman, 1990). A dummy variable, DER identifies the accession of a market to new operators. With five new private operators entering the Taiwanese mobile market in 1998, the value of DER was 0 before 1998, and 1 afterwards.

**Number of operators (OPR)** The number of operators correlates well with intensity of competition and the diffusion of mobile telephony. A raised number of operators implies more intense competition and hence, faster diffusion. To clarify the role of variation in the number of operators, this study treats DER and OPR as two independent variables. The number of mobile operators has fluctuated with three mergers occurring during 2001–2004 and two new operators entering the market in 2006. Therefore, the number of operators (OPR) is an appropriate independent variable for testing its significance to the diffusion rate.

**Fixed-line telephony (FIX)** Mobile telephony was initially considered complementary to fixed-line telephony in industrialized countries and a substitute in developing ones (ITU, 1999). However, other works found that during the initial stage of introducing mobile
telemancy, fixed-line and mobile telephony have a complementary relationship since most phone calls are connected via fixed-line telephony (Ahn and Lee, 1999). However, during the latter stage of diffusion, mobile telephony is prevalent. Individuals often use a mobile phone rather than a fixed-line phone. Fixed-line and mobile telephony switches to have a substitutive relationship. FIX denotes the number of main telephone lines (fixed phones) per 100 inhabitants. If the coefficient of FIX, i.e. $\beta_f$, is positive, then fixed and mobile phones are complementary. If the coefficient is negative, then they are substitutive.

**Pre-payment restriction (PPR)** Anonymity is a by-product of the consumption of commodity-like pre-paid mobile phone cards. Taiwan has witnessed the increasing use of pre-paid mobile phone cards for fraud and deception purposes. Under pressure from the general public and the Legislative Yuan, mobile phone operators have imposed strict requirements on application for pre-paid mobile phone cards since 2004. Such measures include safeguards such as one card limit per customer and two forms of ID as proof in order to receive a card. In response to such restrictions, applications for pre-paid mobile phone cards declined suddenly (DGT, 2005; 2006). This study adopted PPR as a dummy variable to demonstrate its effect on mobile diffusion. The value of PPR was 0 until 2003, and 1 afterwards due to this ongoing policy.

4. Results and discussion

4.1 Diffusion model

4.1.1 Champion: logistic model

Table 1 shows the performance measures for fitted (rmse) and two-year forecast (rmse and mape) for the three models from 1992-2008. Table 2 lists the $p$-value of the Friedman test for model performance comparison. The performance of the Logistic and the Bass model is undistinguishable by the Friedman test (Table 2). According to Table 1, the Logistic model is superior with minimum sum of fitted rmse and 2-year forecast rmse (1.783E+07). Hence, the Logistic model is considered the most appropriate diffusion model for mobile telephony in Taiwan, therefore, is applied to identify the drivers for the growth rate of the diffusion model.

4.1.2 Bass model: degenerating into the logistic model

The Bass model is nearly undistinguishable from the Logistic model in terms of rmse performance (Table 2). To further elucidate why the Bass model is the same as the Logistic model in this case, the first-order differential equations for the Bass and Logistic model are presented as follows:

$$\frac{dN}{dt} = p + q \frac{N}{K}$$

$$\frac{dN}{dt} = r \frac{N}{K}$$  \hspace{1cm} (7)

$$\frac{dN}{dt} = r \frac{N}{K}$$  \hspace{1cm} (8)
Mathematically, if $p=0$ in Equation (7), a special case of the Bass model, Equation (7) is the same as Equation (8), the Logistic model. Namely, if the innovation coefficient ($p$) of the Bass model (Equation (7)) is negligible, the imitation coefficient ($q$) of the Bass model is the same as growth rate ($r$) for the Logistic model (Equation (8)). Thus, the two equations, Eqs. (7) and (8), are identical. Table 3 lists the coefficients of the Bass and Logistic models for 1992–2008. All innovation coefficients ($p$) of the Bass model are small (8.28e-7~5.29e-6) after 1999 (inflection year of the diffusion curve). Imitation coefficients ($q$) in the Bass model after 1999 were the same as the growth rates ($r$) for the Logistic model. The values of $q$ or $r$ were 1.08–1.29 after 1999. Restated, for mobile telephony diffusion after the inflection year (1999) in Taiwan, the innovation effect of the Bass model was so small that only the imitation effect of the Bass model was significant. Thus, the Bass model degenerated into the Logistic model.

Figure 2 compare the performances of diffusion models with trained data until 2004. The curves of the Bass and Logistic models, which almost overlap each other, are undistinguishable.

![Figure 2. Comparison of performances of diffusion models with trained data until 2004](image-url)
Table 1. Comparison of model fit and forecasting performance of the three models

<table>
<thead>
<tr>
<th>Data until year</th>
<th>Accumulated mobile subscriptions</th>
<th>Fitted rmse</th>
<th>2-year forecast rmse</th>
<th>2-year forecast mape</th>
<th>Mobile penetration (%)</th>
<th>Fitted best model</th>
<th>Forecast best model</th>
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<td>8.76E+05</td>
<td>8.76E+05</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>7.15E+06</td>
<td>5.93E+06</td>
<td>5.90E+06</td>
<td>3.78E+07</td>
<td>1.19E+07</td>
<td>1.22E+07</td>
<td></td>
</tr>
</tbody>
</table>

Fitted data of one year with not converged (NC) of any model are deleted from both rmse accumulation calculation and further Friedman test.

Forecast data of one year without any model with mape<20 are deleted from both rmse accumulation calculation and further Friedman test. (sample size: 15)
Table 2. *P*-value of the Friedman test for model comparison in Taiwan

<table>
<thead>
<tr>
<th>Fitted rmse</th>
<th>Forecast rmse (two-year period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLB (^a)</td>
<td>GL</td>
</tr>
<tr>
<td>0.01*</td>
<td>0.07*</td>
</tr>
</tbody>
</table>

\(^a\) G: Gompertz model; L: Logistic model; B: Bass model
Two asterisks (**) and one asterisk (*) denote the statistical significance at the 5% and 10% levels, respectively, (sample size: 15 for fitted rmse, 9 for forecast rmse).

Table 3. Coefficients of the bass and logistic models

<table>
<thead>
<tr>
<th>Year</th>
<th>Bass</th>
<th>Logistic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(p)</td>
<td>(q)</td>
</tr>
<tr>
<td>1992</td>
<td>3.89e-3</td>
<td>0.63</td>
</tr>
<tr>
<td>1993</td>
<td>0.02</td>
<td>1.00</td>
</tr>
<tr>
<td>1994</td>
<td>0.02</td>
<td>1.16</td>
</tr>
<tr>
<td>1995</td>
<td>0.03</td>
<td>0.68</td>
</tr>
<tr>
<td>1996</td>
<td>0.03</td>
<td>0.35</td>
</tr>
<tr>
<td>1997</td>
<td>1.83e-7</td>
<td>0.23</td>
</tr>
<tr>
<td>1998</td>
<td>1.02e-8</td>
<td>0.80</td>
</tr>
<tr>
<td>1999</td>
<td>5.97e-10</td>
<td>0.90</td>
</tr>
<tr>
<td>2000</td>
<td>1.14e-6</td>
<td>1.26</td>
</tr>
<tr>
<td>2001</td>
<td>1.48e-6</td>
<td>1.23</td>
</tr>
<tr>
<td>2002</td>
<td>3.17e-6</td>
<td>1.14</td>
</tr>
<tr>
<td>2003</td>
<td>5.29e-6</td>
<td>1.08</td>
</tr>
<tr>
<td>2004</td>
<td>1.83e-6</td>
<td>1.20</td>
</tr>
<tr>
<td>2005</td>
<td>9.51e-7</td>
<td>1.27</td>
</tr>
<tr>
<td>2006</td>
<td>8.28e-7</td>
<td>1.29</td>
</tr>
<tr>
<td>2007</td>
<td>9.19e-7</td>
<td>1.28</td>
</tr>
<tr>
<td>2008</td>
<td>1.18e-6</td>
<td>1.25</td>
</tr>
</tbody>
</table>

NC: not converged (sample size: 15)
4.1.3 Dynamics of the logistic model: network externalities

Selecting a growth curve that optimally matches the underlying dynamics of the diffusion process is essential (Martino, 1993). The mathematical form of the selected model must fit and explain the diffusion data (Stoneman, 1983). As the Logistic model outperforms the other models in both fitness and forecasting, the underlying controlling mechanism of this model warrants further study. The first-order differential equation of the Logistic model is repeated as follows.

$$\frac{dN}{dt} = \frac{r}{K} N (K - N)$$

(9)

This equation indicates that among non-adopters \((K-N)\), those that decide to adopt \((dN/dt)\) are positively correlated with the number of adopters \(N\) with the coefficient of \(r/K\). Assuming that the adoption decisions by non-adopters positively correlates with the utility value of adoption, Equation (7) defines the network externalities (Jang et al., 2005). Restated, the utility derived by the consumer from a product increases as the number of other agents consuming that product increases; that is, demand-side economies of scale occur (Katz and Shapiro, 1985; 1986).

4.2 Drivers of the diffusion rate

4.2.1 Main driver: deregulation

Table 4 summarizes the estimation results of the drivers (significant variables) for the growth rate. The unrestricted model includes all variables and the restricted model omits three insignificant variables. The criterion to exclude the insignificant variables is by testing, sequentially, whether the adjusted \(R^2\) can be increased by deleting the candidate variables sequentially (Montgomery et al., 2001).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unrestricted</th>
<th>Restricted</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\beta_0)</td>
<td>1.150 (0.646)</td>
<td>1.137** (0.353)</td>
</tr>
<tr>
<td>GDP (\beta_g)</td>
<td>2.70e-7 (6.21e-5)</td>
<td>–</td>
</tr>
<tr>
<td>DIG (\beta_d)</td>
<td>-0.065 (0.174)</td>
<td>–</td>
</tr>
<tr>
<td>DER (\beta_c)</td>
<td>1.110** (0.476)</td>
<td>1.255** (0.228)</td>
</tr>
<tr>
<td>OPR (\beta_o)</td>
<td>-0.028 (0.069)</td>
<td>-0.053 (0.037)</td>
</tr>
<tr>
<td>FIX (\beta_f)</td>
<td>-0.014 (0.023)</td>
<td>-0.019** (0.008)</td>
</tr>
<tr>
<td>PPR (\beta_p)</td>
<td>0.058 (0.173)</td>
<td>–</td>
</tr>
<tr>
<td>Adjusted (R^2)</td>
<td>0.9197</td>
<td>0.9353</td>
</tr>
</tbody>
</table>

Two asterisks (**) and one asterisk (*) denote the statistical significance at the 5% and 10% levels, respectively (sample size: 15).
Estimation results indicate that the deregulation/market competition (DER) and the fixed lines (FIX) are significant, while the economic situation (GDP), technology innovation (DIG), and the number of operators (OPR) are insignificant.

The negative sign of coefficient of FIX indicates that mobile telephony is a substitute for fixed-line telephony in Taiwan. Therefore, DER, the other significant factor for the diffusion rate, is the main driver for the diffusion. This finding matches the comments of Gruber and Verboven (2001b) that “introducing competition has a strong and immediate impact on diffusion.”

4.2.2 Deregulation: pushing the diffusion to the takeoff level

Rogers (2003) asserted that ‘a crucial concept of the diffusion process is the “critical mass, the point at which enough individuals in a system have adopted an innovation and after which further diffusion becomes self-sustaining.’ ‘An S-shaped diffusion curve “take off” at about 10 to 20 percent adoption, when interpersonal networks become activated so that a critical mass of adopters begin using an innovation.’ Restated, after the critical mass of a diffusion process is reached (about 10 to 20 percent adoption), it begins to take off and becomes self-sustaining.

Stoneman and Diederan (1994) and Stoneman and Battisti (2000) thoroughly elucidated how the policy/regulation intervenes the diffusion. This study reflects the importance of policy, indicating that deregulation, i.e. introducing market competition, in mobile telephony is the main driver for the diffusion rate. Deregulation of the mobile telephony market occurred in 1998. Moreover, the penetrations of mobile telephony in Taiwan were 6.9% and 21.6% in 1997 and 1998, respectively. Namely, 1998, the year of deregulation, was the takeoff year of the diffusion. Figure 3 compares the performance of the three models with trained data until 1997 and the actual penetration of mobile telephony for each year. Figure 3 reveals that no model can accurately predict the penetration of 1998, which is only one year after the available data. The three growth models have a poor forecasting accuracy owing to their inability to reflect fluctuations in the development of a market caused by economic factors, in this case deregulation (Meade, 1984). Restated, deregulation causes the diffusion to take off, and cannot be forecast from the natural growth of any of the three models. Restated, 1998 is the takeoff year owing to the deregulation policy, external economic factor, rather than by natural growth trend.

Figure 3. Forecasting by diffusion models with trained data until 1997
5. Implications

An S-shaped diffusion curve is considered to take off when penetration reaches 10–20%, and becomes self-sustaining after the takeoff stage (Rogers, 2003). This study demonstrates that deregulation is the main driver for the accelerated diffusion of mobile telephony in Taiwan since it introduces the market competition, markedly reduces the service prices, and facilitates the diffusion to the takeoff level, which is essential for a successful diffusion.

The Logistic model is the champion model after the diffusion takeoff (Table 1). Network externalities are the dynamics of the Logistic model. Restated, network externalities dominate the fast diffusion after the takeoff level. Overall, network externalities, dynamics of the diffusion model, while following the deregulation, driver of the diffusion to the takeoff level, accelerate the mobile telephony diffusion in Taiwan. Restated, the interaction of deregulation and network externalities is clearly demonstrated in this accelerated diffusion of mobile telephony.

Moreover, in this study, the imitation effect in the Bass model is the same as the network externality effect in the Logistic model (Eqs. (7) and (8)). Imitation could be regarded as some kind of learning. Restated, a learning mechanism is implicitly involved in the accelerated diffusion process (Mansfield, 1963; Stoneman, 1981).

6. Conclusions

This study identifies the drivers behind the accelerated diffusion of mobile telephony in Taiwan, in terms of the dynamics of the diffusion model and the forces driving the diffusion rate of the model.

Empirical results indicate that the Logistic model is the most feasible diffusion model for Taiwan. Network externalities explain the dynamics and superiority of the Logistic model over other models. The network externalities reflected by the Logistic model are the same as the imitation effect of the Bass model, while the innovation effect of the Bass model is negligible.

Moreover, deregulation is the main driver for the diffusion rate owing to its ability to markedly reduce service prices, as well as facilitate the diffusion to the takeoff level, i.e. vital to a successful diffusion. Moreover, fixed-line telephony is a substitute, rather than a complement, for mobile telephony in Taiwan. The economic circumstances, technological innovation, number of operators and pre-payment restriction only slightly affect the diffusion rate.

Overall, network externalities, dynamics of the diffusion model, while following the deregulation, driver of the diffusion to the takeoff level, accelerate the diffusion of mobile telephony in Taiwan. Restated, the interaction of deregulation and network externalities is clearly demonstrated in this accelerated diffusion of mobile telephony.

Many empirical studies have established how deregulation significantly affects the diffusion of mobile telephony. However, this study demonstrates that the deregulation is not only a significant factor, but also essential to the takeoff level of the diffusion. Our empirical results indicate the just-in-time facilitating power of the deregulation policy.

Exactly how deregulation impacts the diffusion of mobile telephony can be defined clearly as more cases are studied, providing a valuable reference for both policy makers in emerging telecom services and future research. Moreover, although mobile telephony penetration may exceed 100%, some individuals have adopted more than one mobile, while some individuals will never purchase one. This dilemma poses a problem of nominal penetration and actual penetration for mobile telephony, and can be elucidated when capable of providing insight further into mobile telephony diffusion.
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References


