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Modified diffusion model with multiple products using a hybrid GA approach

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ABSTRACT

As technology advances, the speed in which new products are developed also increases. Due to such increases, product forecasting has become much more vital for a company. The Bass diffusion model is a demand-forecast model that explores the phases of a product's life cycle that have been successful in the diffusion of forecasting innovation in new products. Recognizing the need for an efficient parameter estimation method for multi-product forecasting, we have conducted research using the hybrid genetic algorithm (HGA). The research conducted will provide an alternate approach to explore the forecasting capability of the diffusion models without having as many limitations as the original method. We used both published data and LCD-monitor global sales data to test and verify our method. Results show that the proposed model using a hybrid GA approach can improve the forecasting efficiency.

1. Introduction

One flaw that appears when new products are forecasted is that all the other products in the market are neglected. This makes the forecasting time even more coveted. Recognizing the situation, Bass introduced the basic mixed influence innovation diffusion model (Bass, 1969). The Bass model, along with its revised forms, has been acclaimed for its success in forecasting a variety of products and services. Mahajan's research has shown that parameter estimation consideration is one of the major five research areas in new product diffusion models (Mahajan, Muller, & Bass, 1990). The ordinary least-squares (OLS) procedure is one of the earliest methods for parameter estimation. The non-linear least-squares (NLS) procedure, proposed by Srinivasan and Mason (1986), was designed to improve the shortcomings of both the maximum likelihood estimation and the OLS procedure; it has been utilized more than all other procedures. The con's of the non-linear least-squares estimation procedure include the use of diverse search routines when estimating parameters, the slow inability of the parameter estimates to converge, the close correlations between final estimates and the initial values for p, q, and m, and also the reality that the procedure may not provide a global optimum. The operational procedures that depend on either the Gauss–Newton method or the Marquardt–Levenberg method contain a problem in initial parameter.

Heuristic methods are usually applied to find the optimal solution. Genetic algorithm (GA) is a well-known heuristic method. Mathematical justification of the success in performance of GA can be found in Holland (1975). GA is a method of searching for a global solution whose value approaches a maximum determined by some evaluation function (Goldberg, 1989). It is also an appropriate method to use when searching for a real number evaluation function in an optimal solution (Gen & Chang, 2000). GA uses parallel, evolutionary search algorithms to locate parameters that optimize the objective function (Venkatesan, Krishnan, & Kumar, 2004). An efficient and accurate hybrid GA (HGA) was found to exist, provided that a proper balance between convergence and diversity was maintained throughout the GA run (Park & Froment, 1998). For the reasons mentioned above, we can also use the GA to solve the Bass model parameter estimation for multi-product forecasting.

The 21st century has seen the thin-film transistor liquid-crystal display (TFT-LCD) becoming increasingly prevalent in our lives. Television monitors, mobile phones, personal digital assistants, and MP3 players all are now becoming more and more LCD dependent. The growth and expansion of LCD products throughout history are presented below, as described by Kawamoto (2002).

The development of liquid-crystal displays began in 1964. A major milestone in the development of LCD products was made in 1988 when an active-matrix (AM) TFT display was demonstrated to be applied to the display. In the 1990s, Japan and Korea companies began to produce the large-sized TFT-LCD. Their global market shares of TFT-LCD reached over 70% in 2000. Taiwan has since then become an arising production source. Jang et al. described the transfer in manufacturing of TFT-LCD products from Japan to Taiwan after the Asian financial crisis in 1997 (Jang, Lim, & Oh, 2002). Since the Asian financial crisis in 1997, Taiwan companies such as AUO, CMO, CPT and Hannstar have produced more than 40% of the world's display products. In 2007, the global

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market of the LCD-monitor exceeded $100 billion US dollars. The production of TFT-LCD products in 2007 was 90% more than that in 2006. Korea, Taiwan and Japan now manufacture the majority of TFT-LCD products. As one could expect, the forecasting of TFT-LCD market sales has become exceedingly vital in these three countries.[1]

Lin et al. used the transfer function model to forecast the supply and demand in the TFT-LCD market (Lin, Wang, Lo, Hsu, & Wang, 2006). Lee et al. derived a dynamic random utility function by using conjoint analysis, which allowed them to estimate an individual random utility function (Lee, Cho, Lee, & Lee, 2006). They then combined the estimated result with the single diffusion model to forecast LCD TVs' sales. Both papers focused on two issues; finding the factors that might affect the sales of LCD products, and discovering the trend of the LCD market. They ignored how the price of the products could potentially affect the trend and sales of the LCD market.

The hybrid GA approach was used in the research to improve the parameter estimation of multiple products. We used one published data source, along with data about the global LCD-monitor sales data to test and verify our method. In the next section, the theoretical backgrounds and practical applications of the Bass diffusion models, the Bass model estimation techniques, and the GA approach are discussed. In Section 3, we propose a modified diffusion model for a variety of products. To validate our proposed model, we contrast the proposed model with other models such as the single product model and inter-product model. Suggested directions for future research are also given.

2. Basic concepts

2.1. The Bass model

The Bass model (Bass, 1969) is a well-known model in the area of forecast first-purchase demands. Despite its popularity, the Bass model contains several assumptions which can potentially limit the usability of the model. Norton and Bass proposed a multi-generation model that considered the sales of successive generations of product. They developed and introduced additional notations to the one-generation model. The one-generation model can be written (Nortan & Bass, 1987) as follows:

$$F(t) = \frac{\left(1 - e^{-(p+q)t}\right)}{\left(1 + \left(\frac{q}{p}\right) \times e^{-(p+q)t}\right)}, \quad t \geqslant 0 \tag{1}$$

The parameters p and q are usually interpreted as coefficient of innovation and imitation. $F(t)$ is the cumulative distribution of adoptions at time t. In the Norton and Bass multi-generation model, the index i represents the products of a particular device type, and n denotes the number of applications for which the innovation is appropriate. Let $X_i(t)$ represent the cumulative sales of the ith generation in time period t. In addition, m_1 refers to the potential for the first generation and m_i refers to the incremental potential served by the ith generation. The index τ_i refers to the time of introduction for the ith generation, $F(t - \tau_i) = 0$, for $t < \tau_i$. Here, the index τ_1 is assumed to be equal to 0. The n generation product form can be written as:

$$X_n(t) = \sum_{k=1}^{n} G_k(1 - F_{n+1}) \tag{2}$$

where $G_k = m_k \prod_{i=k}^{n} F_i,\ i, k = 1, 2, \ldots, n$ and $F_{n+1} = 0$. In addition, the development of diffusion model can be found in Meade and Islam (2006).

[1] http://www.displaysearch.com/.

2.2. The extension of Bass model

A model suggested by Robinson and Lakhani during the 1970's examined the effect of the selling price on adoption rate and found that the model is capable of obtaining a better growth model (Robinson & Lakhani, 1975). Kalish later proposed a model that regarded price a factor to be considered when estimating market potential (Kalish, 1985). Speece and Maclachlan extended the Norton and Bass model by including price and market growth. Mahajan and Muller expanded the Norton and Bass model to downgrade original assumptions having to do with the adopted generations of the multi-generation model. They demonstrated how their model was suitable for IBM mainframe computers cases. Islam and Meade were assured that innovations and imitations of the Norton and Bass model would be made in the future. In their study, the coefficient of imitation (q) was seen to increase over time between multi-national mobile telephones (Islam & Meade, 1997; Kim, Chang, & Shocker, 2000; Mahajan & Muller, 1996).

Kim et al. presented the Norton and Bass model in a different way; they took into consideration the inter-category and generational dynamics. They employed the same function to obtain the data, while including several generations of the same device (Kim et al., 2000). Kim and Srivastava recently extended Kim et al.'s approach, suggesting two kinds of sales growth diffusion models to deal with the effects of dynamic prices on other related products in computing platforms. The forecasting performance of the proposed model was shown to be more valuable than when it was without the inter-category effects' model. The market potential was fixed at a constant base factor for market potential and only the price variations between products were considered (Kim & Srivastava, 2007). Finding the optimal market potential value for this model did not take much time. Data collected from tests performed on the model are included in this paper. To obtain a better forecasting performance, we modified the functions of the model, relaxed the market potential parameter and considered the average price effect.

2.3. Estimation techniques of the Bass model

The common techniques used for estimating the Bass model that have been proposed in the literature, such as ordinary least squares (OLS), maximum likelihood estimation (MLE), and nonlinear least squares (NLS) have drawbacks in the forecasts of product sales growth. There are no restrictions on the number of data points required for estimation for OLS. However, estimates made of the Bass model with OLS are not bounded; estimates in the OLS with fewer data points are also unreliable. Time-interval bias may occur when estimates using OLS assume a discrete process for data generated from a continuous process. Estimates made using OLS also have a disadvantage in that its results are multi-collinear and contain fewer data. They also do not generate standard errors directly for p, q, and m; this makes testing the hypothesis impossible (Schmittlein & Mahajan, 1982). MLE's are efficient in reducing sampling errors associated with survey-based data, but are not efficient in reducing errors related to measuring exogenous factors (e.g. price). Having to obtain the population data before estimation is a disadvantage of using MLE. Four estimation procedures were compared: OLS, MLE, NLS and algebraic estimation (AE). The results show that NLS procedures provide better predictions and more valid estimates of standard errors for the parameter estimates, compared to those of OLS and MLE. The NLS is also elaborate. The result obtained by OLS is equivalent to that obtained by NLS in the parameter estimation of the discrete Bass model. NLS is the most accurate procedure and OLS is the the simplest one. Meade and Islam state that