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APPLICATION OF THE LOTKA-VOLTERRA MODEL IN EXPLORING THE SALES VOLUMES INTERACTIONS OF SMARTPHONES BETWEEN ASIA AND NORTH AMERICA

Bi-Huei Tsai

Professor, Department of Management Science, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 300, Taiwan

ABSTRACT

This study utilizes Smartphone sales volumes to predict the relationships of Smartphone sales volumes in Asia and North America. The empirical results show that the Smartphone sale in Asia substantially enhances the sales growth in North America, whereas the Smartphone sales in North America curtail the sales growth in Asia. The Smartphone are first sold to North America because of the strong consumer purchasing power and consumer acceptance in North America. As the Smartphone vendors sell more Smartphone in North America, the sale in Asia will decrease due to the limited production capacity. Until the production capacity of Smartphone is extended, the sales volumes of Smartphone in Asia increases. When Smartphone get popular in Asia, the widespread of Smartphone entertainments and commercial activities in Asia stimulate the Smartphone sales in North America. The real sales volumes are close to the predicted sales volumes calculated by our proposed model, indicating that our proposed model can accurately predict the trend of Smartphone sales. This study further predicts that the long-term Smartphone sales volumes will not converge to a stable levels in Asia and North America, suggesting that their sales volumes will increase infinitely if no innovative communication products can completely replace Smartphone.

Keywords: Consumer Acceptance, Purchasing Power, Root Mean Square Error, Theil U Statistics

INTRODUCTION

This investigation employs the Lotka-Volterra model to explore the correlations of Smartphone sales between Asia and North America regions. Previous studies analyzed the trade interdependency among various regions, but few studies have highlighted the quantitative evidence of end user relationships. Thus, this study utilizes Smartphone sale volumes to predict the competitive relationships of market sales between Asia and North America. At the beginning,

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North American market becomes the major market of Smartphone for four reasons: communication specifications, advantages of technological development, consumer purchasing power and consumer acceptance. Regarding communication specifications, the development of communication specifications in North America is the most rapid and advanced. Also, the communication specifications of major operators are uniting. As a result, the factories of Smartphone brands can focus on few product lines and enhance product price in North America. In contrast, communication specifications in the region differ from those in North America due to different development situations of infrastructure and communications equipment in various countries. Consequently, Smartphone brand factories in the global market other than North America have to concern the product lines with a variety of communications specifications and price ranges, resulting in resource dispersion.

For the advantages of technological development, since there are many high tech companies in North America, such as Apple, Blackberry, Google, Face book, etc., the related application services of Smartphone in North America are the most complete, which can improve consumers' demand for products and willingness to get a new phone (Entner, 2011). The 4G development in North America is the most complete. It is quick and easy to surf the internet on Smartphone, which promotes not only the video and game markets but also consumers' requirements in highspecification Smartphone (Behe, Campbell, Hall, Khachatryan, Dennis, and Yue, 2013). Referring to consumer purchasing power, higher average income in North America leads to stronger purchasing power on high-priced consumer electronic products because Torkildsen (2005) reveal that income is critical of leisure activities. Also, consumers in North America have established their habits on electronic products. Their purchase intent on new products is higher, so consumers in North America replace their mobile phones with newly developed Smartphone more frequently (Moberg, Borggren, Ambell, Finnveden, Guldbrandsson, Bondesson, and Bergmark, 2014). In the respective of consumer acceptance, as a global leader of technology development, North America has the most abundant technology product categories so that consumers here can better accept new stimuli in the market. Their consumption habits may be changed more easily, and the degree of public acceptance on innovative products and new technologies is higher (Hsieh, Wu, and Hsu, 2014). Consumers in North America accept Smartphone easily, so North America market became the major market of Smartphone when Smartphone entered into market.

Although North America was once the global greatest consumption area of Smartphone before the second quarter of 2011, the cumulative sales volume of Smartphone in Asia is over that in Asia since 2011 due to the huge population and economic development in Asia. As the manufacturing capacity of Smartphone is limited, a great amount of Smartphone sold to one region would reduce the Smartphone volumes sold to other regions. As the Smartphone sales

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volumes in North America increase, the sales volumes in Asia decrease. In addition, people use Smartphone's for the purpose of entertainment, wireless communication, global positioning and media. Cabras *et al.* (2017) and Claussen and Grohsjean (2012) hint the widespread of electronics video games through Smartphone. As Asia and North American enterprises implement worldwide entertainment, media, game and commercial activities through Smartphone's, the interrelationships of Smartphone sales between Asia and North America is increasing, affecting the global Smartphone industry. The feature of a competitive-cooperative relationship, which exists in Smartphone sales across different areas. However, previous studies focused more on the trade interdependency of products when analyzing the economic relationship (Wang, 2003; Xing, 2012; Yeh, 2012), and generally neglected sale dependency. Thus, this study explores the relations of smartphone sales between Asia and North America regions.

This work for the first time utilizes the Lotka-Volterra model to objectively quantify the competitive and cooperative relations of sales relations between North America and Asia. Most previous studies applied S-curve diffusion models to determine the market dynamics of durable products (Bass, 1969). Shao (1999) studied the adoption of expert systems and utilized the diffusion models. Chien et al. (2010) further modified diffusion model to forecast the diffusion of semiconductor product demand. However, these previous models excluded the analysis of reciprocal cooperation or competition among various consumption regions. If we apply the conventional diffusion model to explain the Smartphone sales volumes into Asia and North America, the estimation results may be biased. Tsai (2016) and Tsai et al. (2013) typically use Lotka-Volterra models to describe the competitive interaction between two groups. The Lotka-Volterra model considers the self-diffusing evolution situation based on the traditional S-shape curve (Chien et al., 2010; Zhang, 2012) and includes competitive interaction between two groups (Teng and Huang, 2013). Thus, the purpose of this study is to use the Lotka-Volterra model to consider these interactive effects and predict Smartphone sales volumes in North America and Asia. Second, our forecasting analysis examines the ability of the Lotka–Volterra model to accurately predict sales volumes of Smartphone in Asia and North America. Furthermore, based on long-term equilibrium analysis, this work clarifies whether Smartphone sales of Asia and North China will stably reach and maintain in the long-term equilibrium level. The rest of this paper is organized as follows: Section 2 states our methodology. Section 3 presents a summary of the results of the analysis. Finally, section 4 offers a conclusion.

2. Methodology

2.1 Lotka-Volterra model

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The Lotka-Volterra model uses the logistic equation and a term that accounts for the interaction of Smartphone sales, which is expressed by the following two differential equations:

$$\frac{dX}{dt} = (a_1 - b_1 X - c_1 Y)X = a_1 X - b_1 X^2 - c_1 XY, \qquad (1)$$

and

$$\frac{dY}{dt} = (a_2 - b_2 Y - c_2 X)Y = a_2 Y - b_2 Y^2 - c_2 YX , \qquad (2)$$

where $\frac{dX}{dt}$ and $\frac{dY}{dt}$ denote the quarterly sales volume of Smartphone from Asia and North America at each quarter t. X and Y are the cumulative sales volume of Smartphone from Asia and North America up to quarter t. The cumulative sales volume calculation starts with the first quarter of 2008, and accumulates quarterly until the fourth quarter of 2013. Additionally, X^2 and Y^2 refer to the same sales volumes interacting with themselves. XY and YX denote competing sales volume interactions between North Amarica and Asia. Equations (1) and (2) contain all of the fundamental parameters that affect the growth rates of Asia and North America sales volumes. Regional competition and cooperation can be determined through the parameters a_i , b_i and c_i . Parameter a_i represents the ability of Asia (or North America) to multiply or grow its sales volumes by itself. The sales volume in one region will stimulate the growth of its sales volume, so this term a_i should have positive signs. Parameter b_i refers to the limitation parameter of Asia (or North America). Parameter c_i represents how Asia and North America sales volumes affect each other. This work utilized the parameters a_i , b_i and c_i to examine how Asia and North America Smartphone sales volumes are related. The proposed Lotka-Volterra model forms a pair of nonlinear differential equations, which are solved numerically using the genetic algorithm (GA) approach combined with the simultaneous nonlinear least squares (NLS) method in order to optimize the parameters. The reason of adopting GA approach by this work is to avoid inadequate initial values. This study initially used GAs to randomly select 3,000 different sets of initial values and applied the simultaneous NLS method to solve numerically the nonlinear Equations (1) and (2). 3,000 sets of estimated parameters a_i , b_i , and c_i are obtained so that this work can use the *t*-statistics to examine directly the statistical significance of the competitive evolutionary process between Asia and North America.

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2.2 Forecast Accuracy

This work assesses the predictive ability of the Lotka-Volterra model by mean absolute percentage error (MAPE), mean absolute deviation (MAD), root mean square error (RMSE), and two Theil U statistics, U_1 and U_2 . This work expresses the five criteria as following equations:

$$MAPE = \frac{1}{n} \sum_{t=1}^{n} \frac{\left| Z_{t} - \hat{Z}_{t} \right|}{Z_{t}},$$
(3)

$$MAD = \frac{1}{n} \sum_{t=1}^{n} \left| Z_{t} - \hat{Z}_{t} \right|,$$
(4)

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} (Z_t - \hat{Z}_t)^2}{n}},$$
 (5)

$$U_{1} = \frac{\sqrt{\frac{1}{n} \sum_{t=1}^{n} (\hat{Z}_{t} - Z_{t})^{2}}}{\sqrt{\frac{1}{T} \sum_{t=1}^{n} Z_{t}^{2}} + \sqrt{\frac{1}{T} \sum_{t=1}^{n} \hat{Z}_{t}^{2}}},$$

$$U_{2} = \sqrt{\frac{\frac{1}{T} [\sum_{t=1}^{n} (\hat{Z}_{t} - Z_{t})^{2}]}{\sum_{t=1}^{n} Z_{t}^{2}}},$$
(6)
(7)

in which Z_t is the actual sales volume, \hat{Z}_t is the predicted sales volumes calculated by our proposed model. Parameters are estimated using in-sample data from the first quarter of 2008 to the second quarter of 2013 and out-sample data from the third quarter of 2013 to the fourth quarter of 2013 are then forecasted. Martin and Witt (1989) divided the predicted value of the model into four levels with MAPE. When MAPE is less than 10%, the predictive ability is excellent. When MAPE is between 10% and 20%, the predictive ability is good. When MAPE is between 20% and 50%, the predictive ability is rational. When MAPE is greater than 50%, the predictive ability is irrational.

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2.3 Equilibrium Analysis

Equilibrium analysis investigates the long-term status. The two lines, dX/dt = 0 and dY/dt = 0, cross each other on the equilibrium point. Since sales volumes of Smartphone from Asia and North America cannot be zero, that is, $X \neq 0$ or $Y \neq 0$. The equilibrium solution of Eqs. (1) and

(2) can be obtained from $X = \frac{a_1 - c_1 Y}{b_1}$ and $Y = \frac{a_2 - c_2 X}{b_2}$.

2.4 Data and sample

This work collects the quarterly Smartphone sales volumes to Asia and North America from Gartner technology research database. The study period lasts 24 quarters in total from the first quarter of 2008 to the fourth quarter of 2013. This work divides our sample period into two periods: in-sample period and out-sample period. The in-sample period ranges from the first quarter of 2008 to the second quarter of 2013. The out-sample period ranges from the third quarter of 2013 to the fourth quarter of 2013. Parameters of the proposed Lotka-Volterra model are estimated using the data in the in-sample period. This work utilized the estimated parameters of in-sample data to illustrate the relations of smartphone sales across various areas. Furthermore, this work utilized the estimated parameters of in-sample data to calculate the predicted sales volumes in the out-sample period and then the forecasting capabilities of our proposed models are examined by comparing the real and predicted sales volumes in the out-sample period.

3. Empirical Results

3.1 Results of estimated parameters

The 3,000 sets of estimated parameters were estimated using the Smartphone sales volumes between Asia and North America from the first quarter of 2008 to the second quarter of 2013 and their means and standard deviations of the 3,000 iterations are shown in Table 1. The self-effect parameters of North America, b_2 are positive, indicating that North America sales volumes would compete among themselves in the same region. Because Smartphone are first entered into North America and their diffusions achieved the mature stage of product life cycle in North America, the marginal growth of Smartphone sold in North America is decreasing. The more the Smartphone sold into North America, the less extent in which the Smartphone sales volume will grow. This suggests the severe saturation pressure existing within North America areas. As Smartphone sales volumes amount approaches market saturation, the growth rate of sales volume decreases. In other words, the Smartphone consumption faces heavy internal rivalry within the same region.

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Table 1 The means and standard deviations of the estimated coefficients of the Lotka-
Volterra model over 3,000 iterations of smartphone sold into Asia and North
America

	Asia		
	<i>a</i> ₁	b_1	<i>C</i> ₁
Mean	2.035303×10 ^{-1***}	-3.045922×10 ^{-8***}	1.882183×10 ^{-7***}
Standard Deviation	6.192762×10 ⁻¹⁰	2.096070×10 ⁻¹⁵	4.906268×10 ⁻¹⁵
t-statistics	1.800136×10 ¹⁰	-7.959275×10 ⁸	2.101223×10 ⁹
	North American		
	a_2	b_2	<i>C</i> ₂
Mean	1.856833×10 ^{-1***}	3.397439×10 ^{-7***}	-5.315913×10 ^{-8***}
Standard Deviation	4.529592×10 ⁻⁹	4.134051×10 ⁻¹⁵	1.895469×10 ⁻¹⁵
t-statistics	2.245299×10 ¹⁰	4.501284×10 ⁹	-1.536108×10 ⁹

*Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level.

By contract, the self-effect parameters of Asia, b_1 are negative, indicating that Asia sales volumes would stimulate sales growth in the same region. The marginal growth of Smartphone sold in Asia is increasing. The more the Smartphone sold in Asia, the greater extent in which the Smartphone sales volume will grow. This suggests that the great effect of word of mouth in Asia areas enhances the sales growth as the viewpoints that the word of mouth affect consumer decisions proposed in Juliet and Nzorubara (2017). Because Smartphone entered into Asia later than North America, Asia Smartphone market is far from market saturation until now, the incumbent Asia consumers of Smartphone share the functions of entertainment, wireless communication global positioning and media to other people and attract the successive Asia consumers to purchase Smartphone. Thus, the strong effect of word mouth accelerate the diffusions of Smartphone in Asia.

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On the other hand, the interaction parameter of the Asia sale volumes affected by North America, c_1 , is positive and significant, indicating that the Asia sales volume is squeezed by the massive stress of North American sales volumes. The interaction parameter of the North American sale volumes affected by Asia, c_2 , is negative and significant, indicating that the Asia sales volume enhances North America sales volumes. Sale growth in Asia substantially promotes that in North America, whereas the sale growth in North America curtails that in Asia. North America is the target market of Smartphone. Thus, the Smartphone firms are first sold to North America. As the Smartphone sale to North America increases, the sale in Asia decreases. Until the production capacity of Smartphone is stable and large enough, the sale to Asia increases. When Smartphone get more and more popular in Asia, the widespread of Smartphone entertainments and commercials in Asia stimulate the Smartphone sales in North America.

3.2 Results of forecast accuracy

This work then compares the actual and the simulated cumulative sale volumes. Figures 1 and 2 depict the actual and simulated cumulative sales volumes using the proposed Lotka-Volterra model for Asia and North America sales volumes, respectively in the in-sample and out-sample periods. Figures 1 and 2 depict the predicted sales volumes. Obviously, the predicted sales volume is extremely close to the actual volumes predicted by our proposed Lotka-Volterra model. In addition, the actual and predicted cumulative sales volumes have the consistent trend. Figures 1 and 2 summarize the results of the model goodness and forecast accuracy in in-sample and out-samples, respectively.



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Figure 1 The real and simulated sales volumes of smartphones sold into Asia areas during out-sample period.



Figure 2 The real and simulated sales volumes of Smartphone sold into North American areas during out-sample period.

Table 2 lists the forecast accuracy results of our proposed Lotka–Volterra model using MAPE, MAD and RMSE. A smaller MAPE implies a closer trend of the predicted sales volumes to the actual sales volumes of Smartphone in Asia or North America; otherwise, the prediction accuracy is irrational. The MAPEs of Smartphone sales volumes form Asia and North America predicted by using the Lotka–Volterra model are 3.37% and 7.27% for the out-sample and 10.05% and 10.17% for the in-sample, respectively. This forecast accuracy of the out-sample suggests that the both Smartphone sales predictions in Asia and North America are excellent according to the criteria of Martin and Witt (1989). The forecast accuracy of the in-sample suggests that both the Smartphone sales predictions in Asia and North America are good according to the criteria of Martin and Witt (1989). The proposed Lotka–Volterra model can thus accurately predict the trend of Smartphone sales. Table 3 lists the forecast accuracy results of our

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proposed Lotka–Volterra model using U_1 and U_2 . From Table 3, the proposed Lotka–Volterra model predicts the Smartphone sales volumes in North American better than those in Asia in both in-sample and out sample data.

Table 2 Comparison of real sales volumes and predicted sales volumes from Lotka-Volterra models in the out-sample and in-sample periods using MAPE, MAD, and RMSE.

Out-sample	MAPE	MAD	RMSE
Asia / Pacific	3.371511736×10 ⁻²	3.339268×10 ⁴	3.35872982×10 ⁴
North American	7.269715683×10 ⁻³	3.817027×10 ³	5.30959176×10 ³
In-sample	MAPE	MAD	RMSE
Asia / Pacific	1.0048272140×10 ⁻¹	5.7222866256×10 ³	7.15036145848×10 ³
North American	1.0174404478×10 ⁻¹	3.5358164354×10 ³	4.50516121861×10 ³

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	Asia / Pacific	
	U_1	U_2
In- sample Mean	1.12735398009×10 ⁻²	4.75904715549×10 ⁻³
In- sample Standard Deviation	1.04299655805×10 ⁻¹¹	4.34273317483×10 ⁻¹²
Out-Sample Mean	1.72579751593×10 ⁻²	2.39927597130×10 ⁻²
Out-Sample Standard Deviation	5.41413071488×10 ⁻¹¹	7.40140875987×10 ⁻¹¹
	North American	
	U_1	U_2
In- sample Mean	$\frac{U_1}{1.00959900722 \times 10^{-2}}$	U ₂ 4.296025310699×10 ⁻³
In- sample Mean In- sample Standard Deviation	U_1 1.00959900722×10 ⁻² 1.07688714270×10 ⁻¹¹	U_2 4.296025310699×10 ⁻³ 4.60219733617×10 ⁻¹²
In- sample Mean In- sample Standard Deviation Out-Sample Mean	U_{1} $1.00959900722 \times 10^{-2}$ $1.07688714270 \times 10^{-11}$ $5.26844757824 \times 10^{-3}$	U_2 4.296025310699×10 ⁻³ 4.60219733617×10 ⁻¹² 7.42251516096×10 ⁻³

Table 3 Comparison of real sales volumes and predicted sales volumes from Lotka-Volterra models in the out-sample and in-sample periods using U_1 and U_2 .

3.2 Results of equilibrium analysis

Equilibrium analysis reveals that the equilibrium point for the sales volumes of Asia and North American cannot stabilize. Figure 3 shows that the future trajectory of Smartphone's sales volumes will not converge to the equilibrium points in Asia and North America, respectively. Since the equilibrium status is unstable, the sales volumes from both Asia and North America increase infinitely. It is possibly caused by the fact that people must depends on the communication functions through Smartphone's before other innovative products enter into the market. The Smartphone's will be broken, so consumers should buy a new one after the Smartphone disposals. Sales volumes of Smartphone's in Asia increase in greater extent that those in North America. This continuous growth could be attributed to the great populations in Asia. The future trends of smart phone sales depend on the consumers' populations, income and acceptance in Asia and North America in the future.



Figure 3 Long term prediction trajectory of the smartphone sales volumes in Asia and North America using our proposed Lotka-Volterra models.

4. Conclusions

This study used the Lotka-Volterra model to investigate Smartphone sales and considered the interactive dependence among various regions in the Smartphone industry. Specifically, how consumption centers shifted from North America to Asia is explored by focusing on the intimate relationship of competition and cooperation between Smartphone market in Asia and North America. Empirical results of this investigation show that the Lotka-Volterra model can be used to determine the reciprocal influence among sales volumes of these two consumption regions in the Smartphone industry.

Sale growth in Asia substantially promotes that in North America, whereas the sale growth in North America curtails that in Asia. North America is the target market of Smartphone. Thus, the Smartphone are earliest sold to North America. As the Smartphone sale to North America increases, the sale in Asia decreases. Until the production capacity of Smartphone is stable and large enough, the sale to Asia increases. When Smartphone gets more and more popular in Asia, the widespread of Smartphone entertainments and commercials in Asia stimulate the Smartphone sales in North America.

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Analytical results demonstrate that Smartphone sale in Asia substantially promotes sales growth within Asia, whereas the Smartphone sales in North America curtails sales growth within North America. A possible explanation for this phenomenon is that, in the Smartphone market, North America and Asia are at the mature and early stages of the product life cycle. Thus, the sale of Smartphone deters the sale growth in North America, while the sale of Smartphone accelerates the sale growth in Asia. Regarding the interaction effect between Asia and North America markets, the parameter estimation results of the Lotka-Volterra model show that the Smartphone sale growth in Asia substantially promotes that in North America, whereas the Smartphone sale growth in North America curtails that in Asia. As the Smartphone sale in North America increases, the sale in Asia decreases. Until the production capacity of Smartphone is stable and large enough, the sale in Asia increases. When Smartphone get more and more popular in Asia, the widespread of entertainment, commercial, and communication activities in Asia stimulate the Smartphone sales in North America.

Regarding forecast accuracy, the forecast errors of Smartphone sales volumes form Asia and North America predicted by using the Lotka–Volterra model are small for the out-sample. This suggests that the both Smartphone sales predictions in Asia and North America are excellent for out-sample data according to the criteria of Martin and Witt (1989). The proposed Lotka–Volterra model can thus accurately predict the trend of Smartphone sales. Equilibrium analysis reveals that the equilibrium point for the sales volumes of Asia and North American cannot stabilize. Finally, this study forecasts that the sales volumes from both Asia and North America increase infinitely. Because people must depends on the communication functions through Smartphone before other innovative products enter into the market to replace the Smartphone's, the Smartphone will be broken so that consumers should buy a new one after the Smartphone disposals. Sales volumes of Smartphone in Asia increase in greater extent that those in North America due to the great populations in Asia. The future trends of Smartphone sales depend on the consumers' populations, income and acceptance in Asia and North America in the future.

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