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ABSTRACT

A newer generation of innovative product plays the role of carnivorous predator that feeds on preys, which are often composed of former generations of innovations in the real world. The intriguing aspect of the evolutionary marketplace is that the nature of competitive structure can change over time. In this relentlessly innovative market, the successful factor in innovation launch depends on the precise market demand forecasting. The aim of this article is to develop a comprehensive multi-generation diffusion model to reveal different competitive interactions among multiple generations of innovations. The data calibrated is top three telecommunication carriers in Japan; each has introduced two generations of cellular phone services. Result shows the proposed multi-generation diffusion model fits very well on the prediction of new subscribers. It illustrates dynamic relationship among generations of innovations which provides a better understanding of comparative intensity of competition for new products launches.

Keywords: multi-generation diffusion model, takeoff phenomenon, food-web model and population ecology

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Introduction

A newer generation of innovative product always plays the role of carnivorous predator that feeds on preys which are often composed of former generations of innovations in the real world. The intriguing aspect of the evolutionary marketplace is that the nature of competitive structure can change over time. In this relentlessly innovative market, the successful factor in innovation launch depends on the precise market demand forecasting. However, it is well known that fairly high risks are associated with new product investment, the failure rate has variously been reported in the range of 40 to 90 percent (Crawford 1977; Mahajan, Muller, and Wind 2000). Such high failure rate is due to the difficulty in predestining the diffused “market takeoff” point where a major acceleration of the market has advanced and the innovative firms have prepared themselves to ride the wave prior to their competitors (Agarwal and Bayus 2002; Golder and Tellis 1997, 2004; Moore 1999).

The wealth of research concerning the prediction of innovation diffusion has been particularly influential in both practical and academic areas. Since the pioneer work of Bass (1969), a widely applicable tool was developed to measure innovation characteristics and the potential market magnitude of diffusion. Some modified the specification of model assumption and parameter estimation, while a large number of scholars extended the autonomous Bass model to optimal control applications by adding marketing decision variables such as pricing, advertising, and product benefits (e.g., Bass, Krishnan and Jain 1994; Bass, Jain and Krishnan 2000; Dockner and Jorgensen 1988; Horsky 1990; Kalish 1983). The most drastic modification is to extend the scope of diffusion from single- to multi-generation where the newer generation has taken over the old (Bass ad Bass 2004, Norton and Bass 1987; Danaher, Hardie and Putsis Jr. 2001). In practice, companies develop and launch new products all the time. The multi-generation diffusion model is theoretically sound and more systematic in analyzing the substitution effects between different generations on forecasting the sales volume.

Most of the diffusion models indicate a former and a newer technology in a product category as absolute substitution for a company. Therefore, the sales of the newer technology are composed of the adopters of former products and the potential users. If the adopters of the former generation, however, believe that the newer technology would not lure them to do switching, the growth of the new products might be so blocked that the company's investment in the new technology cannot be recovered. Thus, not only are many multi-generation models not able to shape the demand but also their predicting power are weakened. In addition, the bulk of diffusion models of successive generations simply take account of the influence of different generations in the same product category in the same company. The effects of competition from comparable technologies and competitors are not included in previous diffusion models. Since Bass-based models have limitation in depicting and forecasting the demand (sales) of a market consisting of more than one suppliers and more than one product generation, this study uses the concept of ecosystem, which has recently introduced to the diffusion theory (Shocker, Bayus and Kim, 2004), to introduce an ecological diffusion model to predict the sales of multi-generation products.

The Literature

Single-generation Diffusion Models

The purposes of diffusion models are to describe the degree of dispersing the innovation technology and then to project potential demand as far as possible among a given set of prospective adopters. The first single-generation diffusion model introduced by Bass (1969) aimed at portraying the penetration and saturation situations of the new product diffusion process. The cumulative adoption course between new introduced product and the mature product is shaped by an S curve. The simple Bass model described above provides a basis for researches on diffusion. From 1960s to 1980s, the Bass followers had focused on examining the issues such as first purchase, parameter estimation, flexibility, refinements and extensions, and utilization of the model (Mahajan, Muller and Bass, 1990). For efforts to increase the forecasting accuracy of Bass-based model, the focuses have been on introducing marketing and non-marketing variables, various stages of diffusions and different countries, and successive generations of technology (Meade and Islam, 2006).

The basic single-generation Bass model assumes that the adoption of new product is influenced by two ways of communication, mass media and word of mouth. New product adopters are grouped into innovators and imitators, of which the former is affected by mass media (external influence) and the latter is by word of mouth (internal influence). Hence, the probability that an initial purchase occurs at time *t*, given that no purchase has happened, can be represented by a linear hazard rate, i.e.,

$$h(t) = \frac{f(t)}{1 - F(t)} = p + (q/m) \times N(t)$$

where

f(*t*) is the probability density function of adoption at time *t*; *F*(*t*) defines the cumulative density function of adopters at time *t*; *p* denotes the coefficient of innovation and reflect the importance of innovators and presents the probability of an original purchases at time zero; *q* stands for the coefficient of imitation and measures the stress of the prior adopters on imitators; *m* describes the market potential size of the new product; and *N*(*t*) is the number of previous adopters at time *t* and can be obtained by multiplying *F*(*t*) with parameter *m* (i.e., $N(t) = m \times F(t)$).

In order to fine *F*(*t*), the hazard rate equation can be rearranged as follows:

$$f(t) = \frac{dF(t)}{dt} = [p + qF(t)] \times [1 - F(t)] = p + (q - p)F(t) - qF^2(t)$$

A differential equation can be obtained by rearranging the above equation,

$$dt = \frac{dF(t)}{p + (q = p)F(t) - qF^2(t)}$$

By integrating the above equation, *F*(*t*) can be derived as follows:

$$F(t) = \frac{1 - e^{-(p+q)\times t}}{1 + (q/p) \times e^{-(p+q)\times t}} \qquad (1)$$

The two parameters *p* and *q*, each having a value between zero and one are able to characterize the diffusion process. As values of the parameters are getting closer to one, the speed of new product diffusion is faster. Furthermore, as the coefficient of imitation is greater than that of innovation (i.e., internal influence is larger than the external influence), the amount of adopters is gradually growing up to a peak. On the contrary, should the coefficient of innovation is greater than that of imitation (i.e., the external influence is larger than the internal one) the speed of the diffusion is quite fast yet the number of adopters will continuously decline.

Multi-generation Diffusion Models

Combing the substitution model and the Bass diffusion model, Nortan and Bass (1987) proposed a generational diffusion model, which assumes that the newer products replace the older ones. These relationships instinctively represent that the penetration for successive generations is influenced by the number of adopters of the former generations. In their model, the successive generation will obtain sales not only from the adopters who have chosen earlier generational products but also from the ones who have not made up their mind to choose former generations. The model was first empirically applied to semiconductor devices and extended to electronics, pharmaceutical, consumer and industrial sectors (Norton and Bass, 1992). The Norton-Bass model has several assumptions: (1) Once an application of a particular product includes the new technology, it does not revert to earlier technologies in a pertinent period of time; (2) Sales are composed of the amount of units purchased per user times the number of users, and the average rate of consumption per time period approaches a constant; (3) the number of applications in a new innovation has upper limit which is constant; (4) the advancing generations can do everything the previous generations could do and probably do more; (5) the market potential varies with time along with the density function of time to adoption for each generation; (6) the substitution situation incorporating actual and potential sales happen from earlier to later generations; and (7) most restrict one, $p_i = p$ and $q_i = q$ for all generation i.

The extremely constraints of p and q being constant was latter relaxed by Islam and Meade (1997) by reformulating the Norton-Bass model, which was applied to investigate mobile telephone data from eleven countries, each of which consisted of two or three generations of telephones. Mahajan and Muller (1996) extend the Norton-Bass model to describe the substitution and diffusion patters simultaneously for durable technological goods, which are characterized by continuous purchasing behavior. Their model explicitly accounts for the fact that users might skip the former generation and adopt a later generation product directly, which behavior is called “leapfrogging” phenomenon. The Mahajan-Muller model provides normative guidelines for the key elements to determine launching time (when the former generation product is at maturity stage) as a strategy for introducing new products. The parameters in their model include Bass parameters (market potentials and diffusion and substitution) as well as financial parameters (gross profit margins and the discount factor). For the sources of sales, Bass and Bass (2001) consider the sales of a product generation composed of two categories of buyers: adopter, who purchase the product of a specific category at first time, and repeating buyers, who had bought earlier generation products previously. Bass and Bass (2004) extended the sales-sources model to include sources from adopters, replacements, systems-in-use or subscribers, switchers, leap-foggers, and some other newly identified variables. However, this model simply concerned the substitution relationship between successive generations and few explanations were given to decomposed quantities, which have not been empirically validated.

Taking account of competitions within generations and among competitors, Kim, Chang and Shocker (2000) developed a model to incorporate both the substitution effects within a product category and complementary and competitive effects among product categories under multi-generation circumstances. Their model consists of two component, one of which describes technological substitution, similar to that of Norton-Bass model, and the other comprises the dynamic inter-category effects and is depicted by the variant market potential of each generation of a given product category. Although Kim, Chang and Shocker (2000) allowed for the possible competitive relationship (complementary or substitution) in their model, the inter-category dynamics simply affected the market potential and the attraction between generations was assumed fully substitution. However, the substitution of an old technology by a new one will not always proceed to completion. Versluis (2002) argues that no matter what product categories the technologies belong to, they can either fully substitute each other or arrive at a competitive equilibrium. Furthermore, all technologies are in competition at any point in time no matter what stage of product life cycle they are situated at given that new technology is competing with existing technologies in the light of the level of their market shares. Once a new product, technology, or new material is launched into the market, it takes some time to obtain market share from existing ones. Hence, the competition among successive generations should be incorporated as the covariates that affect the previous sales or subscribers characterized in the Norton-Bass model.

The Model

Dynamic Population Modeling

Multi-generation diffusion models aims at estimating/predicting sales for each generation of technological products. In the process of technological substitution or replacement, consumers of the old generation product are gradually transferring to the new generation product. Thus, what the diffusion models estimate is the interactive dynamic process of the old and the new consumer populations in a competitive market. In ecology, the growth rate of a population of organisms was considered as an unspecified function of the biomass densities of all organisms in the community as well as physical and genetic inputs (Berryman, 1995). Lotka (1925) and Volterra (1926) presented the predator-prey equations, which describe interactions between two species in an ecosystem, a predator and a prey. The simplest Lotka-Volterra equation can be specified as follows:

$$\frac{dH}{dt} = aH(t) - bH(t)P(t)$$
$$\frac{dP}{dt} = cH(t)P(t) - dP(t)$$

The two variables, *H* and *P* are the numbers of prey and predator respectively whereas *dH/dt* and *dP/dt* represents the growth of the two populations against time (*t*). The terms *H(t)P(t)* denotes the interactions between the two species. The four interactive parameters are: intrinsic rate of prey population increase (*a*), predation rate coefficient (*b*), reproduction rate of predators per 1 prey eaten (*c*), and predator mortality rate (*d*).

In this two-species model the subsistence of a predator (or parasite) merely depends on a single species of prey (or host). It presents an exponential growth of the prey (H_t = H_0e^{at}) and a linear functional response ($bH(t)P(t)$) so that the capture rate for an individual predator increased linearly with the number of prey ($cH(t)P(t)$).

Aside from the Lotka-Volterra model, one of the traditional ways of modeling population dynamics is to regard population change as the reproduction and survival of individual organisms. Using two tropical levels, Morris (1959) and Berryman (1999) expresses the number of one species in one generation, $N(t)$ as being equal to the number of the species in previous time scale, $N(t$-1) multiplied by the per-capita reproductive rate, G and various probabilities of surviving exposure in the causes of mortality (equation 2).

$$N(t) = N(t-1) \times G \times S_m \times S_p \times S_c \quad (2)$$

Whereas S_m stands for the probability of an individual surviving against the intra-specific rivalry for fixed resources; S_p denotes the probability of surviving against intra-specific rivalry for depletable resources of the lower tropical level; S_c symbolizes the probability of surviving against the attack of natural enemies in the upper tropical level.

The model of Varley, Gradwell and Hassell's (1973) convert the equation to logarithms to base 10 as:

$$\log_{10} N(t) = \log_{10} N(t-1) \times \log_{10}[\lambda] - k_m - k_p - k_c$$

The model above analyzes key factors of population and is denoted as k-value model, in which k_i = $\log_{10} S_i$, where i=m, p, c. Since the population growth is an exponential process, it is better to use natural logarithms as the tropic chains model elaborated by Berryman (1992) as follows:

$$N(t) = N(t-1) \times e^{a} \times e^{-bxN(t-1)} \times e^{-\left[\frac{c \times [N(t-1)]}{P(t-1)) + W_n}\right]} \times e^{-\left[\frac{d \times [C(t-1)]}{N(t-1) + W_c}\right]} \quad (3)$$

If R is defined as the logarithms of $N(t)$ to natural base, i.e.,

$$R = \ln[N(t)] - \ln[N(t-1)] = \ln[G] + \ln[S_m] + \ln[S_p] + \ln[S_c] \quad (4)$$

Equations (3) and (4) can be rearranged to obtain the "logistic food-chain model" as follows:

$$R = a - [N(t-1)] - \left[\frac{c \times [N(t-1)]}{P(t-1)) + W_n}\right] - \left[\frac{d \times [C(t-1)]}{N(t-1) + W_c}\right]$$

where

$a = \ln[G]$ is the maximum rate of production of prey offspring in a given environment when population density is very sparse, which means no intra-specific competition for resources, and when predators are absent;

$b \times N(t-1) = \ln[S_m]$ is the reduction from the maximum rate of reproduction owing to intra-specific competition for fixed resources, with the coefficient of *b* of intra-specific competition;

$[c \times N(t-1)]/[P(t-1) + W_n] = \ln[S_p]$ is the reduction from the maximum rate of reproduction due to intra-specific competition for depletable resources, with coefficient of *c* of intra-specific competition for a unit of depletable resource in the lower tropical level; and

$[d \times C(t-1)]/[N(t-1) + W_c] = \ln[S_c]$is the reduction from the maximum rate of reproduction due to attack from enemies in the upper tropical level; this is perceived as intra-specific competition for enemy-free-space.

Berryman et al. (1995) further generalized the food-chain model to analyze the dynamics of multi-species food webs to estimate the relevant parameters. The food-webs model is as follows:

$$\frac{1}{N_i}\frac{dN_i}{dt} \equiv R_i = a_i + b_i N_i + \frac{N_i}{\sum_j c_{ij} N_j W_j^{r(i)}} + \frac{\sum_k d_{ik} N_k W_k^{c(i)}}{N_i} \qquad (5)$$

Similarly, a_i is the maximum per-capita rate of increase of the *i*th species and $b_i N$ stands for the intra-specific competition for fixed resources. The term $N_i / \sum_j c_{ij} N_j W_j^{r(i)}$ describes the competition for renewable resources in the lower tropical level while $\sum_k d_{ik} N_k W_k^{c(i)} / N_i$ depicts the defense against the consumers in the upper tropical level. In details, $W_j^{r(i)}$ denotes the fraction of species *j* which is the prey of population *i* and $W_k^{c(i)}$ presents the fraction of species *k* which is a consumer of population *i*. This food web model was employed to determine the structure of the functional web via a series of observations on the densities of discussed populations over time, a multi-species time series. In another word, this model provides clues to the inter-specific associations involved in population regulation.

Developing the Ecological Diffusion Model

The Lotka-Volterra equation and other ecological models are developed based on the assumption of mass action, which argues that reactants (consumer and resource populations) are homogeneously mixed and the rate of encounter between consumers and resources (the reaction rate) would be proportional to the product of their masses (Keitt and Johnson, 1995). As Pareto (1935) indicated that, like physics, society is a system of forces in equilibrium. Based on sociology, diffusion theory examines the group behavior of contemporary man with focus on the identification of individuals responsible for spreading innovated ideas into social systems (Winick, 1961). The domain of ecology has been applied to managerial concerns including marketing diffusion. For instance, Moore (1993) describes the market competition as a business ecosystem. Successful innovative businesses are depicted as "predators" that attract essential energy (resources) such as capital, consumers, and partnership etc. from other companies, which are denoted as "preys". Likewise, the ecosystem exits not only within companies but also within business units, such as product generations. The successive generation of a product (the predator) usually possesses better attributes and competitive advantage than the former one (the prey) and gradually invades the market originally occupied by the preceding generation. The domain of ecology has been applied to marketing-diffusion processes. Shocker, Bayus and Kim (2004) used the ecological concept such as "predator-prey" and "prey-predator" to characterize the dynamic features incorporating displacement, substitute-in-use (co-existence), and product survivals. In addition, Bayus, Kim and Schocker (2000) summarized various multi-product interactions into a three by three matrix framed by two products or generations of technology innovations. The ecological term "predator-prey" was given to the paired generations as PC operating system and web browser while "prey-predator product" was given to the pair of PC floppy and PC hard drive.

The diffusion of a new generation product in the market is determined not only by the intrinsic growth power (as predicted in the Bass model) but also by the extrinsic force of mergers and acquisitions as well as those generations of other competitors. The interactions between generations and among competitors can be well depicted by a food-web model: that the new generation (predator) of a provider preys on the old generations of itself and its competitors. The ecological food-web equations can be used to estimating the extrinsic force on the diffusion pattern of a new generation product.

Ecological Diffusion Model: Single Category

Considering that the two species populations are adopters of the two-generation product. The growth of the newer generation (predator) depends on the feeds from the adopters of the former generation (prey). Therefore, the Lotka-Volterra equation describes the interactions between and the growth and decline of the adopters of the two-generation product. Assume that this two-generation product does not have any competitor, thus substitution effects exist only within generations not across categories. We can rearrange the Lotka-Volterra equation and obtained the relationships between parameters and variables as follows:

$$\frac{dH}{dt} = aH(t) - bH(t)P(t) = bH(t)\left(\frac{a}{b} - P(t)\right)$$

$$\frac{dP}{dt} = cH(t)P(t) - dP(t) = -cP(t)\left(\frac{d}{c} - H(t)\right)$$

Should $H(t) = d/c$ then $\frac{dP}{dt} = 0$, that is, $P(t)$, the number of adopters of the newer generation product, is constant. Furthermore, if $P(t) \neq a/b$, then $\frac{dH}{dt} \neq 0$, which is not possible. Therefore, there exit the following solutions for $P(t)$ and $H(t)$:

$$P(t) = \frac{a}{b} \quad \text{and} \quad H(t) = \frac{d}{c}$$

This solution implies that the newer generation does not fully substitute the former generation and there is competitive equilibrium between them (Versluis, 2002). Since the substitution is continuous going on, this equilibrium is dynamic.

This single category generation diffusion model can also used to find out the takeoff point as follows:.

As $P(t) < \frac{a}{b}$, $H(t)$ is increasing, where as $P(t) > \frac{a}{b}$, $H(t)$ is decreasing. Therefore, when $H(t_0)$ reaches an extreme value, we get $P(t_0) = \frac{a}{b}$

Assume $H(t_0) \neq \frac{d}{c}$, and the second level of differential equation for $H(t)$ is:

$$\frac{d^2H(t_0)}{dt} = \left[b\frac{dH}{dt}\left(\frac{a}{b} - P\right) - bH\frac{dP}{dt} \right]\Bigg|_{t=t_0}$$

$$= bH\left[b\left(\frac{a}{b} - P\right)^2 + cp\left(\frac{d}{c} - H\right) \right]\Bigg| t = t_0$$

$$= c \times b \times H(t_0) \times P(t_0) \times \left(\frac{d}{c} - H(t_0)\right)$$

As a result, if $H(t_0)$ reaches an extreme value, we know that

$H(t_0)$ is maximized $\Leftrightarrow$ $H(t_0) > \frac{d}{c}$ $\Leftrightarrow$ P(t) is increasing and $P(t_0) = \frac{a}{b}$

$H(t_0)$ is minimized $\Leftrightarrow$ $H(t_0) < \frac{d}{c}$ $\Leftrightarrow$ P(t)is decreasing and $P(t_0) = \frac{a}{b}$

The mathematic relationships show several implications. As the number of adopters of the newer generation is less than its equilibrium solution a/b, the adopters of the former generation are increasing. Contrarily, as the number of adopters of the newer generation is greater than its equilibrium solution, the adopters of the former generation are decreasing. While the number of adopters of the newer generation is increasingly across the equilibrium solution, the adopters of the former generation reaches its maximum value, which is greater than the equilibrium solution of the former generation (*d*/*c*).

Ecological Diffusion Model: Multiple Categories

The application of a multi-species ecological equation to marketing diffusion is illustrated below as an example. Assume an ecosystem with only two species of preys (species 1, and 2) and one predator (species 3). We would like to predict the variation of population of species 1 under the attack of the predator. According to Berryman's model (equation 4), the impact of predation by species 3 on species 1 can be expressed as $d_{13} \times \left[N_3 W_3^{c(1)} \middle/ N_1 \right]$, where $W_3^{c(1)}$ is the fraction of population 3 consumed by population 1. If the predator and prey populations are distributed randomly relative to each other, the fraction of predator species 3 attacking prey species 1 is given by:

$$W_3^{c(1)} = \frac{v_{13} N_1}{v_{13} N_1 + v_{23} N_2}$$

In the equation above, v_{ij} stands for the relatively presence degree of prey *i* to consumer *j* (it represents the relative vulnerability of the prey and preferences of the predator). Consider that N_1 and *N*2 are, respectively, the number of adopters of a former generation of two brands and that N_3 is the number of adopters of a new generation introduced by one of the two brands. Therefore, v_{13} and v_{23} measure the tendency of the adopters of the two brands to switch from the former generation to the new generation. These two parameters may also depict the comparative visibility of a new product to the adopters of the former generation. Notice that $W_3^{c(1)}$ is zero should v_{13} equals zero, or the adopters of the former generation of brand 1 (the target) are not interested in the new generation and there would be no switch from the target adopters to the new generation. In addition, $W_3^{c(1)}$ is one as v_{23} equals zero, or adopters of the former generation of brand 2 have no interests in the new generation and the switch to the new generation would be totally from the target adopters.

Other then market competitions, extrinsic bursting growth factors such as mergers and acquisitions usually have substantial impact on sales or the number of subscribers of the products. For example, at the acquisition event between two mobile telecommunication providers, the number of subscribers of the acquiring provider will increase sharply. The influential special event can be incorporated into the diffusion model with a dummy variable.

To integrate equation (5), replace a_i (the maximum per-capita rate of increase) with the Bass model component $m_i \times F_i(t-1)$(measuring the market potential of the ith product) and incorporate one dummy variable, we obtain a generalized ecological diffusion model as equation (6):

$$N_i(t) = m_i \times F_i(t-1) \times \exp\left[b_i D + c_i\left(\frac{N_i}{\sum_j N_j W_j^{r(i)}}\right) + d_t\left(\frac{\sum_k N_k W_k^{c(i)}}{N_i}\right)\right] \quad (6)$$

The terms in the equation (6) can be interpreted in marketing concepts as follow:

The dependent variables, $N_i(t)$ denotes the number of adopters or subscribers of generation i of the predicted product at time t. The first two terms on the right-hand side are those in the Bass equation (Equation 1) at time t-1, in which m_i indicates the parameter indicating the market potential of generation i of the predicted product at the estimating moment. The value of this market potential parameter varies in accordance with the status of competitive interactions in the market place and the spot time. $F_i(t-1)$ denotes the cumulative density function following the Bass model specification along with two parameters of p_i and q_i at time t-1. We deem that the coefficients of innovation (p_i) and imitation (q_i) are varying over different product generations. $m \times F_i(t-1)$ equals the sales volume or number of adopters of generation i, i.e., $N_i(t\text{-}1)$, at time t-1.

$b_i D$ indicates an extrinsic force or event that enhance sales or adopters increase/decrease sharply; b_i is a dummy variable with a value of 0 (without extrinsic force) or 1 (with extrinsic force).

$c_i\left[N_i / \sum_j N_j W_j^{r(i)}\right]$ is the conversion term that describes the ability of gaining sales or adopters of a successive generation from the former generations of the predicted product, in which, parameter c_i presents the conversion rate of the target generation i within a given environment of preys (number of providers); N_i stands for the number of adopters of the target generation i at time t-1; $\sum_j N_j W_j^{r(i)}$ is the sum of adopters of former generation j provided that $W_j^{r(i)}$ denotes the probability of the former generation (the prey) encounters the consumers of generation i (the predator).

$d_t\left[\sum_k N_k W_k^{c(i)} / N_i\right]$ is the defensive term that measures the ability of the former generation to retain adopters from being converting to the new generation, in which, d_i denotes the defense parameter while $\sum_k N_k W_k^{c(i)}$ portrays the total number of adopters of the successive generation k.

The differential equation of the ecological diffusion model is as follows:

$$\frac{dN_i(t)}{dt} = \frac{dF_i(t)}{dt} + d_i \sum_k N_k W_K^{c(i)} - c_i \sum N_j W_j^{c(i)} \ ,$$

where

$$\frac{dF(t)}{dt} = p + (q-p)F(t) - qF^2(t)$$

Similar to the Norton-Bass (1992) multi-general diffusion model, the ecological diffusion model assumes that the conversion behavior can happen only from the former generation to the successive generation since the prey is not able to attack the predator. The model has other implications: (1) other than the innovation (p) and imitation (q) parameters of the Bass component, the conversion and defending ratios affect the characteristics of diffusion as well; (2) the sources of sales of new generation product include not only innovation and imitation but also substitution from existing the former generations; (3) the conversion parameter has a positive effect while the defending parameter has a negative impact on the growth of new generation product; and (4) the substitution effects are only partial and there is competitive equilibrium among generations (Versluis, 2002).

The Ecological Diffusion Model for Empirical Studies

For the purpose of empirical studies, Equation (5) can be applied only to circumstances of one predator (new generation) and n (=1, 2, 3…) kinds (brands) of preys (the former generation). When there is more than one predator in the market, the current computer software is not able to estimate the parameters (p_i and q_1) of the Bass component. To make empirical study possible, the Bass component was replaced by the sales or number of adopters of the previous period, $N_i(t\text{-}1)$. In addition, $W_j^{r(i)}$, the probability of the former generation encounters the consumers of generation i, is hard to estimate should consumers have different preference from each other, thus we assume that the preference of all consumers remain constant to make the estimation possible. The ecological diffusion model used for the empirical study is presented as Equation (6).

$$N_i(t) = N_i(t-1) \times \exp\left[b_i D + c_i \left(\frac{N_i}{\sum_j N_j W_j^{r(i)}} \right) + d_t \left(\frac{\sum_k N_k W_k^{c(i)}}{N_i} \right) \right] \qquad (6)$$

The empirical model shows that the dynamics of population N_i is determined by two parameters c_i and d_i indicating that the variation of sales or adopters of product *i* depends on the attractiveness of the new products to existing consumers and the ability of the existing products in defending attacks from the new products.

The Data

Data is collected from Japanese Telecommunications Carriers Association (JCA). The TCA database composed of monthly data including the number of subscribers and the cellular phone usage traffic. There are three major carriers providing mobile phone services in Japan. They are NTT DoCoMo (NTT), which is the market leader, KDDI Corporation (KDI), and SoftBank Mobile Corporation (SFB). The first generation of both NTT and SFB use “personal digital cellular, PDC” technology, which is denoted as 2G mobile services while the second generation use “Wideband CDMA, WCDMA” technology, which is denoted as 3G mobile services. Alternatively, KDI employs “cdmaOne” technology as the first generation (2G) and “CDMA2000-1X” as the second generation (3G). KDI was established when KDD merged DDI and IDO in October 2000 and started operating CDMA2000-1X (3G) in April 2002. Similarly, “Digital Phone” and “Digital TU-KA” merged in October 1999 and renamed as “Vodaphone”, which was acquired by SoftBank Group to form SFB. The merge activity resulted in a discrete jump in the number of subscribers of the first-generation system of both KDI and SFB.

The time span for fitting the multi-generation model is from November 2001 to January 2007 when there existed at least one series of two generations in the market at the same time. In addition, data of February and March of 2007 were used as input for verifying the predicting accuracy of the model.

Models Fits and Discussions

Data from the telecommunication market consisting three carriers, NTT, KDI and SFB, each has its own successive generation (Figure 1), were used to examine the fitness of the multi-generation ecological model. The model needs an estimation methodology that is able to estimate the parameters of all generations simultaneously. The nonlinear three-stage least squares (3SLS) was employed to meet the requirement. The MODEL procedure provided by SAS ETS package was used to conduct the estimations.

FIGURE 1 ABOUT HERE

The results (Table 1) are satisfactory since that the fitness degree between the estimates and the actual data is high ($R^2 \geq 0.99$) and that all independent variables are significant ($p<0.01$) in explaining the variation of the dependent variable (number of subscribers). The conversion rates (*c*) are positive indicating the ability of the newer generation in converting subscribers from the first generation. The defending parameters *d* are negative showing the resistance of the first generation from losing subscribers to the successive generation, for easy explanation, every defense parameter will be expressed in its absolute value in the following discussions. The coefficient of special event (*b*) exactly captures the discrete sharp increase in number of subscribers of both generation of KDI due to merge and acquisitions of the company in 2000. To simplify the discussion, the first (former) and the second (successive) generations will be denoted as 2G and 3G respectively following the name of the carriers, for example, NTT_2G, KDI_3G etc..

TABLE 1 ABOUT HERE

To examine the results in detail, we found that SFB_3G has the largest conversion rate yet has the lowest defense parameter among the three carriers, which fact indicates that SFB can convert subscribers from the former generation to the successive generation. In addition, KDI_2G has the highest defense parameter presenting a strong ability in keeping its subscribers against the threat from the introduction of the new generations. For marketing strategy, SFB should ensure that its subscribers convert into new generation of its own instead of into that of other carriers'. As for KDI, the focal point is to give incentive to subscribers to adopt its own new generation services.

FIGURE 2 ABOUT HERE

Forecasting

As the models described above obtained a satisfactory fit to the sample data, we applied a new set of data that is two month ahead to verify the predicting power of the models. The mean absolute percentage error (MAPE) is used to evaluate the predicting accuracy. MAPE measures the accuracy in a fitted time series value in statistics, specifically trending and is expressed as follows:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{|e_t|}{Y_t}x100\% \quad , \qquad e_t = Y_t - \hat{Y}_t$$

Whereas:

n- the total number of forecasting periods; Y_t and $\hat{Y}_t$ - the actual and predicted value respectively;

Martin and Witt (1989) suggest to classify the predicting power of a model by the MAPE as highly precise (MAPE<10%), good (10%≤MAPE≤20%), reasonable (20%<MAPE≤50%), and not correct (MAPE>50%). Results (Table 2) show that the accuracy rates in predicting both generations of NTT and SBF are highly precise as 95%-99% provided that the rate for KDI_2G is only 67%, a reasonable level.

TABLE 2 ABOUT HERE

Conclusions

The examined results through our proposed model are presented in the previous chapter. In this chapter, the findings will be discussed in depth to address the research purposes mentioned in the first chapter. Through responding those objectives, it is hoped that a more comprehensive picture of the competitive interactions under multigeneration diffusion specification could offer a better understanding of situations of new products launches.

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Table 1. Parameter Estimation of the Ecological Diffusion Model

Parameters		NTT		KDI		SFB	
		1G	2G	1G	2G	1G	2G
Estimated Value	c		0.025839		0.013631		0.052463
	d	-0.026520		-0.181070		-0.016390	
Approx Pr > | t |	c		<.0001***		<.0001***		<.0001***
	d	<.0001***		<.0001***		<.0001***	
R-Square		0.9994	0.9976	0.9947	0.9956	0.9952	0.9983
Adj R-Square		0.9994	0.9976	0.9947	0.9956	0.9952	0.9983

Table 2. Forecasting Results of the Ecological Diffusion Model

Subscribers		NTT		KDI	SFB
		1G	2G	2G	2G
Feb-07	Actual Value	18,278,700.0000	34,044,400.0000	25,987,900.0000	7,049,000.0000
	Predicted Value	17,991,372.1940	35,082,648.6830	26,402,856.2810	7,423,605.9205
	Residual	287,327.8055	-1,038,248.6830	-414,956.2806	-374,605.9205
Mar-07	Actual Value	17,091,600.0000	35,529,500.0000	26,719,600.0000	7,660,100.0000
	Predicted Value	17,107,722.0580	36,257,871.8890	26,870,113.7410	8,014,491.6457
	Residual	-16,122.0579	-728,371.8891	-150,513.7405	-354,391.6457
MAPE		0.83%	2.55%	1.08%	4.97%

FIGURE 1. Interaction of Three Telecommunication Providers

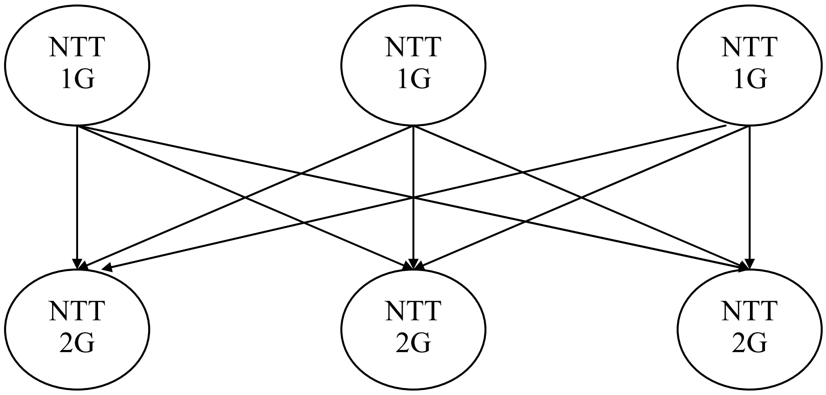

FIGURE 2. The Model Fit of the Ecological Diffusion Model