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Dynamics of Industrial Cluster Scenarios

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Abstract

This research aims to explore the dynamic co-opetition of industrial cluster evolution based on the Lotka-Volterra model. Particularly, an empirical co-opetition case of industrial innovation parks, Southern and Central Taiwan Science Park (STSP and CTSP), will be used to demonstrate the validity of the dynamic approach. The results reveal that the competitive relationship between STSP and CTSP may be a predator-prey interaction type. The existence of STSP and its investment growth will be of positive assistance in developing the latter CTSP area. Contrarily, the growth of CTSP will probably compete with the resources of STSP and inhibit the sustained growth of STSP. In addition, an equilibrium point does not exist in the competition relationship of these two clusters from 2003 to 2010, in which STSP and CTSP areas should coexist with sustained growth in this current short-term stage.

Keywords: industrial cluster, competitive analysis, equilibrium analysis, Lotka-Volterra model, Taiwan Science Park

Introduction

This research explores the dynamic co-opetition of industrial cluster evolution based on the Lotka-Volterra model. Particularly, an empirical co-opetition case of industrial innovation parks, Southern and Central Taiwan Science Park (STSP and CTSP), will be used to demonstrate the validity of this dynamic approach. There is increasing awareness in the important role and potential of dynamic

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analysis among different industrial clusters or districts for fostering economic development in both traditional and high-tech industries. Yet evidence analyzing the phenomenon of dynamic competition among different clusters in a region remains underdeveloped as well as little examination of growth forecasting in industrial clusters based on the results of competitive analysis in the context of a numerical model.

This research will develop a dynamic model to discuss the competitive relationship between the STSP and CTSP in Taiwan based on the Lotka-Volterra equation (Lotka, 1925, Voltera, 1928). In recent management literature, the equation has regenerated interest since it constitutes a simple model used to help understand phenomena such as technology substitution (Morris and Pratt, 2003; Pistorius and Utterback, 1995, 1997), organizational change (Modis, 1997) or organizational learning (Zangwill and Kantor, 2000). The model is a simple system to study different patterns of relationships between various kinds of populations and it provides a tool to analyze chaotic behaviors that are encountered in many modern management phenomena, such as knowledge management and radical innovation (Castiaux, 2007).

Development of Industrial Clusters

A first group of studies focuses on the effect of knowledge diffusion and spillover. Recently, the majority of research in knowledge diffusion has focused on the impact of an industrial cluster, entrepreneurship, and regional R&D activities along with knowledge transfer or spillover (Chen, 1997, Padoan, 1998, Ernst and Kim, 2002, Li, 2002, Dahl and Pederson, 2004, Autio, Hameria and Vuola, 2004, Fritsch and Franke, 2004, Audretsch, 2005, Carayannis *et al*., 2006, Henderson, 2007). In addition, another term of "localized spillovers" was also proposed to emphasize the role of geographical proximity affecting the capabilities of knowledge spillovers (Saxenian, 1994, Audrestch and Feldman, 1996, Lissoni, 2001, Audrestch, 2003). These studies examine the importance of knowledge flow in the fields of economic geography and cluster effect.

A second group of studies highlights the factor of information sharing in cluster building. They emphasize the role a sharing mechanism in a region can create in an industrial agglomeration by the exchange of information, manpower, market, resource, and supply chain among different enterprises (Swann and Prevezer, 1996, Boschma, 1999, Krafft, 2004). Furthermore, another group of studies focuses on the formulation of how a social network in the dimension of social capital such as trust, relationship, understanding and collaboration, plays a critical role in cluster building (Liyanage, 1995, Koka and Prescott, 2002, Steinle and Schiele, 2002, Sorenson, 2003, Andersson, Holm and Johanson, 2007).

Finally, another group of strategic studies discusses the development of industrial cluster from the view of strategic alliance and suggest that the vertical or horizontal strategic alliance among different firms in an industrial value chain will result in a strategic cluster for creating competitive advantage or market demand (Porter, 1998, Porter and Stern, 2001, Dayasindhu, 2002, McNamara *et al*., 2003).

Evolution of Industrial Clusters

Firms are essentially atomistic, in the sense of having no market power, and they will continuously change their relations with other firms and customers in response to market arbitrage opportunities, thereby leading to intense local competition. The industrial complex pattern is characterized primarily by long-term stable and predictable relations between the firms in the cluster and, involves frequent transactions. The social network pattern argues that mutual trust relations between key decision-making agents in different organizations may be at least as important as decision-making hierarchies within individual organizations. These trust relations will be manifested by a variety of features, such as joint lobbying, joint ventures, informal alliances, and reciprocal arrangements regarding trading relationships (McCann and Sheppard, 2003). We have seen, knowledge and innovation processes, technological regimes, organizational, firm and industry-specific characteristics, and institutional and governance settings all play a role in explaining the diversity of industrial clusters and also their evolutionary trajectories (Guerrieri and Pietrobelli, 2004).

Investing in Industrial Clusters

A number of studies have been conducted to show the investment criteria for choosing the industrial clusters in decision-making, which can be separated into several strands. A main group of studies presents that firms will select investment location depending on the development of an innovation system or a technological system in a region (Braunerhjelm *et al*., 2000, Malerba, 2002, Cooke, 2002, Yeh and Chang, 2003, Fleming and Sorenson, 2003, Chang and Shih, 2004, Bell, 2005, Asheim and Coenen, 2005). It is reasonable to expect that industrial clusters will emerge from the location where innovation opportunity is available and accessible, as in the link between firms clustering and their probability to innovate (Baptista and Swann, 1998). These building blocks in the innovation system-research institution, infrastructure, innovation network, and technology transfer mechanism, will affect the competitiveness of the industrial cluster. Network externality (Dayasindhu, 2002) and market proximity (Krugman, 1995, Cook *et al*., 2001) are sometimes the critical criteria when creating a new start-up in an industrial cluster.

Southern and Central Taiwan Science Parks

So far there are three industrial science parks established in Taiwan for fostering the industrial cluster and development, including Hsinchu Science Park (HSP), Southern Taiwan Science Park (STSP), and Central Taiwan Science Park (CTSP). The earliest and major science park is Hsinchu Science Park, located in Hsinchu city in northern Taiwan, covering 1175 ha of land and is home to Taiwan Semiconductor Manufacturing Company, the world's largest made-to-order IC manufacturer (Mathews, 1997, Mathews and Cho, 2000, Lee and Yang, 2000, Saxenian and Hsu, 2001, Hu *et al*., 2005, Lai and Shyu, 2005, Ku *et al*., 2005). This research will not use HSP as a comparable research target due to its mature development and limited growth of enterprises. The competition effect of HSP for the development of STSP and CTSP is relatively low, so its evolutionary situation will not be adopted in the dynamic analysis of industrial cluster evolution in this Lotka-Volterra modeling.

Model and Data

This research adopts the Lotka-Volterra model (Lotka, 1925, Voltera, 1928), which was developed to model the interaction between two competing species based on the logistic curve, and will be considered an alternative competitive diffusion model for analyzing the investment growth of STSP and CTSP in Taiwan. Recently, applications of the Lotka-Volterra equation to the analysis of technology diffusion in a competitive market can be found in relevant literature (Morris and Pratt, 2003; Watanabe *et al*., 2004; Lee, Lee and Oh, 2005, Kim, Lee and Ahn, 2006). The purpose of this paper is to estimate the growth function of enterprises investing in industrial clusters in Taiwan, with an explicit consideration of investment competition effects, and to empirically clarify the dynamic competitive relationship between the STSP and CTSP. In addition, the characteristics of the dynamic competitive relationship in Taiwan's Science Park are empirically examined, including the existence of an equilibrium point and its stability with the estimated growth function.

Lotka-Volterra Equation

In this study, it is assumed that the competitive situations of industrial clusters or Science Park in Taiwan correspond to the original condition of the Lotka-Volterra model. The competing field under the single environment is the market of the Science Park in Taiwan (STSP and CTSP). The constrained resources for the competition are the potential domestic and foreign firms who want to invest in the Science Park in Taiwan. The two competing species are STSP and CTSP areas. This research will not select HSP as a comparable research target due to its mature development and limited growth of enterprises. The competition effect of HSP for the development of STSP and CTSP is relatively low, so its evolutionary situation will not be adopted in the dynamic analysis in this Lotka-Volterra modeling. In addition, although other small industrial zones are also probably competing with STSP and CTSP, this study only focuses on the competition scope between two major and emergent Science Park- STSP and CTSP.

In the Lotka-Volterra model, the interaction between the STSP and CTSP can be expressed in two differential equations, as follows:

$$\frac{dX}{dt} = g_x X - l_x X^2 - k_{xy} XY \tag{1}$$

$$\frac{dY}{dt} = g_y Y - l_y Y^2 - k_{yx} YX \tag{2}$$

where X and Y represent the amount or population of two competing species at time t. In this case, they account for the number of enterprises investing in STSP and CTSP respectively.

The above system of equations also contains all fundamental parameters that affect the growth rate of both species: g_i is the logistic parameter for the species i when it is living alone, l_i is the limitation parameter of the niche capacity related to the niche size for the species i, and k_{ij} is the interaction parameter with the other species j. In this case, these three parameters respectively represent different influence factors of industrial cluster development in terms of investment, policy, legal, resources, financial, industrial, and social dimensions, listed as Table 1.

Table 1. *Managerial explanation of parameters in Lotka-Volterra model*

	Logistic parameter g_i	Limitation parameter l_i	Interaction parameter k_{ij}
Influence factors (Managerial explanation)	Regional competitiveness Investment environment Natural resource Human resource Social condition Legal condition Industrial factor Infrastructure Technological system	Resource limitation Investment risk Legal risk Social risk Financial risk Incentive expiration Infrastructure	Positive interaction: Economic growth Investment promotion Industrial chain Alliance & collaboration Negative interaction: Resource competition Regional competition Policy bias Incentive comparison

Equilibrium analysis of Lotka-Volterra Model

Before estimating the Lotka-Voterra equation by empirical data from the STSP and CTSP, this section will firstly introduce the equilibrium relationship in Lotka-Volterra equation and show it in a phase diagram.

In equilibrium status, Eqs (1) and (2) must be zero because there are no simultaneous changes over time for each competitor. Thus, the following conditions hold:

$$\frac{dX}{dt} = 0 \tag{3}$$

$$\frac{dY}{dt} = 0 \tag{4}$$

By applying conditions (3) and (4) to Eqs (1) and (2), the system will be solved and result in the following:

$$X = \frac{g_x - k_{xy}Y}{l_x} \tag{5}$$

$$Y = \frac{g_y - k_{yx}X}{l_y} \tag{6}$$

and the coordinates of the equilibrium point are given by:

$$X^* = \frac{g_y l_x - g_x k_{yx}}{l_x l_y - k_{xy} k_{yx}} \tag{7}$$

$$Y^* = \frac{g_x l_y - g_y k_{xy}}{l_y l_x - k_{yx} k_{xy}} \tag{8}$$

It reveals that the stability of the equilibrium state depends on the values of the coefficients of the Lotka-Volterra model, and this equilibrium point will appear in the first quadrant of phase diagram of two industrial clusters in $X^*>0$ and $Y^*>0$. It explains that we can judge the equilibrium point depending on the equilibrium conditions as follows: (1) $g_y l_x > k_{yx} g_x$, $g_x l_y > k_{xy} g_y$ or (2) $g_y l_x < k_{yx} g_x$, $g_x l_y < k_{xy} g_y$.

Figure 1 shows an example to depict an equilibrium point in the phase diagram, which represents a stable status of dynamic interaction relationship at the time. In this case, the equilibrium point will mean a status or time that the number of companies both in STSP and CTSP reach stable and stop to grow or decline.

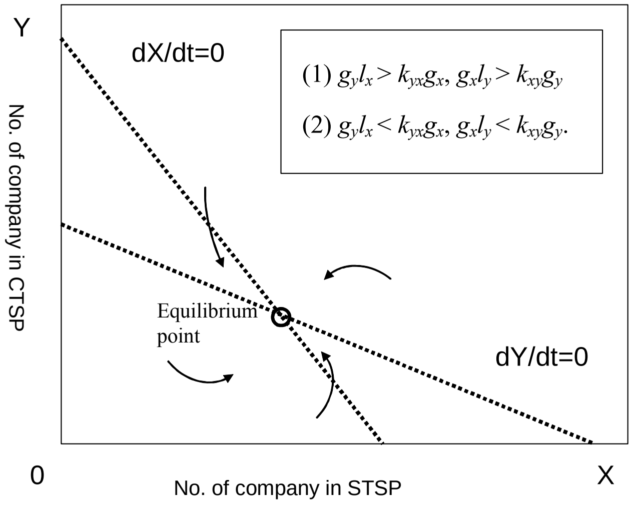

Figure 1. *Equilibrium point in phase diagram*

Data from STSP and CTSP

This study adopts the empirical data from the official website of STSP (http://www.stsipa.gov.tw/web/) and CTSP (http://www.stsipa.gov.tw/web/) to simulate their dynamic relationship in Lotka-Volterra model. Table 2 presents the accumulated number of the approved companies, accumulated number of the effective approved company, and approved investment capital per year of STSP and CTSP from years 2003 to 2007, and this Lotka-Volterra simulation will use the data of accumulated number of the approved companies to represent the trend of investment growth in these two Science Parks and estimate their growth function.

Table 2. *Empirical investment data of STSP and CTSP*

Years	STSP			CTSP		
	Accumulated No. of the approved company	Accumulated No. of the effective approved company	Approved investment capital (billion)	Accumulated No. of the approved company	Accumulated No. of the effective approved company	Approved investment capital (billion)
2003	128	113	155.32	35	35	2.31
2004	158	131	259.43	60	59	243.12
2005	179	114	352.78	82	69	246.63
2006	199	143	451.61	96	74	256.83
2007	220	154	558.87	113	83	293.91

Source: *Website of STSP & CTSP*

Estimation of Lotka-Volterra Equation

To use the Lotka-Volterra model in estimating the growth function of the STSP and CTSP in Taiwan, the parameters of Eqs. (1) and (2) should be estimated. The yearly accumulated number of approved companies in STSP is designated as X, and that in CTSP as Y, in Eqs. (1) and (2).

The hybrid approach of Genetic Algorithm and non-linear least-square method included in the software tool MATLAB 7.1 was used to estimate the coefficients of the model. The estimated coefficients and related statistics are shown in Tables 3. The graph in Figure 2 reveals that the estimated growth function shows almost the same trend as the actual data in both STSP and CTSP, which implies that the Lotka-Volterra model explains the investment growth of these two Science Parks in Taiwan.

Table 3. *Estimation results of Lotka-Volterra model*

STSP		CTSP	
Parameter	Estimate	Parameter	Estimate
g_x	0.138565	g_y	0.256908
l_x	-0.001531	l_y	0.015442
k_{xy}	0.003494	k_{yx}	-0.007020
Total error	11.2826	Total error	11.2826

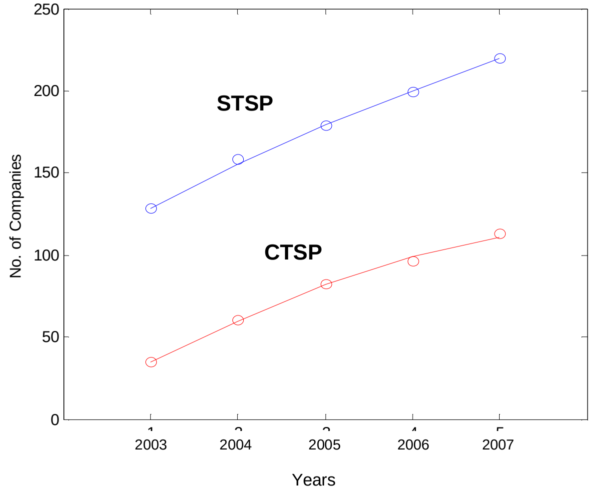

Figure 2. *Actual data and estimated results for the accumulated no. of companies*

The above results show that it is strongly recommended to use the competitive diffusion model like the Lotka-Volterra equation when analyzing the dynamic relationship between two regional industrial clusters in competitive market such as the development of STSP and CTSP in Taiwan.

Discussion

Competitive relationship

The estimated growth function in STSP and CTSP can be expressed as follows using the estimated value of each parameter:

$$\frac{dX}{dt} = 0.138565X + 0.001531X^2 - 0.003494XY \tag{9}$$

$$\frac{dY}{dt} = 0.256908Y - 0.015442Y^2 + 0.007020YX \tag{10}$$

Based on the managerial explanation of the Lotka-Volterra equation, the sign of interaction parameters k_{xy} and k_{yx} can be used to describe a competitive relationship between STSP and CTSP, to determine the type of their competitive roles (Modis, 2003, Kim, Lee and Ahn, 2006) as shown in Table 4.

Table 4. *Type of competitive relationship*

Type	Sign of parameter *k*		Definition
	k_{xy}	k_{yx}	
Pure competition	+	+	Both species suffer from each other's existence.
Predator-prey	+	-	One serves as food for the other
Mutualism	-	-	a win–win situation
Commensalism	-	0	A parasitic type of relationship, in which one species benefits from the existence of the other, which nevertheless remains unaffected.
Amensalism	+	0	One species suffers from the existence of the other, which remains impervious to what is happening.
Neutralism	0	0	No interaction whatsoever

Source: *Modis (2003)*

Compared with the estimated results in Eqs (9) and (10) with the Lotka-Volterra equation (1) and (2), this leads to the conclusion that the competitive relationship between STSP and CTSP may be a predator-prey type as the sign of parameters shown in Table 5. More precisely, the existence of STSP and its investment growth will be a positive assistance for developing the latter CTSP area (k_{yx}>0). Contrarily, the growth of CTSP will probably compete with the resources of STSP and inhibit the sustained growth of STSP (k_{xy}<0).

Table 5. *Sign of parameters in estimation results of Lotka-Volterra model*

STSP		CTSP	
Parameter	Sign	Parameter	Sign
g_x	+	g_y	+
l_x	+	l_y	-
k_{xy}	-	k_{yx}	+

It is reasonable to explain this result with the growth of CHIMEI optoelectronic's cluster in STSP established earlier will stimulate the growth of another AUO optoelectronic cluster in the latter CTSP. Meanwhile, the development of a larger Science Park such as STSP will also promote economic prosperity in optoelectronic and related ICT industries in Taiwan, resulting in the increase of investment in CTSP cluster. On the other hand, CTSP was established 8 years later than STSP, showing the investment in CTSP in recent years, especially in optoelectronics segments, may be the result of the original investment plan in STSP. It explains why the growth of CTSP has a negative interaction or competition effect to STSP, and concludes their dynamic relationship as a predator-prey type. The value of interaction parameters *k* in Eqs (9) and (10) also argue that the positive promotion interaction is much larger than the negative inhibition interaction (0.007020>0.003494).

To elaborate, further information can be obtained from Eqs (9), (10), and Table 5. Firstly, the logistic parameter *g* in CTSP is much larger than that in STSP (0.256908>0.138565). It reveals that the investment environment and competitiveness in CTSP is more attractive than STSP. The cause of this should be the incentive policies in the formulation stage of CTSP that attract many optoelectronic and adjacent mechanical clusters to invest, compared with the older cluster in STSP. In addition, the sign of limitation parameter l_x in STSP is seldom positive. It may represent the efforts of southern local governments to reduce investment risk and expand resource limitation in this region, to maintain dramatically sustained growth in the second decade. Policy tools that encourage the creation of manpower, obtaining natural resources, implementing technology transfer mechanisms, and developing academic institutions and transportation, and improving the quality of life, will be able to retard the decline trend in the logistic growth curve in the case of STSP area.

Equilibrium analysis

The analysis of a competitive relationship by the Lotka-Volterra model can provide information in regards to what the equilibrium state is and how the trajectory changes over time. Additionally, the stability of the equilibrium can be identified.

In Eqs. (5) and (6), if X < $(g_x\text{-}k_{xy}\mathrm{Y})/l_x$, then dX/dt > 0, and the number of companies in STSP would increase. Conversely, if X > $(g_x\text{-}k_{xy}\mathrm{Y})/l_x$, then dX/dt < 0, which implies that the number of companies in STSP would decrease. Similarly, the number of companies in CTSP would increase if Y < $(g_y\text{-}k_{yx}\mathrm{X})/l_y$, and vice versa.

If the two straight lines expressed in Eq. (3) and (4) (dX/dtâo, dY/dtâ0) intersect each other in the first quadrant of the phase diagram, the competing situation between two industrial clusters has an equilibrium point. We can also judge the equilibrium point depending on the equilibrium conditions mentioned as above: (1) $g_y l_x > k_{yx} g_x$, $g_x l_y > k_{xy} g_y$ or (2) $g_y l_x < k_{yx} g_x$, $g_x l_y < k_{xy} g_y$. It reveals that the stability of the equilibrium state depends on the values of the coefficients of the Lotka-Volterra model.

Figure 3 shows the phase diagram of two estimated growth equation in Eqs (9) and (19), This diagram only tries to discuss the scenario from years 2003 to 2010 in the short-term development of cluster competition to avoid too much uncertain and unexpected environmental factors in the long run. The graph shows the two lines dX/dt=0 and dY/dt=0 do not cross each other in the first quadrant, which implies that there does not exist an equilibrium point in this case from 2003 to 2010. Judging from the empirical results, STSP and CTSP could coexist with a sustained growth in this current stage.

To elaborate, the two lines dX/dt=0 and dY/dt=0 separate the first quadrant of phase diagram as three area I, II, III in Figure 3. The initial point located in different areas will represent different managerial meanings in the development of industrial clusters. In area I, it shows the number of companies both in STSP and CTSP will decrease over time, and vice versa in area III. For the points in area II, it accounts for the increase of investment growth in STSP and the decrease of investment growth in CTSP. The trajectory line shown in Figure 3 also reveals the development trend in these two industrial clusters, in which the initial point of year 2003 in area III shows STSP and CTSP both belong to the formulation and growth clusters with dramatic investment growth, and the growth of companies in CTSP will slow down while the trajectory line enters the area II after year 2006, due to the resource limitation or investment risk revealed in limitation parameter l_y. This finding is worth being noticed by the policymakers in CTSP.

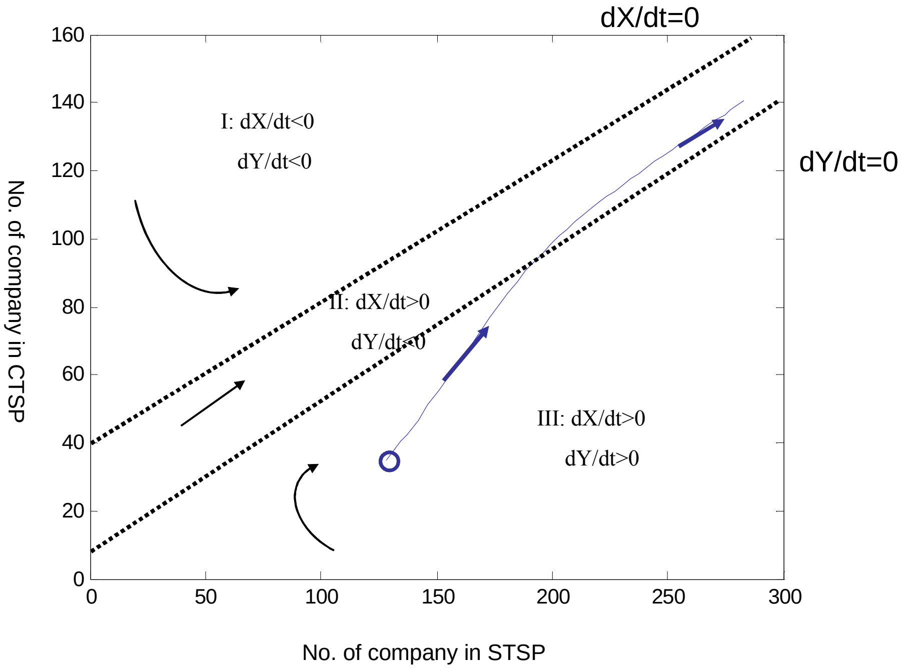

Figure 3. *Phase diagram for the accumulated no. of companies in STSP and CTSP*

In addition, considering only the mathematical explanation instead of managerial meanings, there does exist an equilibrium point of these two estimated growth equations in the first quadrant as Eqs (7) and (8) because the estimated parameters conform with the equilibrium condition: $g_y l_x < k_{yx} g_x$, $g_x l_y < k_{xy} g_y$. This equilibrium status will appear in the far future after year 2050, which means the number of companies both in STSP and CTSP will reach a stable status and stop growing. This study will not discuss this scenario in the far future due to too much unexpected environmental factors.

Forecasting of investment growth

The estimated growth function both in STSP and CTSP can be expressed in a graph to demonstrate short-term investment forecasting. Figure 4 shows the forecasting curve for the accumulated number of companies in both STSP and CTSP based on Eqs (9) and (10). In the graph, the forecasting value in years 2008, 2009, and 2010 (shown as marks in graph), can be taken as the estimated number of company according to the current growth trend. Based on this forecasting result, the policymakers in STSP and CTSP can change resource allocation to avoid overestimation in investment and wasting resources, or further improve the investment environment to avoid insufficient support for possible investment and demand in the near future.

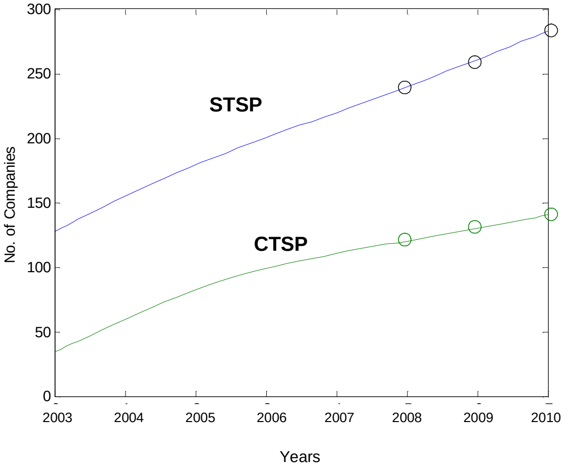

Figure 4. *Forecasting results for the accumulated no. of companies*

Conclusions

It is recommended to use the competitive diffusion model like the Lotka-Volterra equation when analyzing the dynamic relationship between two regional industrial clusters such as the development of STSP and CTSP in Taiwan. The findings also show that the competitive relationship between STSP and CTSP may be a predator-prey interaction type. The existence of STSP and its investment growth will be a positive assistance for developing the latter CTSP area. Contrarily, the growth of CTSP will probably compete with the resource of STSP and inhibit the sustained growth of STSP in the future. In addition, an equilibrium point does not exist in the competition relationship of these two clusters from 2003 to 2010, in which the STSP and CTSP area could coexist with sustained growth in this current short-term stage.

It also concludes that the investment environment, competitiveness, and/or incentive policies in CTSP are more attractive than STSP in recent years, but the efforts of southern local governments in STSP to reduce the investment risk and expand the resource limitation in this region, seem to enable a dramatically sustained growth in the second decade. These policy tools obviously retard the decline trend of logistic growth curve in STSP. This result should be of great academic and practical importance. Not only does it provide a strategic understanding for dynamic relationship of industrial cluster evolution, but it also allows suggestions of resource allocation for policymakers of STSP and CTSP areas in Taiwan.

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