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Competitive diffusion of personal computer shipments in Taiwan

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ABSTRACT

In this work, we explore the innovative growth of personal computer (PC) shipments from Taiwan. Using a revised Lotka–Volterra model, we estimate marketing diffusion by considering competition between desktop computers (DTs) and notebook computers (NBs). The parameters in the Lotka–Volterra model are calibrated with realistic shipment data by using ordinary least square estimation. The time trajectories of DT and NB shipments are then obtained numerically. We analyze the dynamic process of competitive relationship between the shipments of DTs and NBs. Comparisons between the well-known Bass growth model and the revised Lotka–Volterra model are also drawn. In addition, we also make an equilibrium analysis to see the character of the corresponding equilibrium point. Our research shows that there exhibits a prey–predator relationship between DT and NB products from the viewpoint of ecology. In management implication, we show how the competing interplay among the three factors of natural growth, niche capacity and interaction drives the growth of products of DTs and NBs. We also find that there exists a stable equilibrium state showing the growth–decline–plateau type of product life cycle for both DT and NB products from Taiwan, and giving an interpretation of migrating their manufacturing operations to Mainland China.

1. Introduction

Large portions of personal computer (PC) users are located in the United States. The global environment of PC production has been greatly influenced by the subprime mortgage crisis in the United States. The American enterprises and their consumers have adopted a conservative attitude toward PC consumption, which has caused consumer demand of PCs in 2007 to be relatively weak. Originally, the personal computer industry was highly concentrated and it is now becoming even more highly concentrated. Taking the notebook computer (NB) as an example, the market share of the five major NB manufacturers (HP, Dell, Toshiba, IBM, and Fujitsu/FSC) was nearly 67% in 2007. The computer industry continues to become more concentrated. Because the sources of original design manufacturer (ODM) orders of PCs have become increasingly concentrated within a few global brand firms while the gross profits of ODMs have fallen steadily, ODMs capable of holding orders can maintain their basic revenues. Thus, many ODMs would rather sustain the economic losses necessarily to obtain orders and then increase the size of PC shipments, which in turn would make it more difficult for ODMs to profit from the sale of PCs.

The ODM of PCs is the main business within the information technology (IT) industry in Taiwan; moreover, the PC business has also been the main item of development for the manufactures all the time. As the PC industry matures, the yield rate of products becomes lower and lower. However the ODMs in Taiwan are in a particularly advantageous position, since they have a high level of adaptability as well as the strong design and manufacturing abilities, which mean that the Taiwan ODMs are recognized by the global brand-name manufacturers of PCs and thus enjoy the substantial influence within the global PC industry. Since NB prices have been gradually decreasing, desktop computer (DT) users have greater incentives to switch to NB computers.

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In brief, the PC market is extremely competitive throughout the world. Using the Lotka–Volterra diffusion model, we analyze the competition between DTs and NBs with the data of shipments in Taiwan to understand their growth in the PC market. As such, we consider two products, DTs and NBs, as major species in the global PC market, and we analyze their interactive growth potentials. In previous literature, a well-known basic growth model in marketing [1,2] is often used for the estimation of marketing diffusion; the Bass model is based on the notion that there is a direct relationship between the numbers of potential adopters and previous adopters. The original adopters are referred to as innovators, whereas the later adopters are considered to be imitators. The Bass model has been advanced to take into account the marketing mix [3]. However, the model is parsimonious and does not consider the competition factors in the market. Fisher and Pry [4] later developed a simple substitution model based on the assumption that a new technology can displace an older established technology. Their simple formula generates an *S*-curve that can be transformed into a straight line. Fisher and Pry demonstrated using examples that were simplistic but effective. However, the weakness of the Fisher and Pry model is that, again, competition is not taken into account. Any model of industry structure must exhibit the natural competition among the competitive products. The Norton and Bass [5] then adopted the original Bass model but incorporated the Fisher and Pry model to take into account the substitution effect. Their model can be used to forecast technological market growth or decline. In addition, when using the Norton and Bass model to analyze two or more products in a single market, we can identify whether the older technology is substituted by the newer technology, and use it for subsequent market planning. Nevertheless, a major shortcoming of the Norton and Bass model is that it cannot model the dynamic competition between two technologies [6].

In the previous literatures, papers on competition in the PC industry have been almost in qualitative research. The term *competition* is often used within the innovation and management literature [7–15]. While the meaning of competition is generally understood, it is usually not clearly defined or described; moreover, many researchers have applied the Bass model to explore diffusion within the PC market, but they have not considered how the diffusion of DTs would threaten the diffusion of NBs, and vice versa. Hence, many researchers have tried to find a better method to address this problem. The mathematical Lotka–Volterra model has been used in many papers, and in fact, it may well explore both the diffusion phenomenon and reciprocal competition of these two types of computers. The Lotka–Volterra models have already been used to describe the competition for various products [16–26], but the competition between DTs and NBs has not been fully explored. We believe that the study on diffusion growth of PC shipments would benefit IT industry in Taiwan and the global world.

For the first time, we use a revised Lotka–Volterra model to investigate the competition between DTs and NBs by considering the interaction between these two product species. By fitting the historical data on the shipments of DTs and NBs manufactured in Taiwan, the revised Lotka–Volterra model simulates the dynamic competitive process in the PC market. The errors of simulation results are used to compare the performance of Lotka–Volterra model with the Bass model. A stable equilibrium point of DT and NB shipments is also explored.

This paper is organized as follows. In Section 2, we describe the dynamic model and our data sample of the PC shipments from Taiwan. In Section 3, we show the empirical results including the estimates of coefficients, mean squared error in the revised Lotka–Volterra model as well as in the Bass model, and show the advantages in the revised Lotka–Volterra model. We then present an equilibrium analysis in the revised Lotka–Volterra model. Finally, we draw conclusions.

2. Dynamic models

2.1. The revised Lotka–Volterra model

The simplest way of describing the product life cycle theory for one species (in our case, DTs or NBs) is to use the logistic differential equation [27].

$$\frac{dN}{dt} = aN - bN^2, \tag{1}$$

where the demand function $N(t)$ denotes the population of adopters in a market at time t, and its growth rate is measured by the geometric and inhibitive growth terms with the coefficients a and b respectively. It results in an *S*-curve for $N(t)$accounting for the stages of growth, mature, and saturation in the typical product life cycle theory.

Table 1
Multi-mode competitive relationship according to the signs of c_1 and c_2.

c_1	c_2	Type	Explanation
+	+	Mutualism	It is the case of symbiosis or a win–win situation.
+	0	Commensalism	One is promoted by the existence of the other, who is impervious to what is happening.
+	−	Antagonism (predator–prey)	One serves as direct food to the other.
0	0	Neutralism	There is no interaction.
0	−	Amensalism	One suffers from the existence of the other, who is impervious to what is happening.
−	−	Pure competition	Both species suffer from each other's existence.

Turning to the mutual interaction of two competitive species, the original Lotka–Volterra model describes the competition relationship of prey–predator for two species in ecology. The system of prey–predator differential equations is of the form

$$\begin{cases} \dfrac{dX}{dt} = a_1X + c_1XY \quad (a_1 > 0, c_1 < 0) \\ \dfrac{dY}{dt} = a_2Y + c_2YX \quad (a_2 < 0, c_2 > 0) \end{cases} \tag{2}$$

where $X(t)$and$Y(t)$ denote the populations of preys and predators at time t for two species of animals in origin, and hence denote the adopter functions of preys and predators at time t for two competitive products in a market. The original Lotka–Volterra model does not consider the inhibitive growth term. Hence there is a revised Lotka–Volterra model containing the self-interaction term of two species [17–20]. The above system then becomes

$$\begin{cases} \dfrac{dX}{dt} = a_1X + b_1X^2 + c_1XY \\ \dfrac{dY}{dt} = a_2Y + b_2Y^2 + c_2YX \end{cases} . \tag{3}$$

Hence, the self-interaction X^2 and Y^2 terms in Eq. (3) usually represent a negative feedback effect ($b_i<0$) insofar as it accounts for the interaction of a species with itself. The cross-interaction XY and YX terms show two distinct species interacting with each other. The parameter of natural growth a_i is the strength of geometric growth for species i when it is living alone. The parameter of niche capacity b_i is the coupling strength of interaction with same species, and the parameter of interaction c_i is the coupling strength of interaction with the other species for species i. In our study, $X(t)$ and $Y(t)$ denote the adopter functions of two competitive products (DTs and NBs) in the PC market. The revised Lotka–Volterra model contains a multi-mode form illustrated in Table 1 for the case of two species [20,28–30].

Although there are six types of modes, note that there are two possible interactions depending on which type of personal computer (DTs or NBs) is dominant in commesalism, antagonism, and amensalism modes.

2.2. The Bass model

In this study, we also use the Bass model [1,2] in comparison with the revised Lotka–Volterra model to understand DTs and NBs diffusion. Bass [1] described the growth process of new product diffusion by introducing the concept of innovators (such as through policy, advertising or explanations from salesmen), imitators (such as through word-of-mouth communication) and market potential. The dynamics of population growth according to the Bass model is of the form

$$\frac{dN(t)}{dt} = (p + qN(t))(M - N(t)) \tag{4}$$

where the growth rate of demand function is measured by the product of the term with growth factors and the term representing those who have not yet adopted. At the launch of a new product, early owners called innovators who like the product influence others called imitators to adopt it. Hence the parameter$p$is called the coefficient of innovation which is nothing to do with the cumulative adopter function $N(t)$, and the parameter q is called the coefficient of imitation which is related to $N(t)$. The importance of innovators is greater than that of imitators in the beginning but diminishes with time, while the imitator effect increases with time.

2.3. Model assumption and sample source

We assume that the PC market shipments in Taiwan fulfill the following various conditions. First, the competition with personal computer shipments in Taiwan is situated within a global PC market. Second, we are interested in only two competing species, DTs and NBs. Third, the population growth is constrained by potential PC customers globally. Fourth, there are many manufacturers and variables to take into account when analyzing the competitive PC shipments in Taiwan. We simplify this situation to designate DTs as the first generation species and NBs as the second-generation species and analyze the competing relationship between these two PC species in the case that NBs emerge on the market after the monopoly of DT computers. In this way, we consider two products, DTs and NBs, as major species in the global PC market.

Table 2
DT estimation results of the revised Lotka–Volterra model. $MSE = \sqrt{\sum (R_i - S_i)^2 / n}$, R_i = realistic data and S_i = simulation result.

Parameter	Estimates	MSE (shipments)
a_1	0.304403	500759
b_1	-3.74321×10^{-8}	
c_1	-4.65255×10^{-8}	

Table 3
NB estimation results of the revised Lotka–Volterra model. $MSE = \sqrt{\sum (R_i - S_i)^2 / n}$, R_i = realistic data and S_i = simulation result.

Parameter	Estimates	MSE (shipments)
a_2	-0.38584	869787
b_2	1.1725×10^{-10}	
c_2	1.91491×10^{-7}	

Our datasets were obtained from Taiwan's Department of Statistics in the Ministry of Economic Affairs. Data include DT and NB shipments only from manufacturing firms in Taiwan; namely, data do not include Taiwanese firms investing in Mainland China. Our samples were gathered annually from 1988 to 2007, and NBs were first introduced in 1988. During this period, we estimate the diffusion curve using yearly data and thereby examine the dynamic changes in the competitive process between DT and NB products.

3. Results and discussion

3.1. Estimation of the Lotka–Volterra model

In our work, we use the revised Lotka–Volterra model to simulate the growth of shipments of DTs and NBs manufactured in Taiwan. In the revised Lotka–Volterra model, we have a set of two coupled first-order differential equations in which X and Y indicate the yearly shipments of DTs and NBs, respectively. The growth rate of shipments of DTs and NBs, $\mathrm{d}X/\mathrm{d}t$ and $\mathrm{d}Y/\mathrm{d}t$, can be obtained from the data samples X and Y. From the differential equations, we know that $\mathrm{d}X/\mathrm{d}t$ is a linear combination of functions X, X^2 and XY; likewise, $\mathrm{d}Y/\mathrm{d}t$ is also a linear combination of these functions with the exchange of X and Y. The coefficients in the revised Lotka–Volterra model can thus be estimated by using multiple linear regression analysis. Next, we solve the set of differential equations with the estimated parameters numerically through the Runge–Kutta algorithm [31]. Our analysis is conducted using the Mathematica software. The results regarding the competitive relationship between DTs and NBs are shown in Tables 2 and 3.

Based on these estimates of coefficients, the interaction coefficients of DTs and NBs shows negative c_1 and positive c_2. The simulation result from the revised Lotka–Volterra model reveal that the interaction between DTs and NBs exhibits a prey–predator competition relationship according to the classification of Table 1. Prey–predator competition [7–15,32–34] indicates that product DT exerts a positive influence on the growth of NB market share and product NB exerts a negative influence on the growth of DT market share. The shipments of DTs and NBs based on the estimated demand functions X and Y are illustrated in Fig. 1. We see that the estimated demand functions show roughly the same trend as the actual data, which implies that the revised Lotka–Volterra model is adequate in explaining the diffusion of the shipments of DTs and NBs manufactured in Taiwan.

3.2. Comparison between the Bass and Lotka–Volterra models

To further evaluate the performance of the revised Lotka–Volterra model. The Bass model expressed in Eq. (4) is used to compare with the revised Lotka–Volterra model. Note that X and Y denote the cumulative shipments of DTs and NBs respectively in Bass model, and the yearly shipments $\mathrm{d}X/\mathrm{d}t$ can be written as a linear combination of functions 1, X and X^2 in Bass model. Hence, the same technique used in the revised Lotka–Volterra model can be used to generate the estimates of coefficients and solve the Bass diffusion equations numerically. As in the revised Lotka–Volterra model, we simulate the shipments of DTs and NBs

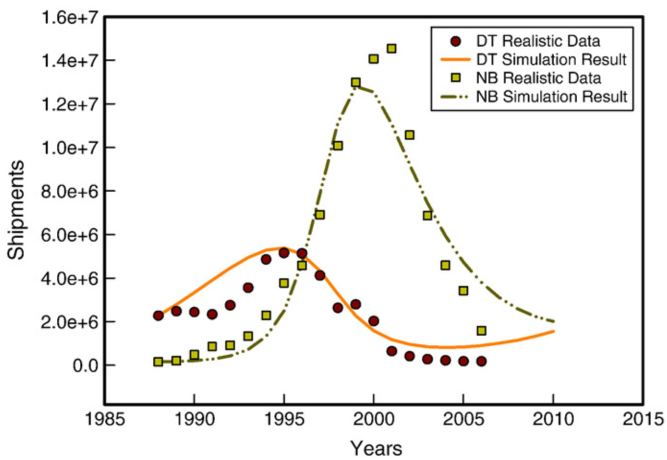

Fig. 1. Simulated and realistic shipments versus time with revised Lotka–Volterra model in years 1988–2007 for DT and NB manufactured in Taiwan.

Table 4
DT estimation results of Bass model, $MSE = \sqrt{\sum (R_i - S_i)^2 / n}$, R_i = realistic data and S_i = simulation result.

Parameter	Estimates	MSE (shipments)
p	4.67421×10^{-16}	756337
q	6.33741×10^{-9}	
M	5.27628×10^{7}	

manufactured in Taiwan from 1988 to 2007, and then we forecast the yearly shipments from 2008 to 2010 in the Bass model. The estimated parameters and related errors for both models are shown through Tables 2–5. Their simulation results are illustrated in Figs. 1 and 2.

According to the results, as shown in Figs. 1 and 2, we see that both models fit the data well. In order to compare these two models, the forecasting errors of each model are measured by MSEs (Mean Squared Error) and presented in Tables 2–5; meanwhile, we combine the simulation results of both models with the actual data, as shown in Figs. 3 and 4. We see that the revised Lotka–Volterra model has a better fit in DT shipments, while Bass model has a better fit in NB shipments. Although the errors of both models look the same on average, we cannot see the strength of interaction in Bass model. Hence it is better to use the revised Lotka–Volterra model to describe the dynamic competitive relationship of two or more species in a single market. From this point of view, the performance of the revised Lotka–Volterra model is superior to that of the parsimonious Bass diffusion model. Thus, we recommend the use of a competitive diffusion model like the revised Lotka–Volterra model to analyze any product or firm in a competitive market to reflect the interaction of competitors.

3.3. Competitive relationship analysis of the market of DTs and NBs

There are six types of competitions classified according to the signs of parameters c_1 and c_2 in the revised Lotka–Volterra Eq. (3), as shown in Table 1 [20]. Referring to Tables 2 and 3, we see negative $c_1$and positive c_2 indicating the prey–predator competition relationship between DTs and NBs. DTs act as preys and NBs act as predators. From the simulation results, we find that DTs and NBs first show the interdependent and restricted relation between eaten baits and predator. In the beginning, DTs (the prey population) grow exponentially under the assumption that the prey population finds ample food at all times, and decrease till enough predators appear, while NBs (the predator population) decay exponentially, and increase till enough preys. As time goes on, we see that an endlessly repeated cycle of interrelated increases and decreases in the populations of these two species. The negative c_1 reflects the decay rate of DTs coming from the ability of NBs hunting DTs, and the positive$c_2$reflects the growth rate of NBs coming from the amount of DTs contributing resources to NBs. It is just the case of prey–predator described by the simple Volterra equations as Eq. (2) used in ecology [35]. However, we do not assume unlimited food supply for preys so that an inhibitive growth term must be implemented in prey equation. For more general cases, we need add the niche capacity terms with the parameters b_1 and b_2 for both preys and predators respectively. Our simulation shows negative b_1 giving an inhibitive growth for DT products and positive but small b_2 giving a little expanding growth for NB products. It can be shown in next section that the trajectories of DT and NB shipments will oscillate and damp down to their stable equilibrium shipments. Therefore, DTs and NBs can coexist in the PC market.

3.4. Equilibrium analysis

We now try to find the nontrivial equilibrium state (X_{eq}, Y_{eq}) and analyze the stability of DT and NB competition system in the revised Lotka–Volterra model by setting zero growth rates of DT and NB shipments; that is,

$$\frac{dX}{dt} = 0 \text{ and } \frac{dY}{dt} = 0. \tag{5}$$

At equilibrium, the differential equations in the revised Lotka–Volterra model are equivalent to the following two algebraic equations:

$$a_1 X + b_1 X^2 + c_1 XY = 0, \tag{6}$$

Table 5
NB estimation results of Bass model, $MSE = \sqrt{\sum (R_i - S_i)^2 / n}$, R_i = realistic data and S_i = simulation result.

Parameter	Estimates	MSE (shipments)
p	2.70927×10^{-16}	515495
q	5.68725×10^{-9}	
M	1.00375×10^{8}	

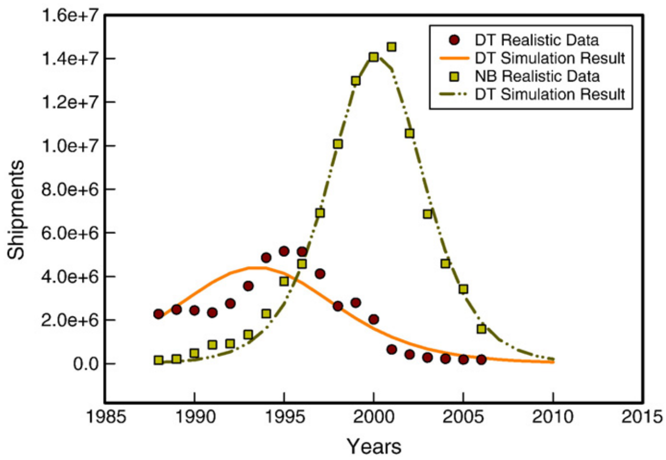

Fig. 2. Simulated and realistic shipments versus time with Bass model in years 1988–2007 for DT and NB manufactured in Taiwan.

and

$$a_2Y + b_2Y^2 + c_2YX = 0. \tag{7}$$

Removing the trivial solutions, we can rewrite the above equations as

$$X = \frac{a_1 - c_1Y}{b_1{}^1} \text{ and } Y = \frac{a_2 - c_2X}{b_2}. \tag{8}$$

In Eq. (8), if $X<(a_1-c_1Y)/b_1$, then the population of species X would increase so that $dX/dt>0$, and if $X>(a_1-c_1Y)/b_1$, then the population of species X would decrease so that $dX/dt<0$. Similarly, if $Y<(a_2-c_2X)/b_2$, then $dY/dt>0$, and if $Y>(a_2-c_2X)/b_2$, then $dY/dt<0$. In the long run, the shipments of DTs and NBs reach equilibrium state at $X=(a_1-c_1Y)/b_1$ and$Y=(a_2-c_2X)/b_2$; that is, the conditions $dX/dt=0$ and $dY/dt=0$ both hold in a state of equilibrium. In Fig. 5, we show the trajectories of actual and simulated shipments in the phase plane. The shorter path represents the trajectory of actual shipments from 1988 to 2007. The dark and light parts of the longer path represent the trajectory of simulated shipments from 1988 to 2007 and predicted shipments from 2008 to 2030 respectively.

In Fig. 5, the vertical and horizontal lines represent the equations $X=(a_1-c_1Y)/b_1$ and $Y=(a_2-c_2X)/b_2$ respectively. From our simulation, Region I represents the conditions under which DT shipments decrease and NB shipments increase in time ($dX/dt<0$, $dY/dt>0$) to approach the equilibrium point. Region II represents the conditions under which both DT and NB shipments decrease in time ($dX/dt<0$, $dY/dt<0$). Region III represents the conditions under which DT shipments increase and NB shipments decrease in time ($dX/dt>0$, $dY/dt<0$). Region IV represents the conditions under which both DT and NB shipments increase in time ($dX/dt>0$, $dY/dt>0$). Obviously, the equilibrium phase (2011905, 4924043) located at the intersection of the two lines is stable in

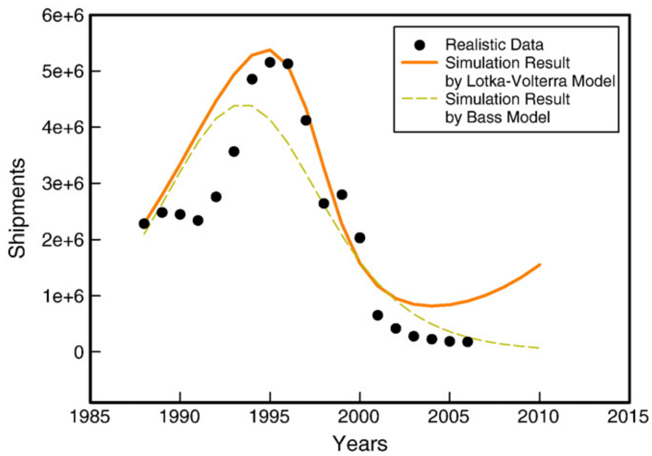

Fig. 3. Comparison of realistic data and simulation result with revised Lotka–Volterra model and Bass model in DT case.

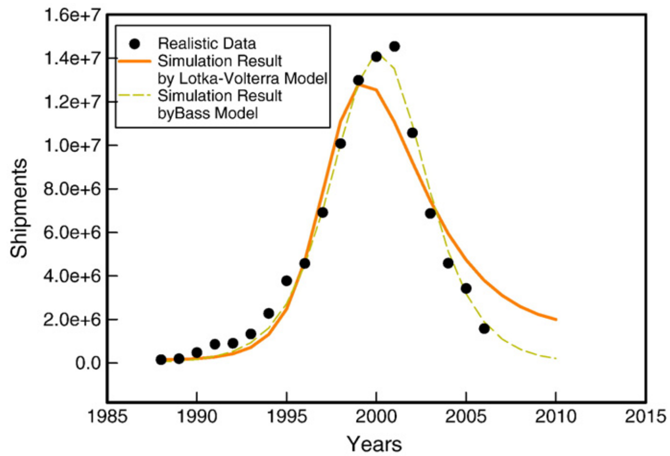

Fig. 4. Comparison of realistic data and simulation result with revised Lotka–Volterra model and Bass model in NB case.

Fig. 5. The existence of stable equilibrium means that the zero growth of DT and NB shipments would happen in the long run; in other words, it is in a maturity stage. The trajectory of simulated shipments in phase plane is a inward spiral which means both the scales of DT and NB production attenuate after each competitive cycle, and hence it will approach to this stable equilibrium in the long run. In Fig. 6, we show the whole dynamic process of marketing diffusion mainly to see the equilibrium state in the revised Lotka–Volterra model. Of course, we can effectively forecast the technological developments of DT and NB only for several years. The circles and the dots are the actual shipments of DTs and NBs respectively. The solid and the dashed lines represent the simulated shipments of DTs and NBs respectively. Both lines show the damped oscillation about their values at equilibrium. The oscillation is a typical prey–predator phenomenon with the damping factor coming from their self-interactions. Due to the fact that both actual shipments of DTs and NBs almost go through a complete cycle, the DT and NB products manufactured in Taiwan have entered the maturity stage. For both products, their life cycles are predicted and their types show an "growth–decline–plateau" form.

Through the constantly wrestling of DTs and NBs, both products will gradually tend to be decreasingly manufactured and at last sustain to a stable state in Taiwan, it does not mean that the DT and NB sales from Taiwan will lose the competitiveness in the world market. The reason is that most Taiwan's manufacturers have been migrating their manufacturing to Mainland China due to the consideration of manufacturing cost, and our datasets do not include the shipments of DTs and NBs manufactured in Mainland China by Taiwan firms.

It is thought that NBs compete with DTs for many years. DTs and NBs have their own unique characteristics. Some customers who bought PCs for business use still purchase DTs, while other customers who bought PCs for personal use now mainly use NBs. When customers decide to buy PCs, they choose a DT or NB computer according to their needs, such as CPU performance, portability, price, energy efficiency or specific business needs. However, there is still a "price gap" between NBs and DTs. The price of NBs is still much higher than DTs. Furthermore, the PCs used for business purposes are difficult to get rid of the safety consideration of portability on NBs. Hence DTs are still needed by certain users, and NBs will not make DTs obsolete. DTs and NBs have their unique consumer bases and should be able to coexist in the global PC market.

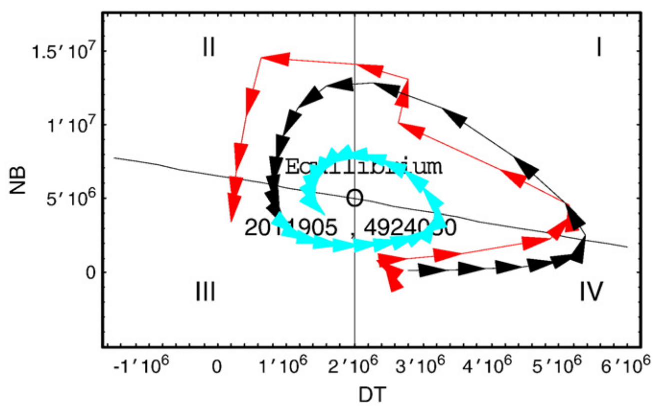

Fig. 5. Phase trajectories of shipments of DTs and NBs manufactured in Taiwan.

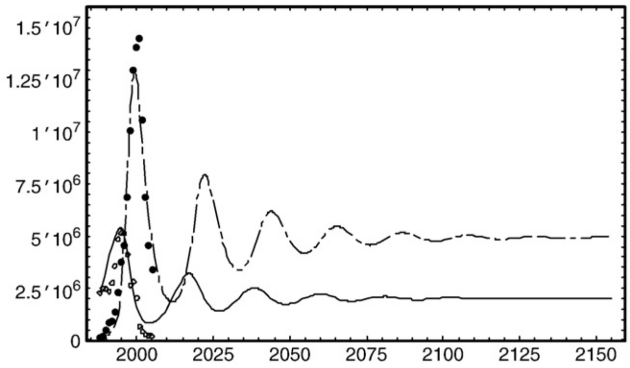

Fig. 6. Time trajectories of shipments of DTs and NBs manufactured in Taiwan

4. Management implications

The revised Lotka–Volterra model gives us the insights into the current competitive relationship between DTs and NBs. The following analysis can help managers develop appropriate qualitative strategies for different competitive environments. Based on our research, we now present managerial implications and suggestions.

In theory, simple prey–predator equations (Eq. (2)) can explain a form useful for ecological interpretation. The signs of the coefficients arise from the assumptions of population regulation. The preys are assumed to have an unlimited food supply, and to produce exponentially unless subject to predation. This exponential growth is represented in the prey equation by the term a_1X. The predation rate upon the prey c_1XY is assumed to be proportional to the rate at which the predators and the preys meet. In the predator equation, c_2YX represents the growth of the predator population positively influenced by the prey, and a_2Y represents the loss rate of the predators due to either natural death or emigration and leads to an exponential decay in the absence of preys. From our simulation result, the parameters $a_i(i=1, 2)$ estimated by the revised Lotka–Volterra model are 0.304403 and -0.38584, and $c_i(i=1, 2)$are -4.65255×10^{-8} and 1.91491×10^{-7} for DTs and NBs respectively. Hence DTs and NBs show the prey–predator relationship; however, the DTs do not act as the "food" for the NBs. Instead the NBs and DTs vie for the same resources in the market; that is, the "food" can be interpreted to be the resources (users or customers) in the market, rather than DT products. In the managerial implications of competition between DTs and NBs, it shows that DTs' growth rate comes from their own users deducting the users robbed by NB manufacturers. In the other hand, NBs growth rate comes from the DTs influencing the NBs' growth in a positive manner and then deducting the losing users owing to the high price at the entering of NB market or migrating their production to Mainland China.

The above interpretation is the result without the consideration of niche capacity. The effect that individuals within the same population start interfering with one another when the population grows can easily be explained with additional terms ($b_i(i=1, 2)$) in Eq. (2). These terms account for the intraspecific competition. The model can further be extended to Eq. (3). The parameter of niche capacity $b_i$is -3.74321×10^{-8}, and 1.1725×10^{-10} for DTs and NBs respectively. Negative b_1 means that diseconomies of scale exist in expanding production of DT manufacturers. Diseconomies of scale consist of the net effect of internal and external diseconomies of scale; that is, the former comes from the arising of the long-term average cost (such as employing more workers or purchasing more production facilities) when the DT manufacturers expand their production scale, and the external diseconomies exist when the production scale of the whole industry becomes very large resulting in the competition among manufacturers. Hence they need pay more cost in vying for production factors such as land and labor, and for the expanding market share. Positive b_2 means that economies of scale exist in expanding production of NB manufacturers. Economies of scale consist of the net effect of internal and external economies of scale; that is, the former comes from the declining of the long-term average cost (such as purchasing the raw materials) when the NB manufacturers expand their production scale, and the latter comes from the external large-scale production brought in cluster effect of enterprises and accumulative knowledge from the expanding of whole industry even facing the global recession.

Through long period of the competition in DT and NB products, they will enter in a equilibrium situation. We presume that there are no changes in any significant external factors. DTs and NBs can coexist in the PC market in the long term. DTs will not disappear in the PC market. The long-term equilibrium point for DT and NB shipments occurs at (2011905, 4924030), which the shipments of NBs are about twice and half as many as those of DTs at equilibrium. Thus, we suggest that Taiwanese PC manufacturers should invest money in NB-related projects twice and half as much as in DT-related projects.

We further suggest that PC manufacturers should engage in more positive promotion and less negative competition; that is, they should work to increase a_i and c_i. Increasing a_i means enlarging the PC consumer base; that is, the number of DT and NB users. Moreover, the PC market can be enhanced by developing new technologies and new functions, such as the Windows 7 and the Quad-core, as well as by developing emerging markets, such as Brazil, China, India and Russia, and high-growth areas, such as Latin America, Canada, the Middle Europe, Eastern Europe, the Middle East and Africa. Increasing $c_i$means that they should avoid low-price competition.

5. Conclusions

The ODMs in Taiwan are in a particularly advantageous position, since they have a high level of adaptability as well as the strong design and manufacturing abilities, which mean that the ODMs in Taiwan are recognized by the global brand manufacturers of PCs and thus enjoy substantial influence within the global PC industry. Among the many debates and discussions on the PC industry, the future development of both DTs and NBs is quite often discussed. There are various ways to answer this question. An analysis of competition in the PC market is useful to explore the competitive phenomena surrounding DTs and NBs. In particular, the revised Lotka–Volterra model may help us examine the effects of competition.

In this paper, we use the revised Lotka–Volterra model to analyze the dynamic competitive relationship between shipments of DTs and NBs manufactured in Taiwan. With the input of yearly datasets gathered from 1988 to 2007, we simulate the time trajectories of DT and NB shipments obeying the revised Lotka–Volterra differential equations. In the revised Lotka–Volterra model, the shipments are controlled by three factors: geometric growth, self- and cross-interaction for each species. The different signs of two interaction coefficients consist of six types of competitive relationship: Mutualism, Commesalism, Antagonism, Neutralism, Amensalism and Pure competition. In our simulation, the estimated coefficients in the interaction terms are negative and positive in DTs and NBs respectively, and hence show the characteristics of prey–predator relationship between DTs and NBs manufactured in Taiwan.Furthermore, we compare the performance of Bass model and revised Lotka–Volterra model. The errors of both models look almost the same on average. In the Bass model, we can distinguish the advertising effect from the word-of-mouth effect; however, we cannot see the strength of cross-interaction in Bass model.

When doing the equilibrium analysis, we show the damped oscillation trajectories of DT and NB shipments reaching in a stable equilibrium state. It means that DT and NB products can coexist in the PC market. Due to the fact that both actual shipments of DTs and NBs almost go through a complete cycle, the DT and NB products manufactured in Taiwan have entered the maturity stage. It gives an interpretation of migrating their manufacturing operations to Mainland China.

In management implications, the coefficients in these three factors of geometric growth, self- and cross-interaction represent the strength of natural growth, niche capacity and interaction respectively. The natural growth comes from product attraction; namely, the needs of consumers on products, such as the portability and wireless internet in NBs and periodicity upgrade in DTs. The niche capacity shows that diseconomies of scale exist in the DT production; however, economies of scale exist in NB production. The interaction determines the type of prey–predator relationship in DTs and NBs. We suggest that DTs and NBs should engage in more positive promotion and less negative competition by increasing a_i and c_i. The means of increasing a_i mainly come from developing new technologies, functions and emerging markets. Increasing c_i means that they should avoid low-price competition.

Although many articles have recently reported the growth of PC market from different points of view, there are few quantitative studies that explore the competitive relationship between DT and NB shipments using the revised Lotka–Volterra model. Thus, the results of this work have contributed to understanding the dynamic, competitive relations between DT and NB shipments manufactured in Taiwan. This work is also meaningful in that it shows how the entry of a new product, the notebook computer, changes the market structure within the limited environment of a single market.

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