World Academy of Science, Engineering and Technology
International Journal of Economics and Management Engineering
Vol:9, No:9, 2015

Predicting Foreign Direct Investment of IC Design Firms from Taiwan to East and South China Using Lotka-Volterra Model

Bi-Huei Tsai

***Abstract*—**This work explores the inter-region investment behaviors of Integrated Circuit (IC) design industry from Taiwan to China using the amount of foreign direct investment (FDI). According to the mutual dependence among different IC design industrial locations, Lotka-Volterra model is utilized to explore the FDI interactions between South and East China. Effects of inter-regional collaborations on FDI flows into China are considered. The analysis results show that FDIs into South China for IC design industry significantly inspire the subsequent FDIs into East China, while FDIs into East China for Taiwan's IC design industry significantly hinder the subsequent FDIs into South China. Because the supply chain along IC industry includes upstream IC design, midstream manufacturing, as well as downstream packing and testing enterprises, IC design industry has to cooperate with IC manufacturing, packaging and testing industries in the same area to form a strong IC industrial cluster. Taiwan's IC design industry implement the largest FDI amount into East China and the second largest FDI amount into South China among the four regions: North, East, Mid-West and South China. If IC design houses undertake more FDIs in South China, those in East China are urged to incrementally implement more FDIs into East China to maintain the competitive advantages of the IC supply chain in East China. On the other hand, as the FDIs in East China rise, the FDIs in South China will successively decline since capitals have concentrated in East China. In addition, this investigation proves that the prediction of Lotka-Volterra model in FDI trends is accurate because the industrial interactions between the two regions are included. Finally, this work confirms that the FDI flows cannot reach a stable equilibrium point, so the FDI inflows into East and South China will expand in the future.

***Keywords*—**Lotka-Volterra model, Foreign direct investment, Competitive, Equilibrium analysis.

I. Introduction

THIS work utilized a Lotka-Volterra model to explore the relationships involved in the foreign direct investment (FDI) of integrated circuit (IC) design firms from Taiwan to East China and those from Taiwan to South China. In this study, FDI from Taiwan to China is defined as the capital flows from Taiwan to buy lands, build factories and recruit employees in China minus the capital flows coming back to Taiwan from Chinese branches. Most previous studies have employed qualitative methods to map industrial clusters through FDIs [1]-[4]. However, previous studies lack quantifying the relationship between FDIs flowing into East and South China in Taiwan's IC design industry. Thus, this study explores the relations between FDIs of Taiwanese IC design firms investing into different locations. We then compared the difference in firm characteristics, incentives and the size of the FDIs among these IC design firms which choose East and South China to implement FDIs.

Taiwanese firms have dominated the global IC design industry and are concentrated in the Hsinchu Science and Industrial Park [5]. Since 2000, China has provided inexpensive land, cheap labor, preferential tax treatment, and administrative support for Taiwanese IC design enterprises to establish subsidiaries in China. More and more Taiwanese IC design firms engage in FDIs in China, but these firms locates in different areas. Fig. 1 shows that the cumulative FDI amount of Taiwan's IC design industry into China up to the third quarter of 2012, indicating the close relations between Taiwan and China in the IC industry. By the third quarter of 2012, the FDI amount from Taiwan's IC design industry into East China is the greatest among the four regions: North, East, Mid-West and South China. The FDI amount in the South China is the second largest. Taiwanese IC design firms invest into South China and East China earlier than other Chinese areas, so this study examines the relations between FDIs of Taiwanese IC design firms choosing to invest into East China and South China.

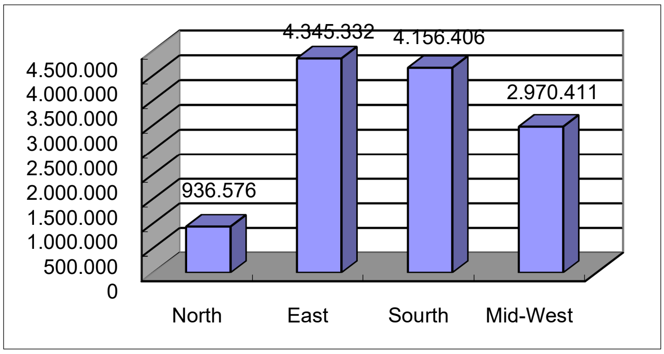

Fig. 1 The cumulative FDI of Taiwan's IC design industry into various regions in China up to the third quarter of 2012 (unit: thousand NT dollars)

With regard to parameter optimization, previous studies have employed ordinary least squares regression to estimate parameters [6], [7]; however, ordinary least squares regression causes the problem of estimation bias in a relatively small

Bi-Huei Tsai is with the Department of Management Science, College of Management, National Chiao Tung University, Taiwan (phone: 886-3-5712121 ext. 57111; e-mail: bhtsai@faculty.nctu.edu.tw).

The authors would like to thank National Science Council of the Republic of China, Taiwan, for partially supporting this research under Contract No. MOST 104-2410-H-009 -005 -MY2. The authors also gratefully appreciate the helpful comments and suggestions of the reviewers.

sample. Because the sample of this study is relatively small since our sample only has 51 observations in East and South, China, respectively, conventional ordinary least squares regression is not suitable for our research. By contrast, [8] and [9] indicated that genetic algorithm (GA) based optimization method has successfully found out global solution for the small sample. GA integrated with nonlinear least square (NLS) based numerical simulation is capable of producing good estimates of unknown model parameters with a relatively small dataset. Thus, this work further adopted the GA with the NLS to solve our proposed Lotka-Volterra differential equation. This is the first study to compare the FDI evolution difference among IC design companies which choose different Chinese regions to engage in FDIs. No previous studies have quantified the relations between FDIs choose to flow into East and South China from the Taiwanese IC design companies. This article explores the interactions between different FDI locations in which Taiwanese IC design companies choose to implement FDIs.

II. Data and Sample

The sample includes 42 and 48 IC design firms investing into East and South China, respectively. The investigated time period is from the fourth quarter of 2000 to the second quarter of 2013 and the sample data is measured in New Taiwan (NT) dollars (thousands). The collected FDI amount is defined as the net FDI amount to China, namely, the FDI amount remitting to China minus the amount returning to Taiwan. The data of permitted amount of FDI of IC design houses from Taiwan to East and South China are collected from Taiwan Economic Journal (TEJ) database. Taiwan Economic Journal (TEJ) database collected the FDI data from each firm's FDI application forms which are submitted to Ministry of Economics Affairs, Taiwan. Because FDI flows indicate the constructions of factories and plants abroad, the FDI value of Taiwan's IC houses into East and South China is an objectively quantified indicator of industrial cluster formation of Taiwan's IC design firms in China.

III. Methodology

A. Lotka-Volterra Model

The Lotka-Volterra model uses the logistic equation as basis, plus a term of the interaction with the other region. The interaction between two regions can be expressed in two differential equations as [10]-[12]:

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

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

where X and Y represent the FDI amount of Taiwan's IC design firms investing in to East and South China at time t. The above system of equations contains all fundamental parameters that affect the growth rate of both species. In (1) and (2), X^2 and Y^2 terms represent the IC firms investing in the same region interacting internally with itself, while the terms XY and YX show different region interacting with the other. a_i is the self-growth parameter for the region i , b_i is the limitation parameter of the FDI for region i, and c_i generally is the interaction parameter with the other region. The multi-mode form can be illustrated by the coefficient c_i between East and South China. The types of competitive roles can be determined according to the signs of c_i [13]. When both c_1 and c_2 are positive, the relationship is classified as pure competition, a situation in which both variables hurt each other. When c_1 is positive and c_2 is negative, the relationship is classified as predator-prey, a situation in which one of them benefits the other. When both c_1 and c_2 are negative, the relationship is classified as mutualism, a symbiosis case or a win-win situation. When one suffers from the existence of the other, who is impervious to what is happening; the relationship is classified as commensalism. When one benefits from the existence of the other, who nevertheless remains unaffected, the relationship is classified as amensalism. When there is no interaction, the relationship is classified as neutralism.

Previous studies on the Lotka-Volterra model, such as those by [14], typically use the Leslie [15] discrete difference equation to indirectly estimate parameters in Lotka-Volterra models. The methodologies adopted in previous studies are unable to examine the statistical significance of the parameters, and thus, cannot demonstrate the statistical significance of competitive and cooperative relationships. To overcome this inability to perform statistical examination, our hybrid evolutionary and numerical optimization can be summarized in two steps: First, this work iterates 3,000 GA simulations to randomly select 3,000 different initial values. Second, this study employs the initial values from the first step to optimize parameters. Simultaneous NLS is iterated until the optimized parameter could result in a predicted value that generates errors smaller than the tolerable margin. Because this study uses 3,000 GA iterations to obtain 3,000 sets of initial values, so these 3,000 sets of initial values are used to solve the Lotka-Volterra model by means of the simultaneous NLS method of [16], [17]. Because our GA integrated with simultaneous NLS approach obtained 3,000 sets of estimated parameters, we can use of t statistics to examine the statistical significance of the competitive evolutionary process across various FDI regions, and to identify estimated parameters within acceptable intervals.

B. Assumptions

We assume that the Lotka-Volterra model stands for the two FDI values of Taiwan's IC design houses investing into East and South China. The FDI value is defined as the total FDI amount remitting to China minus the total amount returning to Taiwan. Since prior literature has never ascertained whether mutual dependence exists between Taiwan's IC design clusters in the East and South China, this study seeks to verify the reciprocal influence between Taiwan's IC design firms which engage FDIs in these two industrial locations.

C. Prediction Accuracy

To further demonstrate the performance of Lotka-Volterra model, the prediction ability of this model is measured by error rates. The lower the error rates are, the more accurate the predictions of Lotka-Volterra model are. This study utilizes mean absolute prediction error (MAPE), mean absolute deviation (MAD), and root mean square error (RMSE) as the criteria of error rates. The MAPE, MAD and RMSE are expressed as:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{\left|W_t - \hat{W}_t\right|}{W_t}, \tag{3}$$

$$MAD = \frac{1}{n}\sum_{t=1}^{n}\left|W_t - \hat{W}_t\right|, \tag{4}$$

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

where W_t is the actual shipment, $\hat{W}_t$ is the predicted shipment calculated by our proposed model at time *t* and *n* is the number of observations. The calculated errors could manifest which model is more efficient.

D. Equilibrium Analysis

The analysis of competitive relationship by Lotka-Volterra model can provide information as regards what the equilibrium state is and how the trajectory changes over time. Additionally, the stability of equilibrium can be clearly identified. In equilibrium, (1) and (2) must be zero because there are no simultaneous changes over time for each region:

$$\frac{dX}{dt} = 0 \text{ and } \frac{dY}{dt} = 0 . \tag{6}$$

By applying condition (6) to (1) and (2), the following system of equations is obtained:

$$\frac{dX}{dt} = a_1 X - b_1 X^2 - c_1 XY = 0, \tag{7}$$

$$\frac{dY}{dt} = a_2 Y - b_2 Y^2 - c_2 YX = 0, \tag{8}$$

Solving the system of (6) will result in

$$X = \frac{a_1 - c_1 Y}{b_1}, \text{ and } Y = \frac{a_2 - c_2 X}{b_2}. \tag{9}$$

The two lines $dX / dt = 0$ and $dY / dt = 0$ are crossing each other, which implies that there exists an equilibrium point. If $X < \frac{a_1 - c_1 Y}{b_1}$, then $dX/dt > 0$. Conversely, if $X > \frac{a_1 - c_1 Y}{b_1}$, then $dX / dt < 0$. Similarly, $dY / dt > 0$ if $Y < \frac{a_2 - c_2 X}{b_2}$, and $dY / dt < 0$ if $Y > \frac{a_2 - c_2 X}{b_2}$.

The stability of equilibrium point depends on the values of the coefficients in the Lotka-Volterra model [18]. The eigenvalue calculations at the equilibrium point comprise three steps: First, we use the estimated parameters listed in Table I to compute the equilibrium point. Second, two linear functions for equilibrium are analyzed by inputting the parameter values. We use the parameters and the equilibrium point values to compute the Jacobian Matrix for the equilibrium point. Third, the eigenvalues of the Jacobian Matrix and the value of Lyapunov function for the equilibrium point are calculated.

After the stability of equilibrium points are proved, we compare the realistic FDI amount with the equilibrium point value to highlight the Taiwan's IC design industry in the future. If the two straight lines expressed in (6) intersect each other in the first quadrant, the pair of the quarterly FDI flows into China is expected to maintain a constant level. If the two straight lines expressed in (6) intersect each other in the second or fourth quadrant, this equilibrium point informs us that only one region finally become the industrial centers of Taiwan's IC design firms. In the future, Taiwan's IC design firms is expected to withdraw their FDIs from other areas in China

IV. Results and Discussion

A. The Results of Coefficient Estimation

The quarterly FDI amount to China of the IC design industries from the fourth quarter of 2000 to the third quarter of 2012 are used to estimate the coefficients. The coefficients and related statistics are shown in Table I. For the East China, the interaction parameters are significantly negative. These results indicate that the expansion of Taiwanese IC clusters in the South China significantly inspires the subsequent expansion of Taiwanese IC clusters in the East China. The results imply that Taiwan's IC design firms choosing East China to implement FDIs would actively respond to the FDI decisions of IC design houses which undertake their FDIs in South China. IC manufacturing, packaging and testing industries depend on IC design industry for advanced business benefits. The FDI amount from Taiwan's IC design industry into East China is the greatest among the four regions: North, East, Mid-West and South China. The FDI amount from Taiwan's IC design industry into South China is the second largest. If Taiwan's IC design houses bring more capitals in South China, those in East China are encouraged to take more FDIs into East China to support its leading position concerning the IC supply chain in East China. On the other hand, the results of Table I shows that the quarterly FDIs into East China for Taiwan's IC design industry significantly decreases the subsequent growth of FDIs into South China. As the FDIs in East China rise, the FDIs in South China will successively decline since capitals have concentrated in East China.

TABLE I
THE RESULTS OF PARAMETER ESTIMATION

East China	a_1	b_1	c_1
Mean	0.111263	3.6887×10^{-8}	-1.8586×10^{-8}
Standard Deviation	1.9758×10^{-10}	1.3840×10^{-15}	1.0055×10^{-15}
t-value	$3.0843\times10^{10***}$	$1.4598\times10^{10***}$	$-1.0124\times10^{10***}$
South China	a_2	b_2	c_2
Mean	0.099709	-3.0661×10^{-8}	3.9359×10^{-8}
Standard Deviation	5.8889×10^{-10}	2.6445×10^{-15}	3.8062×10^{-15}
t-value	$9.2739\times10^{9***}$	$-6.3504\times10^{9***}$	$5.6639\times10^{9***}$

B. The Results of Forecast Accuracy

The prediction ability is compared between the Taiwan's IC design firms choosing to invest in East and South China using the Lotka-Volterra model. To do so, the parameters of both models are estimated with the quarterly FDI amount to China up to the first quarter of 2012, and then the forecasts of quarterly FDI amount from the second quarter of 2012 to the second quarter of 2013 are compared with the actual realistic quarterly FDI amount. Comparison between the predicted FDI values which are computed by the Lotka-Volterra model and realistic FDIs is shown in Figs. 2 and 3. The actual quarterly FDIs and computed quarterly FDIs predicted by Lotka–Volterra model are plotted in Figs. 2 and 3. It can be obviously observed from these figures that simulated FDIs by Lotka–Volterra model are close to the actual FDIs.

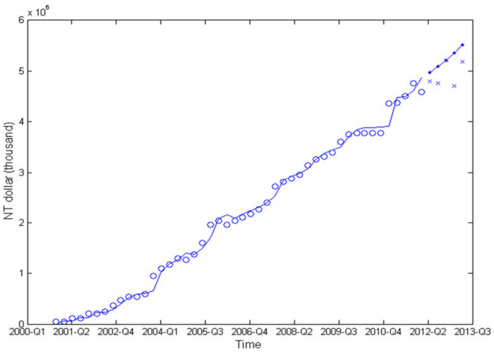

Fig. 2 Comparison among the realistic FDIs and Lotka-Volterra predicted FDIs of IC design firms investing from Taiwan to East China

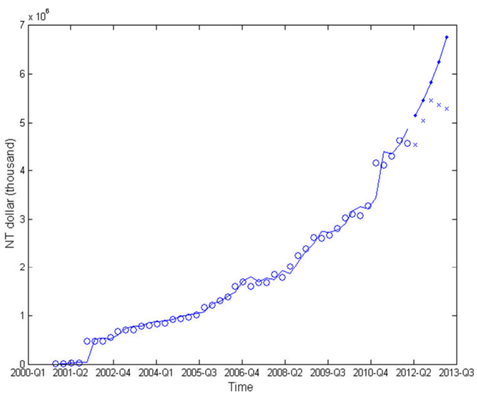

Fig. 3 Comparison among the realistic FDIs and Lotka-Volterra predicted FDIs of IC design firms investing from Taiwan to South China

Table II summarizes the results of the forecast accuracy in the sample from the second quarter of 2012 to the second quarter of 2013. Analytical results indicate that MAPE of the proposed Lotka-Volterra model are 0.061607% and 0.145534% for Taiwan's IC design firms engaging FDIs into East and South China, respectively. MAPEs of FDIs into East China are lower than 10%. Notably, the proposed model correlates well with the actual FDIs. According to Martin and Witt [19], the predictive ability is excellent if the MAPE is lower than 10%. Analytical results demonstrate the reliability of the proposed Lotka-Volterra model in predicting FDIs of Taiwan's IC design firms flowing into East China.

TABLE II
THE RESULTS OF PREDICTION ACCURACY

	MAPE	*MAD*	*RMSE*
East	0.061607	297,808.97	365,507.94
South	0.145534	749,674.74	850,773.68

C. The Results of Equilibrium Analysis Results

The eigenvalues of the Jacobian Matrix for the equilibrium point are then computed to be -0.1138 and 0.0243. Analytical results of the eigenvalues indicate that the orbits computed using our estimated Lotka–Volterra equations fail to satisfy the Hritonenko and Yatsenko [18] stability conditions, indicating the instability of the equilibrium point for FDI amounts of Taiwan's IC design firms from Taiwan flowing into East and South China. Next, this work calculates the negative Lyapunov function value -4.9885×10^{14}, demonstrating that the trajectory fails to satisfy the stable conditions of its equilibrium point. The equilibrium analysis has revealed that the instability of the equilibrium points between FDI amounts of Taiwan's IC design firms choosing to invest in South and East China. These FDI flows cannot reach a stable status for Taiwan's IC design industry clustering into East and South China. The FDI size will expand in East and South China in the long run.

After the instability of equilibrium points are proved, we realize that the pair of the industrial FDI flows from Taiwan into East and South China is impossible to maintain a constant level for IC design industry. East China is located around the Yangtze River Delta. Apparently, most Taiwanese IC firms in South China engage in original equipment manufacturer of laptops, personal PCs, and mobile phone. Because the encouragements of East China government, the FDIs from Taiwan to East China will continuously rise. South China contains the second largest IC industrial cluster of Taiwan IC design firms. Intensive development in this area develops convenient transportation, high-quality R&D human resources, and the most comprehensive investment environment, all of which are highly attractive for foreign investment to enter and form high-tech industry clusters.

V. CONCLUSIONS

This paper focuses on Taiwan's IC design industry which chooses to engage FDIs in east and south China. The essential purpose of this article is to quantify the interactions between Taiwan's upstream IC design industries choosing to implement

FDIs in East and South China. Because we take account of mutual dependence between FDIs flowing into East and South China, this work applies Lotka-Volterra model. The results show that Taiwan IC design industry's FDI amount into East and South China is predicted to cumulatively increase, which suggests the clustering tendency of Taiwan's IC design firms into East and South China for Taiwan IC design houses.

The FDIs into South China fundamentally enhance the FDIs into East China, which hardly obstruct FDIs into South China. This relationship implies that IC design houses choosing to engage FDIs in East China would actively respond to the FDI decisions of IC design houses in South China. IC manufacturing, packaging and testing industries depend on IC design industry to gain advanced business benefits. If IC design houses buy more equipment and bring more capitals in South China, those in East China will have pressure to undertake more FDIs into East China to maintain leading position of their supply chain.

It was also shown that Lotka-Volterra model is effective in explicating the dynamics of IC clustering from Taiwan to East and South China. The prediction capacity is good as the relations between the two IC locations were taken into account. Furthermore, the equilibrium analysis has revealed the instability of equilibrium points between FDIs of Taiwan's IC design firms choosing to invest in South and East China. These FDI flows cannot reach a stable status for Taiwan's IC design industry clustering into East and South China. The FDI size will expand in East and South China in the long run.

The framework presented in this paper could be extensively applied to other Taiwan's industries which implement FDIs into various Chinese locations since mutual dependence among different Chinese locations still exist in other industries. Our proposed model is expected to more accurately forecast the evolution process of Taiwan's FDIs into China.

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Bi-Huei Tsai is a Professor in the Department of Management Science, National Chiao Tung University, Hsinchu, Taiwan. Her research focuses on management science and finance in hi-technology industry; both computational and statistical approaches are conducted to explore the marketing dynamics, industrial competitions, foreign direct investment and credit risk forecasting.