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Modelling Competition of Different Manufacturing Strategies Based on Lotka-Volterra Equations

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Abstract: This work is the first to explore the competitive relationships between own brand manufacturing (OBM) and original equipment/design manufacturing (OEM/ODM) strategies. The most significant difference between the two aforementioned strategies is that companies adopting OEM/ODM strategies simply supply manufacturing services according to the clients' demands but do not develop their own brands. This study applies Lotka-Volterra models to elucidate market competition between OBM and OEM/ODM strategies in the global motherboard industry. This work quantifies the interactive dynamics between OBM and OEM/ODM strategies by using shipment as an indicator of sales performance and consumer purchase. The results of parameter estimation show that OEM/ODM enterprises rely on OBM enterprises to absorb production related knowledge and enhance their sales, and OBM enterprises depend on OEM/ODM factories to enhance their economies of scale. The results of Lyapunov functions further prove that the shipments of OBM and the OEM/ODM strategies will reach a stable long-term equilibrium and the potential production of OEM/ODM strategy will ultimately be nearly two times as large as that of OBM strategy. In terms of forecast accuracy, our proposed Lotka-Volterra model performs better than Bass model in predicting motherboard shipments since the Lotka-Volterra model incorporates the interactive relation across different strategies.

Keywords: Lotka-Volterra model, Bass model, Own brand manufacturing, Original equipment manufacturing

JEL Classifications: L10, C62, M11

1. Introduction

In this study, we analyze the competitive relationship between own brand manufacturing (OBM) and original equipment/design manufacturing (OEM/ODM) strategies in the global motherboard manufacturing industry by using the Lotka-Volterra model and Lyapunov functions. Firms adopting OBM strategies develop and sell products under their brand name. Firms adopting OEM/ODM strategies do not develop their own brands but only provide manufacturing services to other companies. Li *et al.* (2011) illustrate that those companies adopting OEM strategies manufacture products or components that are sold to consigned companies and are retailed under the brand name of the consigned company. Companies adopting ODM strategies design and manufacture a product, which is then branded by a consigned firm for sale. In other words, OEM and ODM are the fundamental production services in high-tech industries. Generally, the operating strategies for high-tech electronics firms can be sorted into two types: the development of firms' own brands and the supply of manufacturing services. The main difference is that own brand manufacturers concentrate on brand image and selling their own products under the brand names; however, enterprises under such manufacturing services strategies as OEM and ODM do not develop any brands. OBM and OEM/ODM enterprises have long closely collaborated under a complete supply chain (Feenstra *et al.*, 2011). Enterprises that possess their own brands transfer the latest innovative schemes for new products to their supplying OEM/ODM factories to launch updated products using their own brand names. Consequently, OEM/ODM enterprises, which produce a finished product based on the specifications of the OBM enterprises, are able to avoid the huge cost burdens and risks involved in research and development activities (Li *et al.*, 2011). In 2008, OBM shipments accounted for only 62.04% of the OEM/ODM shipments in the global motherboard industry since close interdependent relationships exist between these two strategies (Kang *et al*, 2009). A motherboard manufacturer that adopts the OBM strategy must consider the supply chain of OEM/ODM factories. To discuss the interactive relationship of the two strategies, this work distinguishes the operating strategies of motherboard companies as two types: One is the OBM strategy, under which motherboard companies focus on brand-driven activities. The other is the OEM/ODM strategy, under which motherboard companies simply provide production services. We attempt to determine the level of effectiveness on which OBM and OEM/ODM operate in the supply chain of industrial manufacturing.

Previous research primarily utilized questionnaires or qualitative methods to survey the business model and strategies (Eng and Spickett-Jones, 2009; Chu, 2009). Zhai *et al.* (2007) describes the firm growth and internal capability development of electronics manufacturing service companies based on case studies. Li *et al.* (2011) used three cases of Japanese manufacturing service supplier to state how they achieve further growth and resilience to marketplace uncertainties through the reorganizations of manufacturing supply chain and economies of scale. However, literature that applies the quantitative approach for illustrating OEM/ODM or OBM strategies is scant because collecting empirical data for quantifying the relationships between these two strategies is difficult. Therefore, we attempt to quantify the interactive dynamics between OEM/ODM and OBM strategies by using shipment units as an indicator of sales performance and consumer purchase decisions. Enterprises that possess their own brands may possibly receive two types of orders: OBM and OEM/ODM for their production. The Market Intelligence Consulting Institute database collects OBM and OEM/ODM shipment-related information for the entire motherboard industry. The data, which separate shipments of OBM orders from those of OEM/ODM orders, enable us to analyze the respective time-series shipment volumes of both OBM and OEM/ODM orders. The competitive or cooperative correlations between different manufacturing strategies are quantified empirically based on the motherboard shipment units. The results of the empirical quantification provide further insights in manufacturing strategies in both the motherboard industry and other high-tech industries. Because high-tech industries display the same characteristics as the motherboard industry with regard to a complete supply chain composed of OBM and OEM/ODM enterprises, the findings of this study are applicable for predicting how various strategies and business models compete in other high-tech industries, such as the TFT-LCD, computers, communications, information technology, and consumer electronics industries.

Most previous studies have applied diffusion theory to determine the market dynamics by using a logistical S-curve (Bass, 1969; Li and Amini, 2012). Chien *et al*. (2010) utilized a modified diffusion model to forecast the market dynamics of semiconductor product demand. Tsai (2013a) and Tsai (2013b) applied logistic models to forecast the diffusion of liquid crystal display televisions, respectively. However, these models presupposed a monopolistic market, which excludes analyses of reciprocal cooperation or competition among various manufacturing strategies. The interactive dependence between OEM/ODM and OBM is inevitable in high-tech industry supply chains. A prediction of the shipment volume of OEM/ODM or OBM strategies would be inaccurate if the research applied conventional diffusion model, which does not incorporate the intricate relationship among different strategies. Thus, this work explores the competitive and cooperative relationships of manufacturing strategies by using the Lotka-Volterra model.

This work has made an incremental contribution in management and features a unique model specification and equilibrium analysis. By applying the Lotka-Volterra model, this study focuses on the shipment of OBM and OEM/ODM factories to discuss competition and cooperation in manufacturing strategies. The stability of the equilibrium point between OBM and OEM/ODM strategies is further analyzed by Lyapunov functions. Finally, we demonstrate the forecasting accuracy by disclosing the prediction errors using a comparison of the actual shipment and the predicted shipment, as estimated by the proposed Lotka-Volterra model.

2. Methodology

2.1 Data and sample

The data collected from the Market Intelligence Consulting Institute database are worldwide motherboard-industry shipment information. Quarterly global motherboard shipments are applied to measure sale performance in this study. The study period is from the first quarter of 2003 to the third quarter of 2010, totaling 31 quarters. Certain enterprises that transitioned from OEM/ODM enterprises to OBM enterprises may also accept orders from OEM/ODM factories, resulting in shipment volumes from OBM and OEM/ODM strategies at same time. Because the segment-reporting data in the accounting reports respectively reveal the OBM and OEM/ODM shipment-related volume of each enterprise, the Market Intelligence Consulting Institute database can collect and organize the OBM and OEM/ODM shipment information of the entire motherboard industry; thus, these unique data satisfy our research purposes. This work employs the shipments of the two production strategies separately for analysis.

2.2 Lotka-Volterra model

The Lotka-Volterra model uses the logistic equation and a term that accounts for the interaction with different species. The interaction between OBM and OEM/ODM shipments orders can be expressed by the following two differential equations:

$$(\frac{dX_1}{dt})/X_1 = (a_1 - b_1 X_1 - c_1 X_2)\,, \tag{1}$$

$$(\frac{dX_2}{dt})/X_2 = (a_2 - b_2 X_2 - c_2 X_1) \tag{2}$$

where $\frac{dX_1}{dt}$ and $\frac{dX_2}{dt}$ denote the quarterly shipment volume of motherboard OBM and OEM/ODM orders at each quarter *t*. Also, X_1 and X_2 are the cumulative shipment volume of OBM and OEM/ODM orders up to quarter *t*. Additionally, $X_1^{\,2}$ and $X_2^{\,2}$ refer to the same shipment interacting with itself, while X_1X_2 and X_2X_1 denote competing shipment interactions. As the volume of shipment can fully represent the volume of sales, a_i represents the ability of OEM/ODM (or OBM) enterprises to multiply OEM/ODM (or OBM) sales by itself; b_i refers to the limitation parameter of OEM/ODM (or OBM) sales during expansions; and c_i is the parameter for interactive influence between OBM and OEM/ODM sales. In Lotka-Verterra models, the positive coefficient b_i mainly accentuates that the more the market demand of OEM/ODM (or

OBM) strategy approaches saturation, the more the growth of follow-up sales for OEM/ODM (or OBM) strategy decreases. The coefficient c_i represents how OBM and OEM/ODM shipments affect each other. Equations (1) and (2) contain all of the fundamental parameters that affect the growth rates of OBM and OEM/ODM shipments. The competitive relations across different strategies can be obtained by coefficient c_i for OBM and OEM/ODM shipments.

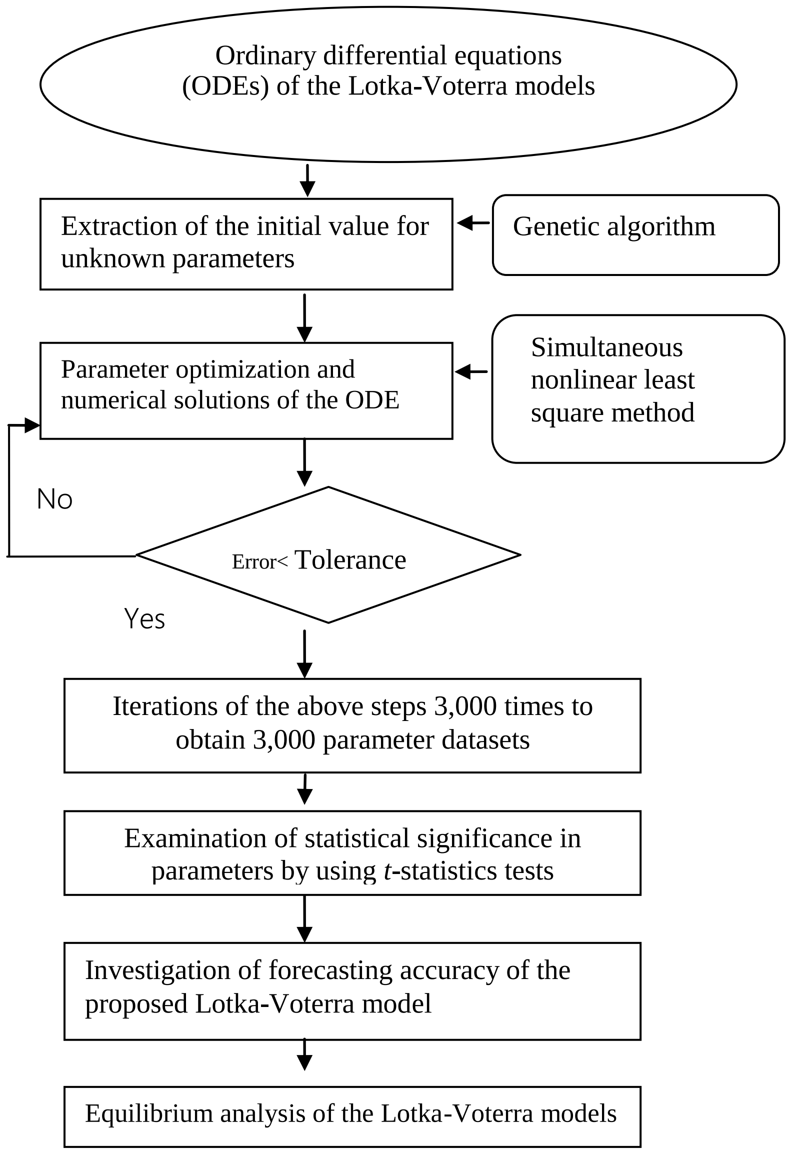

Figure 1 Flowchart of the computational procedure and investigation steps in this work

The proposed Lotka-Volterra model forms a pair of nonlinear ordinary differential equations. Figure 1 shows a flowchart of our proposed computational procedure and investigation steps. Our hybrid evolutionary and numerical optimization can be summarized in two steps: First, this work iterates GA simulations to randomly select different initial values. Second, this study employs the initial values from the first step to optimize parameters. The parameter optimization method is to iterate simultaneous nonlinear least square estimation until the optimized parameter could result in a predicted shipment value that generates errors smaller than the tolerable margin. This work iterates GA simulations 3,000 times to obtain 3,000 sets of initial values. Through these sets, this work obtains 3,000 sets of estimated parameters a_i, b_i, and c_i, allowing for use of the *t*-statistics to examine directly the statistical significance of the competitive evolutionary process across various manufacturing strategies and identify the estimated parameters located within acceptable intervals. Then, this work investigates the forecasting accuracy of our proposed Lotka-Voterra model and conducts the equilibrium analysis.

2.3 Forecasting accuracy

The Lotka-Volterra model in Equations (1) and (2) adds the competitive interaction between the two group in addition to implementing a self-diffusing evolution situation based on the logistic curve (Lin, 2013; Teng and Huang, 2013; Tsai, *et al*., 2013; Manfredi and Fanti, 2004). However, previous model has extensively use the Bass (1969) model which only illustrates self-diffusing evolutions without considering the competitors' interactions. To judge whether our proposed Lotka-Volterra model performs better than the conventional Bass model, this work constructs the Bass model using Equations (3) and (4) and compares forecast accuracy between Lotka-Volterra and Bass models:

$$\frac{dX_1}{dt} = (p_1 + q_1 X_1)(M_1 - X_1) \tag{3}$$

$$\frac{dX_2}{dt} = (p_2 + q_2 X_2)(M_2 - X_2) \tag{4}$$

where $\frac{dX_1}{dt}$ and $\frac{dX_2}{dt}$ denote the quarterly shipment volume of motherboard OBM and OEM/ODM orders at each quarter *t*. Also, X_1 and X_2 are the cumulative shipment volume of OBM and OEM/ODM orders up to quarter *t*. This study follows Bass (1969) to estimate the parameters p_1, q_1, M_1, p_2, q_2, and M_2. M_1 and M_2 are defined as market potential under OBM and OEM/ODM strategies, respectively. After motherboard shipment volumes are estimated by Bass and Lotka-Volterra models using the training sample ranging from the first quarter of 2003 to the fourth quarter of 2009, the prediction accuracy of our proposed Lotka-Volterra model is compared with that of Bass model.

The ability of the Lotka-Volterra model to predict motherboard shipments is assessed by mean absolute percentage error (MAPE), mean absolute deviation (MAD), and root mean square error (RMSE). The MAPEs are calculated as $MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{Z_t - \hat{Z}_t}{Z_t}\right|$; the MADs are calculated as $MAD = \frac{1}{n}\sum_{t=1}^{n}\left|Z_t - \hat{Z}_t\right|$; and RMSEs are calculated as $RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(Z_t - \hat{Z}_t)^2}$, in which Z_t is the actual shipments, $\hat{Z}_t$ is the predicted shipments calculated by our proposed model. Parameters of both models are estimated using motherboard shipments from the first quarter of 2003 to the fourth quarter of 2009. Forecasted quarterly motherboard shipments from the first quarter of 2010 to the third quarter of 2010 are then compared with actual shipments.

2.4 Equilibrium analysis

Analyzing the competitive relationship using the Lotka-Volterra model provides insight into the equilibrium state and illustrates the trajectory of change over time. In equilibrium, Equations (1) and (2) must equal zero because no simultaneous changes occur over time for each industry. Thus,

$$\frac{dX_1}{dt} = 0 \quad \text{and} \quad \frac{dX_2}{dt} = 0 \tag{5}$$

Solving equation (5) yields:

$$X_1 = \frac{a_1 - c_1 X_2}{b_1}, \text{ and } X_2 = \frac{a_2 - c_2 X_1}{b_2} \tag{6}$$

The two lines, $dX_1/dt = 0$ and $dX_2/dt = 0$, cross each other, implying an equilibrium point. Stability of the equilibrium point in our proposed Lotka-Volterra model is then examined under the following two approaches: Eigenvalues of Jacobian matrix at equilibrium point and Lyapunov equation. First, this work chooses the equilibrium point on our trajectory to make linear approximation and then calculates the eigenvalues of the Jacobian matrix $\boldsymbol{A}$ at the equilibrium point. Equilibrium points can be stable only if the real parts of both eigenvalues are negative. Because the equilibrium point is the terminal point of OEM/ODM and OBM cumulative shipments trajectories, the stable equilibrium point illustrates the market potential of OBM or OEM/ODM strategies. Neither OBM nor OEM/ODM strategies are expelled from the market because of each other.

3. Results and Discussion

3.1 Competitive relationship between OBM and OEM/ODM strategies

The 3,000 sets of estimated coefficients were optimized using the motherboard shipments of OBM and OEM/ODM strategies from the first quarter of 2003 to the fourth quarter of 2009. The means and standard deviations of the all 3,000 sets of estimated coefficients of the proposed Lotka-Volterra model are shown in Table 1. All 3,000 sets of the estimated coefficients a_i, b_i, and c_i are approximate; therefore, the standard deviations of all 3,000 sets of the estimated coefficients are fairly small (Table 1). Although the 3,000 sets of the initial values are different, the optimized parameters are similar and stably located within a reasonable range. This finding suggests that our simulation involving the GA approach, which is combined with the simultaneous nonlinear least squares method, generates stable and reliable parameters with only slight deviation.

According to the *t*-statistics results from the 3,000 sets of estimated coefficients of the proposed Lotka-Volterra model, the statistical significance for all the 3,000 sets of estimated coefficient are all maintained at a level of less than 1%. The interactive parameter of the OBM strategy affected by the OEM/ODM strategy c_1 is significant and negative. Conversely, the interaction parameter of the OEM/ODM strategy affected by the OBM strategy c_2 is positive and significant. The shipments using the OBM strategy erodes that of the OEM/ODM strategy and the shipment obtained from the OEM/ODM strategy promotes the growth of shipment obtained from the OBM strategy. Since the shipment volume is a good indicator of sales performance, the implication is that if OEM/ODM enterprises assisted in product manufacturing, OBM enterprises could focus on marketing, product design, and research and development activities, which could further boost sales growth. OBM enterprises use the outstanding manufacturing capability of OEM/ODM factories to achieve significant competitive advantages (Sanchez, Heene, and Thomas, 1996). The parameter estimation results indicate that the sale of the OEM/ODM strategy is reduced by the massive stress caused by the OBM strategy. Sales using the OEM/ODM strategy promote the sales that use the OBM strategy, but OBM sales curtail the sales obtained using the OEM/ODM strategy.

Table 1 The means and standard deviations of the estimated coefficients

OBM	a_1	b_1	c_1
Mean	0.335^{***}	$3.161\times10^{-6***}$	$-1.376\times10^{-6***}$
Standard deviation	2.664×10^{-6}	3.852×10^{-11}	1.868×10^{-11}
OEM/ODM	a_2	b_2	c_2
Mean	0.320^{***}	$-9.965\times10^{-7***}$	$2.460\times10^{-6***}$
Standard deviation	2.562×10^{-5}	1.773×10^{-10}	3.672×10^{-10}

Notes: (1)The estimation of the proposed Lotka-Volterra model is based on over 3,000 iterations of OBM and OEM/ODM strategies in the motherboard manufacturing industry

(2) *,**, and *** indicate statistically $p<0.10$, $p<0.05$, and $p<0.01$, respectively.

The b_2 value of the OEM/ODM strategy is negative and significant. This finding suggests that the inner regeneration power of the OEM/ODM strategy is strong. The positively self-growing dynamic within the OEM/ODM enterprises can accelerate shipments. A sailing-ship effect described in Sahal (1979) may occur when OEM/ODM enterprises are pressured by enterprises that possess their own brands. This finding implies that OEM/ODM enterprises might be devoted to exploring new applications in the market to avoid decay or elimination. Therefore, their strategy is to expand their niche by absorbing the spillover knowledge and technology from enterprises that possess their brands, elevating their scale of economy, lowering their cost and enhancing their quality, so their shipment growth rate can increase progressively as shipments increase.

When motherboard OEM/ODM factories handle frequent product design changes that are requested by personal computer clients (e.g., HP, IBM, and NEC), they aggressively absorb knowledge from these companies, thereby promoting their own productivity, quality, and customer satisfaction, and reducing their overall costs. The empirical results correspond to the statements of previous studies in which companies in industrialized countries apply OEM/ODM strategies to improve core power, gain new competitive advantages, and diversify risks (Zhai *et al*, 2007). Conversely, coefficient b_1 of the OBM strategy is positive, implying the existence of severe saturation pressure within the OBM units. As cumulative OBM shipment moves close to market saturation, the growth rate of shipment decreases; that is, OBM enterprises face heavier pressure from internal rivalry within the same industry than OEM/ODM enterprises do. With increasing shipment volumes from companies using the OBM strategy, the market demand for motherboards produced from OBM orders approaches saturation, resulting in the decreased follow-up sales and shipments of OBM motherboards. In the Lotka-Volterra models, the positive coefficient b_1 mainly accentuates the limiting pressure on OBM motherboard shipments within enterprises that possess OBM brands.

3.2 The results of forecast accuracy

This work then applies the average parameter values of the 3,000 sets of optimized parameters in the proposed Lotka-Volterra model to simulate cumulative shipments. Next, the forecast accuracy is compared between Bass and our proposed Lotka-Volterra models. Figures 2 and 3 show the actual and predicted cumulative shipment using the proposed Lotka-Volterra models for OEM/ODM and OBM strategies in the training and test periods, respectively.

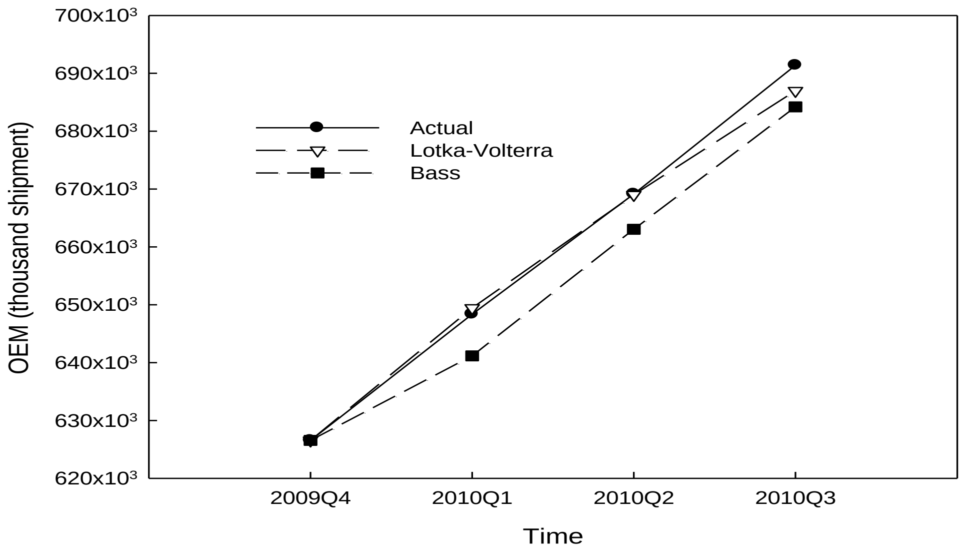

Figure 2 Comparison of actual OEM/ODM cumulative shipments of motherboard with Lotka-Volterra and Bass models' predicted values in test period from the first quarter of 2010 to the third quarter of 2010

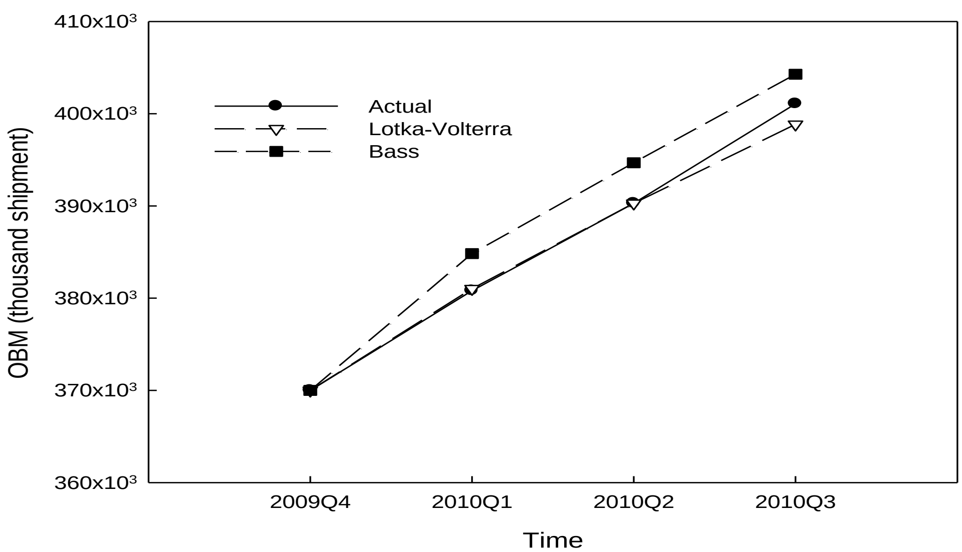

Figure 3 Comparison of actual OBM cumulative shipments of motherboard with Lotka-Volterra and Bass models' predicted values in test period from the first quarter of 2010 to the third quarter of 2010

As for both OEM/ODM and OBM strategies, the forecasted value is extremely close to the actual shipments. However, the predicted values of Bass model are far away from the actual cumulative motherboard shipments under both OBM and OEM/ODM strategies. Regarding model fitness, the adjusted R^2 value of the Lotka-Volterra model is close to one. This value shows the goodness of fit between the simulated and actual shipments using OBM and OEM/ODM strategies. The interaction among OBM and OEM/ODM shipments can be explained using the proposed Lotka-Volterra model.

Table 2 presents a summary of the results of the model goodness in the training period and forecast accuracy in the test period, respectively. The analytical results indicate that the MAPE of the predicted cumulative shipments 2.915% and 3.097% for OBM and OEM/ODM strategies, respectively, during the training period. Both of the MAPEs of these strategies are lower than 5%. The proposed model correlates well with the actual shipments. In addition, the MAPE of the forecasted cumulative shipments of the proposed Lotka-Volterra model during the test period for both OBM and OEM/ODM strategies are 0.244% and 0.302%, respectively. Both MAPEs of these strategies are less than 5%. According to the Martin and Witt (1989) criteria, the forecast accuracy is excellent. For the forecast of the cumulative shipments using the Bass model, the forecast accuracy of Bass model in the training period is similar to that of Lotka-Volterra model for OEM/ODM cumulative shipments because the MAPE of the cumulative shipment is located in the interval between 3% and 4%. However, MAPE of the Bass model is nearly four times as large as that of Lotka-Volterra model under the OBM strategy. MAPE of the Bass model is nearly three times as large as that of Lotka-Volterra model under OEM/ODM strategies. The analytical results show that the forecast accuracy of Lotka-Volterra is superior to that of Bass model for predicting motherboard OBM and OEM/ODM shipments in the test period.

Table 2 Forecasting accuracy of the Lotka-Volterra model and Bass model

Test	MAPE	MAD	RMSE
Lotka-Volterra model			
OBM	0.244%	964.92	1,262.08
OEM/ODM	0.302%	2,074.30	2,947.77
Bass model			
OBM	0.992%	3,869.15	3,900.36
OEM/ODM	1.021%	6,830.40	6,849.31
Training	MAPE	MAD	RMSE
Lotka-Volterra model			
OBM	2.915%	2,093.16	3,074.20
OEM/ODM	3.097%	2,555.47	3,689.70
Bass model			
OBM	1.015%	2,109.73	2,785.53
OEM/ODM	3.441%	8,259.81	8,756.21

Notes: (1) Two types of models are used to predict the motherboard shipments of the OBM and OEM/ODM strategies during training and test periods
(2) MAPE, MAD and RMSE are the MAPE, MAD and RMSE of cumulative shipments, respectively.

3.3 Analysis results of equilibrium points

3.3.1 The results of the equilibrium analysis

The equilibrium analysis is performed by selecting the means of parameters to examine the stability of the equilibrium point when using the OBM and OEM/ODM strategies. The eigenvalue calculations at the equilibrium point comprise two steps: First, we use the mean of the 3,000 sets of the estimated parameters (Table 1) to compute the equilibrium point in equation (6), 454,298 and 800,077 thousand pieces for OBM and OEM/ODM strategies, respectively. Second, the eigenvalues of the Jacobian matrix for the equilibrium point ***A*** are calculated -0.4467 and -0.1921. The fact that both eigenvalues of our Jacobian matrix for the equilibrium point are negative proves the stability of the equilibrium point. Figure 4 shows that the cumulative shipment trajectory of OBM and OEM/ODM strategies eventually converges to the equilibrium point. The two straight lines in equation (6) intersect in the first quadrant, indicating the existence of an equilibrium point for these two series of shipments.

In Fig. 4, the area on the left side of line $dX_1/dt = 0$ represents the region where the OBM cumulative shipment increases ($dX_1/dt > 0$). Similarly, the area on the bottom side of line $dX_2/dt = 0$ represents the region where OEM/ODM cumulative shipment increases ($dX_2/dt > 0$). For the 2009 fourth quarter, 370,004 thousand pieces of OBM and 626,561 thousand pieces of OEM/ODM motherboards were shipped. Those numbers correspond to a point where the two manufacturing strategies have not reached their equilibrium point. The stability of the equilibrium point has been proven through the above eigenvalues of the Jacobian matrix, so the cumulative shipment trajectory of both OBM and OEM/ODM strategies eventually converges to the equilibrium point. Currently, neither OBM nor OEM/ODM shipment diffusion has reached market saturation. They both eventually achieve a stable market potential equilibrium in 2020, totaling 454,298 and 800,077 thousand motherboards for the OBM and OEM/ODM strategies, respectively.

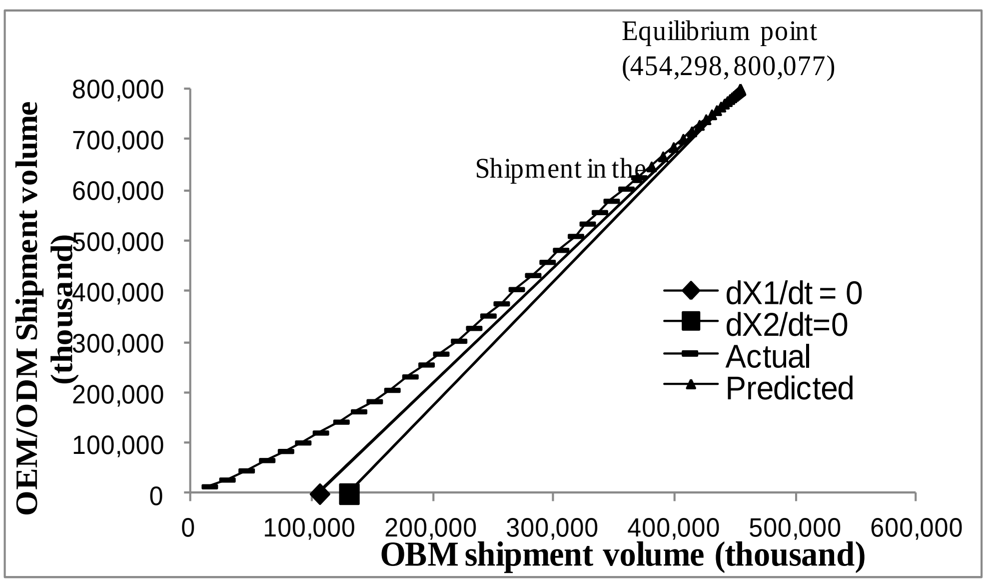

Figure 4 Shipment trajectory and equilibrium point of OBM and OEM/ODM strategies in the motherboard industry

3.3.2 The results of Lyapunov analysis

Referring to the Lyapunov stability equilibrium analysis, this study transforms the equilibrium point as the new origin on the coordinate axis. By way of the coordinate transformation, a calculated point on the trajectory, 454,268 and 800,007 thousand motherboards for OBM and OEM/ODM strategies, respectively, is noted in the new coordinate system as $z=(u, v)$ =(-30.2075, -70.8000). Incorporating the Jacobian matrix into Lyapunov function, this work computes the Lyapunov function is equal to $1.43\times 10^{12} > 0$ and the first-order differential of Lyapunov function is equal to $-8.46\times 10^{11} < 0$, proving that the trajectory satisfies the stable conditions of its equilibrium point, and will at last converge to equilibrium point, 454,298 and 800,077 thousand motherboards for OBM and OEM/ODM strategies, respectively.

Figure 5 shows the time series on the X-axis and the cumulative shipments on the Y-axis. Figure 5 shows that the market saturation expected in 2020 and the saturated values shown in Fig. 5 converge to the equilibrium point values depicted in Fig. 4. In Fig. 5, the shipments in the fourth quarter of 2009 are 370,004 and 626,561 thousand pieces for OBM and OEM/ODM strategies, and have not reached the equilibrium point values. Because the equilibrium point describes the shipment volume of market saturation, these illustrations imply that OEM/ODM and OBM orders will continue to ship additionally 84,294 and 173,516 thousand pieces, respectively. Although orders from companies using the OBM strategy reduce those of companies using OEM/ODM strategies, both OBM and OEM/ODM strategies continue to receive orders and produce shipments until they reach market saturation. Hence, OBM and OEM/ODM strategies currently coexist and finally converge at the equilibrium point.

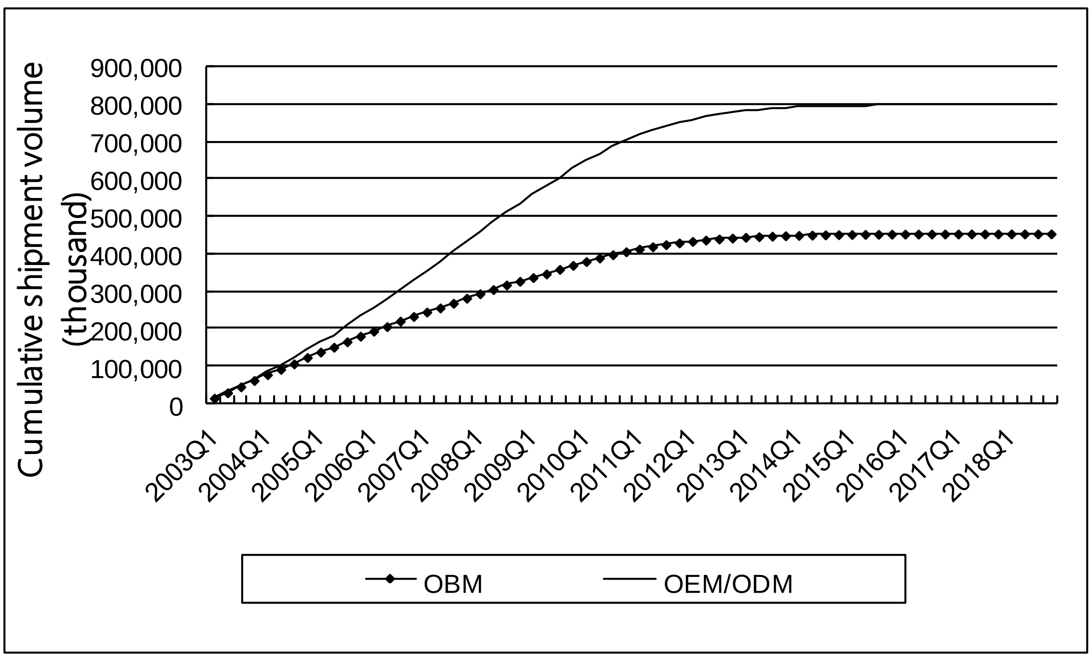

Figure 5 Long-term predicted orbits of OBM and OEM/ODM cumulative shipments using the proposed Lotka-Volterra model

The cumulative shipment volume value of the equilibrium point represents the market potential of OBM and OEM/ODM motherboard orders. We infer from the equilibrium point that the market potential of the OEM/ODM strategy (800,077) is nearly twice that of the OBM strategy

(454,298). While the OEM/ODM technologies mature, enterprises that possess their own brands search for OEM/ODM factories to manufacture products, thereby reducing the cost of operating OBM enterprises. Because of the series of global financial crises that have occurred since the Lehman Brothers bankruptcy in 2008, consumers are more sensitive to product prices. Hence, OEM/ODM functions as an effective means of securing OBM companies to profit in the competitive market. The formidable OEM/ODM supply chain can develop the economies of scale to enhance product quality and reduce product price by mass production, which explains why consumers can afford and prefer products produced by OEM/ODM enterprises more than before. Consequently, the OEM/ODM strategy continues to dominate shipments in the motherboard manufacturing sector.

4. Conclusions

The Lotka-Volterra model developed in this study is the first to predict global motherboard shipment growth by thoroughly considering the mutual dependence among various strategies in the motherboard industry. Parameter optimization, forecast accuracy, and equilibrium analysis were first undertaken using a GA combined with the simultaneous nonlinear least squares methods. The analytical results indicate that the relationship between OBM and OEM/ODM strategies is that of predator and prey, in which OBM shipments are driven mainly by OEM/ODM shipments. Concurrently, OEM/ODM shipments are significantly reduced by OBM shipments. In addition, the empirical results of equilibrium analysis demonstrate the stability of the equilibrium point of OBM and OEM/ODM cumulative shipments in the motherboard industry. The current market will continue to observe motherboard production and orders from companies using OEM/ODM and OBM strategies until the market saturates or until the cumulative shipment volume of OEM/ODM and OBM strategies reaches the equilibrium point. Neither OBM nor OEM/ODM shipment diffusion has achieved market saturation, but both of their markets are predicted to expand until they achieve a stable market potential equilibrium. Because the competitive pressure from the OBM strategy is mild and is offset by the strong self-growing capability of the OEM/ODM strategy, the OBM strategy cannot replace the OEM/ODM strategy in the motherboard industry. Thus, market potential and current market shares are higher for companies using OEM/ODM strategies than for those using OBM strategies. Finally, the proposed Lotka-Volterra model performs superior to Bass model in predicting motherboard shipments in the test period because Lotka-Volterra model considers the interactive relationship between OBM and OEM/ODM strategies, which conforms to manufacturing practices.

The contribution of this research includes the development of a Lotka-Volterra model through which academics and practitioners can better understand the characteristics of business models beyond what were possible through previous studies. Our proposed predictive model represents a major step forward in the fields of management, highlighted by the following four aspects: unique data, model specification, parameter optimization, and applicability in industrial analysis. For unique data, our Lotka-Volterra model uses OBM and OEM/ODM shipment strategies as quantitative indicators for measuring the iterations between various business strategies. Most literature regarding strategic management lacks quantification data; thus, our unique data were used to quantify the collaborations between OBM and OEM/ODM strategies as the basis of strategic management. Regarding model specifications, this study is the first to construct a model incorporating the competitive and cooperative relationships among various strategies. The results from this study suggest that OBM and OEM/ODM strategies coexist in the motherboard industry in a relationship of competition and cooperation. In contrast to the conventional diffusion model used in previous research (Bass, 1969), we eliminated the restrictive assumption that OEM/ODM and

OBM strategies are unrelated. The specifications of our proposed model are more in line with the practical reality than those of the conventional Bass model.

For parameter optimization, we combined a GA and the simultaneous nonlinear least squares to optimize parameters to avoid the shortcomings of previous studies, using conventional nonlinear least squares methods in which poor initial values converged to a local instead of a global solution. Our empirical results demonstrate that the standard deviation of the estimated parameters is small, confirming that the optimized parameters remain similar, despite the 3,000 sets of initial values that were used in our GA simulations. This finding suggests that the proposed approach generates stable and reliable parameters with little deviation. Regarding the applicability in technological forecasting, the results of the equilibrium analysis show that OEM/ODM orders are the major supply channel of motherboards and contain a greater market potential than OBM orders. The stable long-term coexistence of OEM/ODM and OBM strategies has not been quantitatively demonstrated in previous studies. Our proposed equilibrium analysis is applicable to predict the competition of various strategies and business models in other high-tech industries, such as TFT-LCD, computers, communications, information technology, and the consumer electronics industries.

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References

[1] Bass, F.M. (1969). “A new product growth model for consumer durables”, *Management Science*, 15(5): 215-227.

[2] Chien, C.F., Chen, Y.J., and Peng, J.T. (2010). “Manufacturing intelligence for semiconductor demand forecast based on technology diffusion and product life cycle”, *International Journal of Production Economics*, 128(2): 496-509.

[3] Chu, W.-W. (2009). “Can Taiwan's second movers upgrade via branding?” *Research Policy*, 38(6): 1054-1065.

[4] Eng, T.-Y., and Spickett-Jones, J.G. (2009). “An investigation of marketing capabilities and upgrading performance of manufacturers in mainland China and Hong Kong”, *Journal of World Business*, 44(4): 463-475.

[5] Feenstra, R.C., and Hamilton, G.G. (2006). *Emergent Economies, Divergent Paths: Economic Organization and International Trade in South Korea and Taiwan*, Cambridge, England: Cambridge University Press.

[6] Hritonenko, N.V., and Yatsenko, Y.P. (1999). *Mathematical Modelling in Economics, Ecology and the Environment*, Springer.

[7] Kang, M.-P., Mahoney, J.T., and Tan, D. (2009). “Why firms make unilateral investments specific to other firms: the case of OEM suppliers”, *Strategic Management Journal*, 30(1): 117-135.

[8] Li, H., and Amini, M. (2012). “A hybrid optimization approach to configure a supply chain for new product diffusion: a case study of multiple-sourcing strategy”, *International Journal of Production Research*, 50(11): 3152-3171.

[9] Li, H.-H. J.K., Tan, K.H., and Hida, A. (2011). “Sustaining growth in electronic manufacturing sector: lessons from Japanese mid-size EMS providers”, *International Journal of Production Research*, 49(18): 5415-5430.

[10] Lin, C.-S. (2013). “Forecasting and analyzing the competitive diffusion of mobile cellular broadband and fixed broadband in Taiwan with limited historical data”, *Economic Modelling*, 35(1): 207–213.

[11] Manfredi, P., and Fanti, L. (2004). “Cycles in dynamic economic modelling”, *Economic Modelling*, 21(3): 573–594.

[12] Martin, C.A., and Witt, S.F. (1989). “Accuracy of econometric forecasts of tourism”, *Annals of Tourism Research*, 16(3): 407-428.

[13] Sahal, D. (1979). “The temporal and spatial aspects of diffusion of technology”, *IEEE Transactions on Systems, MAN, and Cybernetics*, SMC, 9(12): 829-839.

[14] Sanchez, R. Heene, A., and Thomas, H. (1996). Introduction: Towards the theory and practice of competence-based competition, Dynamics of Competence-based Competition: Theory and Practice in the New strategic Management, Oxford, London: Elsevier Science Ltd, 67-89.

[15] Starkov, K.K., Pogromsky, A.Y., and Rooda, J.E. (2012). “Performance analysis for tandem manufacturing lines under variable structure production control method”, *International Journal of Production Research*, 50(8): 2363-2375.

[16] Teng, H., and Huang, Y. (2013). “The use for the competition theory of the industrial investment decisions — a case study of the Taiwan IC assembly industry”, *International Journal of Production Research*, 141(1): 335-338.

[17] Tsai, B.-H. (2013). “Modeling diffusion of multi-generational LCD TVs while considering generation-specific price effects and consumer behaviors”, *Technovation* ,33(10/11): 345-354.

[18] Tsai, B.-H., (2013). “Predicting the diffusion of LCD TVs by incorporating price in the extended Gompertz model”, *Technological Forecasting & Social Change*, 80(1): 106-131.

[19] Tsai, B.-H., Hsu, C.-S., and Balachandran, B.K.R. (2013). “Modeling competition between mobile and desktop personal computer LCD panels based on segment reporting sales information”, *Journal of Accounting, Auditing and Finance*, 28 (3): 273-291.

[20] Zhai, E., Shi, Y., and Gregory, M. (2007). “The growth and capability development of electronics manufacturing service (EMS) companies”, *International Journal of Production Research*, 107(1): 1-19.