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Application of the grey Lotka–Volterra model to forecast the diffusion and competition analysis of the TV and smartphone industries

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A B S T R A C T

To achieve competitive advantages, companies need to embrace changes and evolve strategies for coping with challenges when time and data are limited. This study applies grey forecast theory with the Lotka–Volterra competition model to explore the dynamic competition between smart TVs and flat panel TVs, as well as Android and iOS smartphone operating systems (OS). The results show the growing strength of smart TVs and the Android OS is superior to other competing products. With respect to the interactive relationship between products, the two aforementioned products represent the competition relationship of predators and prey: flat panel TVs and iOS are playing the role of prey, while smart TVs and Android are the predators. After comparing forecast accuracy among the model proposed in this study, the grey forecasting model GM(1,1), and Lotka–Volterra model, we found the proposed model has the best accuracy. Companies can use the proposed model to develop a strategic plan feasible enough to secure a sustainable competitive advantage.

1. Introduction

When CRT TVs dominated the television market in the year of 2000, people's desire for thinner and lighter-weigh products kicked off a new technology of flat panel TVs. However, during the period between 2012 and 2013, flat panel TVs shipments showed a 6% annual decline. The evolution of television industry was thus turning toward smart TVs.

Google launched the first-generation Google TV programs, conceptualized with “TV meets Web, Web meets TV” at the Google I/O General Assembly in May 2010. In September of the same year, Apple released the second generation of Apple TVs; subsequently, a wave of smart TVs was released. With the appearance of Google and Apple TVs, competition of television products formally became the new main battlefield of content-based applications rather than the hardware specifications war. According to a report on quarterly smart TV shipments and forecasting released by NPD DisplaySearch, smart TVs were gradually transforming into the mainstream market, with a global shipments growth rate estimated to be 15% by the year 2012. Among the growth regions, Japan's penetration rate reached 55% and that of China and Western Europe exceeded 40%.

In the period between 2009 and 2011, Europe, America, and Asia set off a wave of smartphones. Smartphone shipments grew from 330.4 million sets in 2010 to more than 450 million sets in 2011. According to a TrendForce survey, it is estimated that smartphones are expected to reach an annual growth rate of 24.3% by 2013, at which point global shipments will reach 876 million sets. Thus, the phenomenon shows that the emergence of smartphones changed the whole picture of the market and has brought huge business opportunities for the entire communications industry.

With respect to the ongoing changes in the market share for smartphone operating systems, the Android market share was increased significantly from 22.5% in 2010 to over 80% after 2013 and continues to rank first in global market share. In contrast, Apple iOS is installed only on iPhones; nevertheless, Apple's products have fixed faithful patrons, so its market share has remained stable.

There are several methods applied in many studies to analyze the life cycles and diffusion of products and most of the studies were conducted with sufficient data. The question is are those methods still good enough to accurately forecast diffusion of new products when the product life cycles are short and information and data are limited? In response, this study used grey forecasting theory linked with the Lotka–Volterra competition model, under the situation of limited data, to explore the behavior of dynamic competition in the TVs and smartphones operating system industries.

2. Literature review

The product diffusion model makes forecasts aimed at new product development, product life cycles and product purchases so as to better understand when and which period of the life cycle the product will enter. It is also used to gauge the mentality and behavior of consumers in such periods to facilitate suppliers in making proper decisions in production, marketing, and finance. Since being developed by Bass (1969),

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the model has been continuing to expand, amend, or integrate with new methods by many scholars in order to reflect the complexity of the market. Jain and Rao (1990) believed that the process of product diffusion would be affected by marketing strategy; thus, they added price function to the original model. Pae and Lehmann (2003) considered the status of different generations of technology diffusion and found that the longer the interval between two product generations, the slower the adoption of new technologies. Norton and Bass (1987) proposed an alternative and diffusion patterns between different generations of products and so on. However, most previous diffusion models extended from Bass (1969) assumed a monopolistic market, which is thus not be very efficient to apply in this mutually competitive market.

The analysis of product development and sales in this study presents the framework of market competition; therefore, the diffusion model is not able to fully explain the diffusion behavior and mechanism in a mutually competitive market. Accordingly, being able to obtain the mode of competitive effect of mutual interaction is required.

The Lotka–Volterra model is based on the growth development curve and is used to explore interactions between two or more competing species. The model focuses on the interaction relationship generated in an environment and between two or among diversified competitors. In recent years, it has been applied to the study of social economy and social population control, and in the exploration of competitive relationships among different products or markets. Modis (1997) used the Lotka–Volterra model to explore the dynamic competitive relationship between competitors in a limited growth space, and put forward competing models between both sides. Modis (1999) also used this model to analyze the behavior of stocks and bond markets from the perspective of two species competing for investors' resources. Lopez and Sanjuan (2001) analyzed a website's dynamic competition behavior model. From their analysis on mode stability, they established a series of guidelines that aid in Internet strategy making. Maurer and Huberman (2003) used the competitive effects among the web sites and impact on the market explored by Lotka–Volterra. Lee et al. (2005) analyzed the dynamic competitive relationship between two Korean stock markets and found that the competitive relationship changed with time. Kim et al. (2006) estimated the demand for mobile phones in Korea. In their study, they incorporated market competitive factors and dynamic competition factors of cell phones and PCs and found that a symbiotic relationship lay between the two. Kreng et al. (2012) adopted this model to analyze the competitive relationship of product items among three television technologies, and verified and explored the equilibrium point by means of quarterly sales.

The grey system was put forward by Professor Deng Julong in “Control Problem of Grey System” in 1982. Many scholars have subsequently applied this system in their research, including the fields of economics, science, technology, ecology, and others. Hsu (2003) made a comparison of predictive power among time series, exponential smoothing, grey forecast, and grey forecast correction models for the global IC industry sales volume and concluded that the grey forecast was more suitable for short-term forecasting. Wang (2004) used grey theory and the neural network model to forecast the number of inbound visitors to Taiwan from Hong Kong, Germany, and the United States between 1989 and 2000. Chen et al. (2008) used grey theory to predict Taiwan's 3G mobile phone market, the results of which showed that grey forecasting had more accurate than that of regression model. Tao and Xi (2010) used the grey theory to predict sales volume of China's auto industry and to analyze the advantages and disadvantages of China's auto industry. Chang et al. (2013) used grey forecast to perform predictions and analyses based on three types of data items, namely, the number of Internet users, the number of online game players, and , online game value of production. The analysis revealed that Taiwan's online game industry had sustained significant growth from 2011 to 2013.

3. Methodology

This study explored competition relationship targeting smart TVs and flat panel TVs, as well as Android and iOS smartphones operating systems, under the circumstances of limited data. It was hoped that a demand curve for individual products and a mutually competitive relationship would be achieved. This study was based on the grey Lotka–Volterra model adopted by Wu et al. (2012) and explored the growth curve and competition relationship and compared this prediction performance model with other forecast models. The methods used in this study are described below.

3.1. Grey prediction model

Grey forecast is a method based on the GM (1, 1) basic model to predict uncertain and incomplete information systems to determine the elements' future dynamic situation among a certain sequence of numbers. The advantage of using grey forecast is small amount of data is sufficient to do the prediction. Establishing the processes of the GM (1, 1) model are shown as follows:

Assume the original data sequence $X^{(0)}$is

$$X^{(0)} = \left\{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)\right\} \tag{1}$$

Then construct the accumulated generating operation (AGO), which is defined as

$$\begin{aligned} x^{(1)}(k) &= \sum_{i=1}^{k} x^{(0)}(i), k{=}1,2,\ldots,n \\ x^{(1)} &= \left\{x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)\right\} \end{aligned} \tag{2}$$

The equation

$$x^{(0)}(k) + az^{(1)}(k) = b \tag{3}$$

is called a GM(1,1) model, where

$$z^{(1)}(k) = \frac{x^{(1)}(k) + x^{(1)}(k+1)}{2}, k = 1, 2, \ldots, n-1 \tag{4}$$

For the GM (1, 1) model, the values of the GM (1, 1) parameters a and b must be calculated first. The parameters a and b are calculated by using the ordinary least square method to estimate these parameters.

$$\begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix} = \left(B^T B\right)^{-1} B^T Y \tag{5}$$

where

$$\mathrm{Y} = \begin{pmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{pmatrix}, \quad \mathrm{B} = \begin{pmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{pmatrix}$$

After estimation, the grey prediction equation can be obtained and solved as follows:

$$\hat{x}^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak} + \frac{b}{a} \tag{6}$$

Using the inverse accumulated generating operation (IAGO), the following can be obtained

$$\begin{aligned} x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak}(1 - e^{a}), \\ k = 1, 2, \ldots, n-1 \end{aligned} \tag{7}$$