

Forecasting Foreign Direct Investment with Modified Diffusion Model

Bi-Huei Tsai

Abstract—Prior research has not effectively investigated how the profitability of Chinese branches affect FDIs in China [1, 2], so this study for the first time incorporates realistic earnings information to systematically investigate effects of innovation, imitation, and profit factors of FDI diffusions from Taiwan to China. Our nonlinear least square (NLS) model, which incorporates earnings factors, forms a nonlinear ordinary differential equation (ODE) in numerical simulation programs. The model parameters are obtained through a genetic algorithms (GA) technique and then optimized with the collected data for the best accuracy. Particularly, Taiwanese regulatory FDI restrictions are also considered in our modified model to meet the realistic conditions. To validate the model's effectiveness, this investigation compares the prediction accuracy of modified model with the conventional diffusion model, which does not take account of the profitability factors.

The results clearly demonstrate the internal influence to be positive, as early FDI adopters' consistent praises of FDI attract potential firms to make the same move. The former erects a behavior model for the latter to imitate their foreign investment decision. Particularly, the results of modified diffusion models show that the earnings from Chinese branches are positively related to the internal influence. In general, the imitating tendency of potential consumers is substantially hindered by the losses in the Chinese branches, and these firms would invest less into China. The FDI inflow extension depends on earnings of Chinese branches, and companies will adjust their FDI strategies based on the returns. Since this research has proved that earning is an influential factor on FDI dynamics, our revised model explicitly performs superior in prediction ability than conventional diffusion model.

Keywords—diffusion model, genetic algorithms, nonlinear least squares (NLS) model, prediction error.

I. INTRODUCTION

THIS paper computationally clarifies the profitability impact on foreign direct investment (FDI) in Taiwan integrated circuit (IC) manufacturing industry based on genetic algorithms (GA) methods in numerical simulations. Taiwan champions the foundry integrated circuit (IC) manufacturing industry around the world as its global market share has been the largest since 2000. However, IC manufacturing firms in Taiwan is losing their competitive advantages due to factors such as changes in operating environment, rising compensation costs, shortage in supply of employees and a lack of industrial lands. On the other hand, China has an advantage in attracting foreign enterprises with low labor cost in recent years. As location theory (Smith [3]) indicates that corporations need to take into account of transportation (distance to market), natural resources, and market access factors to build their plants abroad, most Taiwan IC manufacturing firms have chosen to move their production plants to Mainland China

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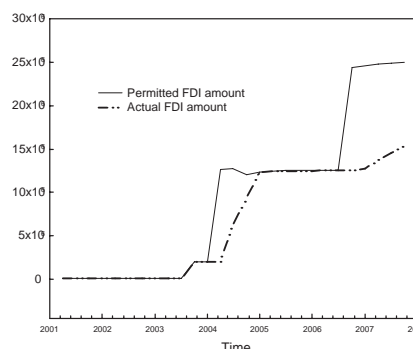


Fig. 1. The permitted FDI and Realistic FDI amount of semiconductor manufacturing industry from Taiwan to China (Unit:thousand NT dollars)

in order to make use of cheap labors and lands. According to governmental statistics of Taiwan in Figure 1, foreign direct investment (FDI) of IC manufacturing industry into China has risen dramatically from 2001. The FDI of Taiwanese firms in China is defined as a flow of capitals from a parent country (Taiwan) to a host country (China) to establish production or service facilities and conduct business activities. Because Taiwanese IC manufacturing firms are the production center of worldwide semiconductor chips, their direct investment into China has thus become an issue not only relevant to the academia but also the industry. Hence, this study focuses on FDIs of Taiwan IC manufacturing firms in Mainland China.

Previous literature has addressed the industrial FDIs from Taiwan to China [2]. Taiwan IC firms that have conducted FDIs into China have attracted other IC firms to do the same, as well as construct business bases in China. In the previous study, we utilized conventional diffusion theory to estimate the industrial clustering evolutions via Bass [4] model. In the series of Bass model [5-9], the internal and external influences of diffusion evolutions are precisely captured. The line of these studies also highlight price factors in determining internal or external influence dynamics [10-12] in the growth model. In the financial investment areas, the external influence includes promotions or announcements from the host country (China). These are great stimulation to innovators to adopt FDI practices. The internal influence is defined as the interpersonal communications among enterprises. Enterprises adopted FDI strategies earlier influence potential followers by persuading the latter to imitate their FDI decisions. In other words, the internal influence, driven by the "word of mouth", illustrates the imitating behavior of the FDI adoptions. In reality, profits

from the branches in China are likely to stimulate the imitating behaviors of enterprise to engage in FDI into China. However, prior research assumes the FDI dynamics is unrelated to the profitability of the branches in the host country, so earnings in a host country (China) have been ignored in such study [1, 2]. There remains, for now, a scarcity of literature that considers the effect of earnings on FDI dynamics. It is worthwhile to formulate a model that explicitly incorporates the profitability to explain the evolutionary process of FDI from Taiwan to China.

In this work, we relax the restrictive assumptions of constant internal influence in the conventional growth model for diffusion of FDI from Taiwan to China. In original Bass [4] setting, the diffusion of FDI is assumed to be constant (unaffected by earnings in the host country); however, what accompanies the diffusive FDI growth is the earnings from the host country. Profitability from the foreign branches accelerates the internal influence of FDI diffusion. As the earnings keep increasing, the potential FDI adopters are more encouraged by the previous FDI adopters' general praises. Since the time-varying internal influence should be correlated to profit gained in the host countries, the estimation may be biased if the FDI evolutions are calculated within restrictive Bass model, in which the internal influence is assumed to be fixed. Thus, we are motivated to specify the internal influence of FDI in an IC manufacturing enterprise as a function of its profitability in the host country.

Another contribution of this article is that this paper applies the genetic algorithms (GA) to provide initial values for the unknown parameters for the optimization of the FDI nonlinear least squares (NLS) model. Generally, different estimation methods of unknown parameters of NLS models have their advantages and drawbacks. Tsai, Li, and Lee [13] indicated that nonlinear least squares (NLS) method used in popular simulation programs employs a sequential searching technique to obtain parameter estimates. Its drawbacks are that the use of iterative procedures requires the user to provide initial values for the unknown parameters before the software can begin the optimization. The initial values must be reasonably close to the yet unknown parameter estimates or the optimization procedure may not converge. Bad initial values can also cause the software to converge to a local solution rather than a global solution. To overcome the problems, this paper is the first in Taiwan to employ the GA methodology to measure the initial value for the parameters of FDI dynamics models.

GA is a simulated method that based on ideas from Darwin's theory of natural selection and evolution. In GA, a chromosome (or an individual) can be defined as an enciphered entity of a candidate solution, which is expressed as a set of variables. A chromosome is represented by a binary bit string and an initial population of chromosomes is created in a random way. Based upon the values of the fitness functions, the chromosomes of the next generation are produced by selection, crossover and mutation operations. The characteristic of GA is the capability to escape local optimum and no need for initial guesses. GA makes an initial set of solutions evolve to a final set of solutions while making a total improvement according to a fixed criterion [14]. Many researches have also investigated

the properties of parameter estimates from genetic algorithms (GA) and have also compared the performance of estimates from GA with traditional gradient search algorithms [15-18]. This article is the foremost to employ GA technique to address the topics of financial investment.

Particularly under "Regulations Governing the Approval of Investment or Technical Cooperation in Mainland China", Taiwanese firms should submit applications to the Investment Commission, Ministry of Economic Affairs (MOEA) in Taiwan for their FDI in China. After the Investment Commission reviews the FDI application documents, it will determine whether to approve these applications and then assign the maximum investment quota for each applicant's FDI amount in China. Taiwanese government prevents the FDI amount of each firm from exceeding the maximum investment quota permitted by the Investment Commission. The maximum investment quota is defined as the permitted FDI amount in Figure 1. In Figure 1, it is obvious that IC manufacturing firms are strictly prohibited from conducting FDI in China. Except Winbond Corporation, no other IC manufacturing firms are allowed to engage in FDI into China before 2002. However, prior FDI related research seldom considers the governmental restrictions [19, 2]. It is essential to consider the regulatory restrictions of capital flows in analyzing FDI diffusion. Models incorporating maximum regulatory amount are employed in our numerical simulation to explore the FDI flow into China. In addition, the numerical simulation of conventional Bass [4] diffusion model are also conducted without considering FDI restrictions in our studies, so we can compare the performance of these alternative models.

This paper focuses on the FDI of Taiwanese IC manufacturing firms to China, and the sample ranges from the second quarter of 2001 to the first quarter of 2009. The aims of this study are to incorporate realistic earnings data to systematically investigate effects of innovation, imitation, and profit factors in FDI diffusions. Since our sample of quarterly FDI, which ranges from 2001 to 2009, is relatively small, it is more reliable to apply numerical simulations to explore the FDI diffusive evolutions. To solve our nonlinear ordinary differential equation (ODE), nonlinear least squares (NLS) method in numerical simulation programs and GA techniques are employed in parameter estimations. In order to find out a generally recognized diffusion model that is appropriate for predicting FDI from Taiwan to China, this research uses model to predict FDI amounts in Taiwanese IC manufacturing industry. The accuracy inferred from the modified model, which incorporate profitability factors, are compared with that of conventional diffusion model.

The results clearly demonstrate the internal influence to be positive through previous FDI adopters' consistent praises for FDI. Previous FDI adopters erect a behavior model for potential ones by persuading the latter to imitate the former in foreign investment decision. Particularly, the results of modified diffusion models show that the earnings from foreign investment branches are positively related to the growth of internal influence and then foster more FDI into China. In general, the imitating tendency of potential consumers is substantially driven by the profit-gaining ability through the

foreign subsidiary institutions. With the global capital flows into China, the FDI inflow extension relies on earnings of Chinese branches in transmitting corporate FDI perceptions and accelerating their diffusions. Since this research has proved that earning is an influential factor on FDI to China, our revised model explicitly performs superior in prediction capability to Bass model. The findings can ultimately forecast future FDI trajectory from Taiwan to China.

The organization of this paper is as follows. In the next section, basic assumption and model formulation are explained. In the third section, solution methods are discussed. In the fourth section, sample and data are presented. In the fifth section, the results of coefficient estimations, parameter stability analysis, and forecast accuracy are provided. Finally, the conclusion is drawn in the last section.

II. BASIC ASSUMPTION AND MODEL FORMULATION

A. Conventional Diffusion Model

To explain the dynamics of FDI behaviour, we state a FDI growth model based upon the theory of dynamic growth with the following assumptions [1, 19, 20]. The increment of capital outflow from the parent country (Taiwan) at any given point of time is directly proportional to the amount of remaining potential size ($M - N(t)$) at that time. Mathematically, this can be represented as:

$$dN(t)/dt = g(t)(M - N(t)), \quad (1)$$

where M is the potential size of FDI capital amount. The difference between M and N indicates the remaining amount of potential capital at time t .

The growth rate, depending on the internal and external influences, is given by,

$$g(t) = (p + q \frac{N(t)}{M}). \quad (2)$$

Substituting Eq. (2) into Eq. (1), using the assumptions above, we find that the dynamic change rate of the capital amounts is proportional to the current cumulative amount. Thus, the dynamics of FDI flow is expressed as:

$$n(t) = \frac{dN(t)}{dt} = (p + q \frac{N(t)}{M})(M - N(t)). \quad (3)$$

Under diffusion theory frameworks, the parameter p precisely captures the FDI growth factor that is unrelated to the cumulative FDI amounts from previous experienced firms. The external influence, p , is determined by two components: (i) the intrinsic tendency of the individual firm to deal with FDI, and (ii) the external Chinese promotions or advertisings which encourages foreign corporations to conduct FDIs in China. In other words, the external influence p gives rise to innovators' adopting FDI, especially in the beginning of the FDI process. On the other hand, q illustrates the impact of early FDIs adopter firms on the growth rate of FDIs into China. The internal influence, q , represents the impact on the FDI involvement through the contact with early FDI adopters, namely, the imitating behaviour of conducting FDI.

Such internal communication as interpersonal communication (interpersonal communication, interaction among members of a social system) is more influential when the FDI process has already started. And more interestingly, this imitating behaviour serves as a logic explanation of the acceleration of the diffusion process. Furthermore, these two coefficients, p and q , can be used to compare the differential internal and external influences for FDI evolutions of IC manufacturing industry.

B. The Modified Model that Incorporates Price Factors

Prior studies verify that imitators' behavior (internal influences) have greater influence than innovators' behavior (external influences) on both product diffusions [4, 9, 13] and FDI dynamics [1, 2]. Imitating and previous adopters' word of mouth play more important roles than innovators' behavior. Particularly, the profit-gaining experience further strongly encourages the successive enterprises to follow the practices of previous FDI-adopted firms. Profitability is the key factor to strengthen the imitating behaviors of potential followers, so this study relaxes the restrictive assumption concerning constant internal influence. Our internal influence dynamics is specified as the function of profit-gaining ability. The internal influence of FDI diffusion in our model is now expressed as Eq. (4):

$$q_t = q_1 \frac{\exp(eps_t \times \delta)}{M}. \quad (4)$$

In Eq. (4), EPS_t is the additional contribution of the Chinese subsidiary institutions to the earnings per share (EPS) of the IC manufacturing firms in present country (Taiwan) at time t . The EPS for the Chinese branch (EPS_t) is defined as the earnings produced by the foreign branches in China (host country) divided by the outstanding shares for each firms. Earnings in Taiwan (parent country) are excluded in the quarterly EPS data for the Chinese branch. The average quarterly EPS in this research is defined as the sum of total EPS for all the sample firms, which engage in FDIs in China, divided by the number of our sample firms.

Obviously, the term $\exp(EPS_t \times \delta)$ in Eq. (4) represents how profitability reductions enhance the imitating behaviors of FDI decisions, the coefficients of imitation, at period t , q_t varies with earnings factors over time and is stated as a function of average earnings per share. The parameter denotes the profit effect, which represents the marginal effect of profitability on internal influence. For this reason, we put the Eq. (4) into Eq. (3) and it can be rewritten as Eq. (5):

$$n(t) = \left(p + q_1 \frac{\exp(EPS_t \times \delta)}{M} \times \frac{N(t)}{M} \right) [M - N(t)]. \quad (5)$$

In Eq. (5), the imitating behavior depends on the profit-earning capacity of foreign branches and is not constant all the time. Generally, IC manufacturing industry is capital intensive. In the initial stage of FDI, shipment orders or revenue is hardly obtained, while huge amount of depreciation expense is realized for the foreign branches. Namely, net loss is usually generated at the beginning of FDIs. Because all

the Taiwan IC manufacturing firms in our sample start to implement FDI into China after 2001, the average EPS in our quarterly sample data never exceed zero. If the EPS is negative, the negative profitability coefficient represents that profit is positively correlated to the corporate imitating behaviors. Huge losses from host country (China) slow down such imitating behavior and lead to less FDI diffusions. This paper makes use of this coefficient δ to capture how earnings factors enhance FDI growth dynamics. In addition, since FDI is constrained by the governmental regulations, so their potential market size corresponds to the maximum permitted amount. Potential market dynamics of FDI can hardly be driven by profit factors. Hence, the potential market is presumed to be unaffected by EPS in our work. In addition, because Taiwan set a upper bound on FDI from Taiwan to China, the potential FDI capital amount (M) of our modified model (equation (5)) is assumed to be confined to the regulatory limit (26,524,023 thousands NT dollars) in our modified model.

III. SOLUTION METHODS

A. Numerical Solution

Conventionally, the coefficient of external and internal influence is estimated by Bass [4] ordinary least squares (OLS) regression. However, regression model has some shortcomings, such as the possibility of multicollinearity between variables. Besides, FDI restriction cannot be considered in OLS regression models. Furthermore, numerical simulation can produce good estimates of the unknown parameters in the model with relatively small data set, it is a fairly well-developed theory for computing confidence, prediction and calibration intervals to answer questions, particularly for our small sample set of quarterly FDI data. Hence, the numerical model that incorporates FDI limits is employed to solve Eq. (5) in our modified model which incorporates profitability factors. Under current regulations, FDI amount cannot exceed the maximum permitted amounts approved by the Taiwanese government, so the maximum permitted amounts are equivalent to the upper bounds for potential FDI size. Therefore, the maximum permitted amounts (26,524,023 thousand NT dollars for IC manufacturing industries) are specified as the potential size of FDI outflows into China in the numerical model incorporating maximum FDI limits.

The computational procedure for the simulation-based optimization method is adopted [13] and flow chart of our simulation is shown in Figure 2. Genetic algorithm (GA) is conducted to find exact or approximate solutions to optimization and search problems. The computational procedure of GA is mainly composed of four stages: initialization, selection, crossover and mutation, and termination. Next, a 4th-order Runge-Kutta algorithm [21] is implemented to solve the ODE numerically. Once the computed solution is obtained, it is calibrated with realistic data to generate an accurate simulation. If the tolerance of the result is greater than the error, the optimal parameters and results are thus obtained. Otherwise, a least square optimization technique enables the updating of modifying parameters for the next simulation.

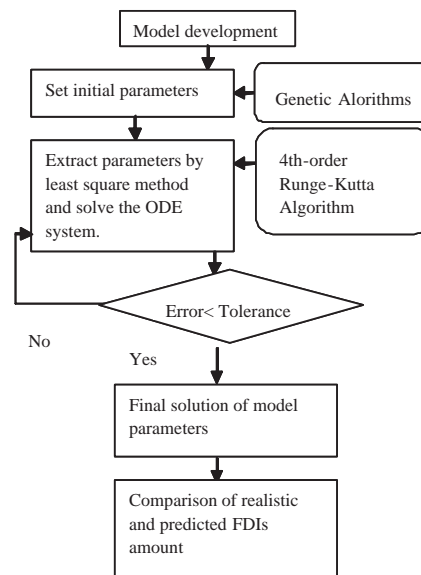


Fig. 2. Flow chart of simulation procedure

B. Comparison of Prediction Ability

Two approaches are applied in our research. One is the numerical solution of conventional Bass [4] diffusion model (Eq. (3)) and the other is the numerical solution of our modified model (Eq. (5)). Previous studies measure the prediction errors to the forecast ability among various models [22-23]. This article further follows prior investigations and utilizes the mean absolute prediction error (MAPE) to compare the performance among the alternative models: numerical model incorporating maximum FDI limits, and numerical model of conventional diffusion model without FDI limits. This MAPE is calculated by the equation (6).

$$MAPE = \frac{1}{n} \sum_{t=1}^n \frac{|Y_t - \hat{Y}_t|}{Y_t}, \quad (6)$$

where Y_t and \hat{Y}_t represent, respectively, the realistic and predicted FDI at time t . The prediction ability of the four models is compared. To do so, the parameters of these models are estimated with the quarterly FDI amount to China up to the first quarter of 2008. The forecasts of quarterly FDI amount from the second quarter of 2008 to the first quarter of 2009 are compared with the actual realistic quarterly FDI amount.

IV. SAMPLE AND DATA

The study collected data on integrated circuit (IC) manufacturing firms in Taiwan. IC foundry manufacturing firms are not permitted to conduct FDI until the second quarter in 2001 by Taiwanese government. The sample period covers from the second quarter of 2001 to the first quarter of 2009 and the sample data are measured in New Taiwan (NT) dollars (thousands). In regards to the data sources, the data of actual

TABLE I
DESCRIPTIVE STATISTICS OF QUARTERLY CUMULATIVE FDI AMOUNT
AND AVERAGE QUARTERLY EPS OF SAMPLE FIRMS

	FDI amount (NT thousand dollars)	EPS(NT dol- lars)
Mean	8,293,926	-0.00585
Median	12,286,782	-0.00333
Maximum	47,250	-0.02571
Minimum	18,209,728	0
Standard Deviation	6,985,728	0.00752

FDI amounts and permitted FDI amounts into China are collected from Taiwan Economic Journal (TEJ) database. The actual 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 sample data are measured in New Taiwan (NT) dollars (thousands). Sample data are divided into two groups according to the year span to examine the accuracy of our models. All the prediction models are developed by using the training sample from the second quarter of 2001 to the first quarter of 2008, and their accuracy are evaluated by comparing with the test sample from the second quarter of 2008 to the first quarter of 2009.

V. EMPIRICAL RESULTS

A. Results of Dynamic Growth Model

Table 1 demonstrates the descriptive statistics of net FDI amount to China for IC manufacturing industries in this study. From table 1, the mean and median of firm's EPS is negative. Because all the Taiwan IC manufacturing firms in our sample start to implement FDI into China after 2001, huge amount of depreciation expense is allocated for the Chinese branches during our sample period. Besides, in this initial stage of FDI, shipment orders or revenue was seldom received, so the average EPS in our quarterly sample data never exceed zero.

The results of the modified model incorporating maximum FDI limits and conventional model without FDI limits are shown in Table 2. Consistent with product life cycle theory [24], new products are first introduced to a few developed countries before they make their appearance in developing countries. The relatively low Chinese labor costs are more likely to stimulate IC manufacturing firms to engage in directing large amount of FDI into China. Although recent plant expansions of Chinese IC manufacturing firms are expected to hinder Taiwan's enterprises incentives to direct FDI into China, our findings of the realistic FDIs and estimated potential FDI size still indicate a strong inclination to direct FDI into China for IC manufacturing industry.

In regard to the alternative models, the coefficients of internal influence q are all estimated positive for IC manufacturing industries. The positive effects of internal influence exist. Owing to the results of the modified model incorporating profitability factors and regulatory restrictions (Eq. (5)) and conventional model without FDI limits (Eq. (3)), the relationship of $p < q$ is always held for both alternative models. This suggests that the internal influence is larger than the external one. Thus, the imitating behavior of Taiwanese IC

TABLE II
THE RESULTS OF THE ALTERNATIVE MODELS. THE UNIT OF POTENTIAL
FDI CAPITAL AMOUNT (M) IS NT DOLLARS (THOUSANDS) FOR THE
CONVENTIONAL BASS MODEL. THE POTENTIAL FDI CAPITAL AMOUNT
(M) OF OUR MODIFIED MODEL IS ASSUMED TO BE CONFINED TO THE
REGULATORY LIMIT (26,524,023 THOUSANDS NT DOLLARS).

	Conventional Bass model (Eq.(3))	Modified model incorporating FDI limits and earnings factors (Ep.(5))	
p	2.949×10^{-12}	p	0.006551
q	0.422056	q_1	0.161411
M	10,609,609	δ	-23.538539
MAPE	0.155342	MAPE	0.009644

manufacturing firms dominates the dynamics of FDI flow in China. Because of the highly risky economical environment and uncertainty in China, most Taiwanese firms avoid investing in China under the premise that no other firms has conducted FDIs in China before. After potential firms heard FDI experiences from others presently conducting FDI into China, these firms will evaluate the risk tolerance of their involvement in FDI in China. Consistent with clustering theory, the IC industrial clusters are gradually established by means of this interactive communications among enterprises that are interested in conducting FDI.

In regard to the modified model that incorporates profit factor, EPS effect coefficient is all negative. As the descriptive statistics shown in table 1, the average EPS in our quarterly sample data never exceeds zero. Since the EPS is negative, the negative profitability coefficient in Eq. (5) represents that the profit is positively related to corporate imitating behaviors. Huge losses from host country (China) slow down such imitating behaviors, and thus reduce FDI diffusions. Due to the significance of the modeled profitability effect in FDI decisions, the model incorporating the effect of earnings performs better in prediction capability than the conventional ones. Namely, profit-gaining capacity of China division strengthens the influence of general praise from the experienced FDI adopters, so the imitating behaviors of successive FDI adopters become more prevalent. This accelerates the diffusion of FDI flows into China.

B. Forecast Accuracy Analysis

Two series of the predicted FDI amount are calculated by using these alternative models. Both the actual FDI and predicted FDI amount show an increase in both models- the modified model which incorporates profitability and time-varying FDI limits (Eq. (5)), and the conventional model without FDI limits (Eq. (3)). The increase of the FDI flow into China once again supports the industrial clustering tendency of Taiwanese IC enterprises. Also, the evidence refutes the claim that Taiwan government closes its country's gate to international transaction or prohibits its enterprises from conducting foreign investment in China.

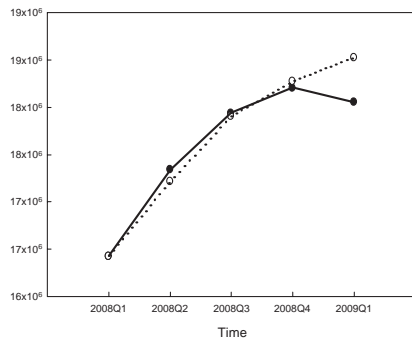


Fig. 3. Realistic and simulated cumulative FDIs computed based on our modified model from the first quarter of 2008 to the first quarter of 2009 (unit: NT thousand dollar)

The results of forecast accuracy for the test sample are also shown in Table 2. The forecasting results, displayed in Table 2, show that MAPE of the conventional diffusion model is 0.155342 and that of our modified model, 0.009644. It is evident that MAPEs of the numerical model incorporating FDI limits and profit factors are much lower. This implies that the dynamic growth model, which takes account of profit factors and regulatory FDI limits, performs better in predicting Taiwanese IC manufacturing industry's FDI into China. The model can help researchers to make accurate prediction on the trend of FDI from Taiwan to China with profit factors considered.

Also, the realistic FDIs and the simulated FDIs for the calculation with our modified models versus the time are plotted in Fig 3. Except for the forecasted FDIs on the first quarter of 2009, which slightly shift away from the realistic FDIs, the simulated shipments of modified model are close to the actual shipments. The FDIs from Taiwan to China probably decreased by the financial crisis, which suddenly occurred surrounding 2008 all over the world. Thus, the predicted FDI amount computed by our modified model is higher than the realistic amount. The prediction ability of the modified model might be reduced due to the occurrence of the infrequent event, financial crisis.

VI. CONCLUSIONS

This paper focuses on the FDI flows of IC manufacturing firms from Taiwan into China, and the period ranges from the second quarter of 2001 to the first quarter of 2009. We utilize GA methods in numerical simulations to computationally clarify the profitability impact on foreign direct investment (FDI) in Taiwan integrated circuit (IC) manufacturing industry. The effects of the innovation, imitation and profit factors on the FDI behaviors are systematically considered under growth model framework. In contrast to the assumptions in prior research, we relax the restrictive assumptions of constant internal influence in the conventional growth model for FDI evolutions from Taiwan to China. Based upon the profitability impact on the FDI decision, we incorporate earning per share (EPS) factor into the growth model to study whether earnings from

host country accelerate the flow of FDI from present country. In addition, under "Regulations Governing the Approval of Investment or Technical Cooperation in Mainland China", Taiwanese firms have to obtain governmental approvals to implement FDI in China and their FDI amounts are confined to the maximum quotas permitted by the government. It is reliable to consider the regulatory limits of capital outflow into China to explore the FDI dynamics. The second contribution of this article is to include FDI limits in prediction models. Our dynamic model is specified as an ordinary differential equation (ODE), where the cumulative flow can be solved and optimized. Conventional models which exclude the profitability in host country and capital control are also used, so forecast accuracy of these two models can be compared with the modified model incorporating FDI limits and profitability in host country. Another contribution of this article is that this paper applies the GA to provide initial values for the optimization of NLS model. GA can make an initial set of solutions evolve to a final set of solutions while making a total improvement.

The results indicate the significant internal influence of intra-industry communications on the FDI evolution into China. Although Taiwan sets capital control to confine Taiwan IC firms from implementing FDI in China, Taiwan firms still implement FDIs into China probably to serve for the Chinese branches of the IC assembly and test firms (e.g. Amokor, Infieon, Montage and so on) to obtain market share in China. Taiwan IC manufacturing firms tend to successively imitate the experienced firms to engage in FDIs in China. The amount of FDI directed from Taiwan IC industry is predicted as increasing, which once again supports the FDI tendency to China. In particular, this model illustrates that losses from host country (China) slow down imitating behaviors of successive firms concerning FDI in China and reduce FDI diffusions. Due to the significance of the modeled profitability effect in FDI decisions, the model which considers the effect of earnings performs better in prediction ability than the conventional ones.

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REFERENCES

- [1] Tsai, B.-H., 2009. Analysis of dynamic growth model in foreign direct investment of Taiwan IC industry into China, *International Journal of Accounting Studies*, 49, 73-94. 2
- [2] Tsai, B.-H. 2010. Application of dynamic diffusion theory in foreign direct investment of Taiwan IC industry into China. *International Journal of Computational Science and Engineering*, 5(1), 2-8. 3
- [3] Smith, D. M. 1981. *Industrial location: An economic geographical analysis*. 2nd edition. New York: John Wiley. 4
- [4] Bass, F. M. 1969. A modified product growth model for consumer durable. *Management Science*, 15, 215-227. 5
- [5] Mahajan, V., E. Muller, and F. M. Bass. 1990. New product diffusion models in marketing: A review and directions for future research. *Journal of Marketing*, 54, 1-26. 6
- [6] Rogers, E. M. 2003. *Diffusion of Innovations*, 5th edition. New York: Free Press. 7

- [7] Bass, F. M. 2004. Comments on a new product growth for model consumer durables. *Management Science*, 50 (12), 1833-1840. 8
- [8] Meade, N., and T. Islam. 2006. Modelling and forecasting the diffusion of innovation: A 25-year review. *International Journal of Forecasting*, 22, 519-545. 9
- [9] Ruiz, E., and Leeflang, P. S. H. 2006. Diffusion of franchising as an innovation of managerial organization. *Marketing JRM*, 65-75. 10
- [10] Mesak, H., and Berg, W. 1995. Incorporating price and replacement purchases in modified products diffusion models for consumer durables. *Decision Science*, 26, 425-449. 11
- [11] Mesak, H. (1996). Incorporating price, advertising and distribution in diffusion models of innovation: some theoretical and empirical results expectations in diffusion models. *Computers and Operations Research*, 23, 1007-1023. 12
- [12] Parker, P. (1992). Price elasticity dynamics over the adoption life cycle. *Journal of Marketing Research*, 9, 358-367. 13
- [13] Tsai, B.-H., Li, Y. and Lee, G.-H., 2010. Forecasting global adoption of crystal display televisions with modified product diffusion model, *Computers and Industrial Engineering* 58 (4), 553-562. 14
- [14] Berkoune, D., Mesghouni, K and Rabenasolo, B. 2006. Lower bounds for the scheduling problem with uncertain demands. *International Journal of Applied Mathematics and Computer Science*, 16 (2), 263-269. 15
- [15] Czekalski, P. 2006. Evolution-fuzzy rule based system with parameterized consequences. *International Journal of Applied Mathematics and Computer Science*, 16 (3), 373-385. 16
- [16] McCall, J. 2005. Genetic algorithms for modelling and optimization, *J. Comput. Appl. Math.* 184, 205-222. 17
- [17] Venkatesan, R., T. V. Krishnan and V. Kumar 2004, Evolutionary Estimation of Macro-Level Diffusion Models Using Genetic Algorithms: An Alternative to Nonlinear Least Squares, *Marketing Science* 23, 451-464. 18
- [18] Goldberg, D.E. 1989. *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley. 19
- [19] Kalish, S., and S. K. Sen. 1986. Diffusion models and the marketing mix for single products. In *Innovation Diffusion Models of New Product Acceptance*, edited by V. Mahajan, and Y. Wind, 87-115. Cambridge, MA: Ballinger.

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