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台灣積體電路產業赴中國直接投資的動態成長分析*

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摘要

本文首度利用動態成長模型，探討法令限額內，台灣積體電路(IC)赴中國直接投資資金的動態過程。「在大陸地區從事投資或技術合作許可辦法」限制臺灣廠商需於政府核准限額內赴中國投資，故本研究考量該投資上限額度進行模擬分析，該動態模型係一階微分方程，因此本文利用前瞻的數值方法(numerical method)求解與分析影響廠商赴中國直接投資的主要因素。本文進而將研究期間區分為兩段時期，以估計期間樣本建構未考量投資限額的數值模擬模型與迴歸模型，再比較在測試期間不同模型的預測誤差，以驗證考量投資限額的數值模擬模型是否涵蓋較高的模型精確度。

本實證結果發現台灣半導體產業當期赴中國直接投資的金額與累積投資金額呈顯著正相關，隱含當台灣積體電路設計或封測產業赴中國大陸的累積金額增加，個別廠商為維護競爭優勢，會增加當期直接投資金額，產業間同儕競相赴大陸投資的內部影響力是驅動當期繼續赴大陸投資的主要動因。此外，IC 封測廠商間內部影響因素均大於 IC 設計產業，研究結果隱含 IC 封測廠商若在中國設廠，上游設備商與原料供應商會相繼在中國設據點，吸引更多台灣 IC 封測廠赴大陸直接投資，IC 封測產業赴大陸直接投資的群聚效應較為強烈，反之，IC 設計廠對上游設備商與原料商的仰賴不及 IC 封測廠，故 IC 設計產業內部影響力較 IC 封測產業為低。最後，模型的精確度檢定證實考量隨時間變動的投資限額數值模擬模型平均絕對誤差水準最低，模型精確度最高，顯示該模型能有效地解釋台灣廠商赴中國投資的演化過程。

關鍵詞：海外直接投資、微分方程、平均絕對誤差、數值模擬

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Analysis of Dynamic Growth Model in Foreign Direct Investment of Taiwan IC Industry into China

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Abstract

Numerical models which incorporate constant or time-varying foreign direct investment (FDI) limits are simulated in our study. 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 to explore the FDI dynamics into China. Our dynamic model incorporates the time-varying FDI limits and is specified as an ordinary differential equation (ODE), where the cumulative flow can be solved. Two models which ignore the FDI limits, the regression model and the numerical model without FDI limits, are also estimated, so forecast accuracy of these two models can be compared with the numerical model incorporating FDI limits.

The results indicate the positive internal influence through intra-firm communications on the FDIs into China, which suggests that Taiwan IC firms tend to successively imitate experienced firms to undertake FDIs into China. Once more and more IC corporations proliferate production bases in China, the other IC firms are likely to follow and construct production centers to maintain their competitive advantages and share the available resources. Specifically, the internal impact is stronger for IC packaging and testing firms than for IC design ones, revealing the profound imitating inclination of IC packaging and testing industry. In addition, the results of prediction ability illustrate the lowest prediction errors for the numerical model incorporating time-varying FDI limits. Models incorporating time-varying FDI limits perform superior because of taking account of regulatory restrictions. This supports the important influence of regulatory FDI limits.

Keywords: *Foreign direct investment, ODE, Mean absolute prediction errors, Numerical simulation.*

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1. INTRODUCTION

In recent years, manufacturing firms in Taiwan have been losing their competitive advantage due to such factors as changes in operating environment, rising compensation costs, employee supply shortages and insufficient supply of industrial land. From the strategic perspective, an enterprise’s motivation to invest overseas is efficiency and effectiveness. As location theory (Smith 1981) indicates that corporations need to take account of transportation (distance to market), natural resources, and market access factors to build their plants abroad, China has an advantage in attracting Taiwanese enterprises due to its lower labor cost and cultural intimacy with Taiwan. Most firms have chosen to move their production plants to Mainland China in order to capture lower labor and land costs. According to governmental statistics of Taiwan, foreign direct investment (FDI) in China has risen dramatically from 1992 to 2007. 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. The Taiwan-permitted FDI amount in China increased dramatically from US$ 246,992 in 1999 to US$ 9,970,544 in 2007. These figures indicate the importance of Mainland China as the FDI bases for Taiwan corporations. As a result, Taiwanese firms’ behaviour of FDI in China has thus become an issue of, not only academic, but also practical relevance.

In addition to aforementioned location theory (Smith 1981), FDI-related literatures also propose product life cycle theory (Vernon 1966) and clustering theory (Porter 1998, 2000) to state the FDI origins. Clustering theory (Porter 1998, 2000) hints that firms involve in FDIs in order to gather together and access available materials and basic equipment abroad. Product life cycle (Vernon 1966) elucidates that new products are converted from developed countries to developing areas, causing firm’s FDIs. Most of these previous investigations employ historical discrete-time data to interpret FDIs from the statistical or econometrical viewpoints (Dunning, Kim and Lee 2007; Hooper and Kim 2007; Kugler and Rapoport 2007; Yeyati, Panizza and Stein 2007). The statistical or econometrical methodologies measure future data points based on past data points. However, prior studies have never focused on the continuous growth rate to numerically measure the FDI dynamics (Hymer 1976; Kindleberg 1969; Caves 1971; Choi and Jeon 2007; Deng 2007). The difference forms in statistical methods cannot be transformed into differential forms, while the differential forms of continuous growth rate in numerical approaches can be converted into difference forms. In numerical simulation, ordinary differential equations are employed to precisely capture the continuous growth rate dynamics. Particularly, nonlinear least squares (NLS) method in numerical simulation programs employs a sequential searching technique to obtain parameter estimates. Consequently, numerical simulation can produce good estimates of the unknown parameters in the model with relatively small data set. Thus, it is a fairly well-developed theory for computing prediction and calibration intervals to answer question. The FDI data set is relatively small because China has not aggressively allowed foreign enterprises to directly invest in China until 2000. It is thus more reliable to apply numerical simulations to explore the FDI evolutions of IC industry from Taiwan to China. Hence, this investigation for the first time specifies FDI growth rate dynamics based on an ordinary differential equation (ODE) framework.

The concept of “growth or diffusion on innovation” originated in the 1960s. Since then, diffusion theory has received much attention (Bass 1969; Robinson and Lakhani 1975). Diffusion theory applications and extensions have been written in different fields of innovation, such as high-tech or consumer product, technology, service and organization (Mahajan, Muller and Bass 1990; Meade and Islam 2006). However, research in the field of investment innovation has not been reported yet (Rugman 1979; Rugman 1986; Hennart 1982). It will be a new application if the evolution of FDI capital flow could be explored from the viewpoints of diffusion theory (Tsai 2008, 2009; Tsai and Li 2009). Based upon diffusion theory, FDI flow could be defined as a process that transmits throughout a given social system by way of diverse communication channels. FDI growth is the propagation of messages related to the FDI outcomes that lead to subsequent decision making, awaiting a change in the behaviour of the receiver in our research.

This study focuses on FDIs of Taiwan integrated circuit (IC) firms, since Taiwan holds the leading position in IC industry. The global market shares of Taiwan’s foundry IC packaging and testing industry have long been the largest and the global market share of Taiwan’s IC design industry was ranked number two from 2000. Particularly under “Regulations Governing the Approval of Investment or Technical Cooperation in Mainland China”, Taiwanese firms should apply to the Investment Commission, Ministry of Economic Affair (MOEA) in Taiwan for their FDIs in China. After the Investment Commission reviews the FDI application documents, the commission determines whether these applications would be approved and then assigns 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 Table 1. From Table 1, it is obviously observed that IC packing and testing firms are strictly prohibited from FDI in China. It is essential to consider the FDI restrictions in analysing FDI diffusion. As a result, models incorporating maximum regulatory limit amount and models incorporating time-varying limits amount are employed in our numerical simulation to explore the FDI flow into China. In addition, the numerical simulation and the regression are also conducted without considering FDI restrictions in our studies, so we can compare the performance among these alternative models: regression model, numerical model incorporating FDI limits, and numerical model without FDI limits. Since the cumulative FDI amounts are up to 6,144,467 and 16,643,989 thousand NT dollars for IC design and IC packaging and testing industries by 2007, it is worthwhile to measure the prediction errors of our FDI forecasting models under the regulatory framework.

Table 1 The Permitted and Actual FDI Amount from Taiwan to China

	IC packing and testing		IC design	
Year	Permitted	Actual	Permitted	Actual
2000	36,001	36,001	181,882	85,959
2001	1,242,539	444,984	1,456,728	894,648
2002	2,465,567	1,688,093	2,786,212	1,601,342
2003	3,598,655	2,579,665	3,428,795	2,489,698
2004	6,527,870	5,612,450	4,199,260	3,293,861
2005	11,126,242	9,570,344	5,316,912	4,385,577
2006	15,590,467	12,667,510	6,305,167	5,240,580
2007	18,367,663	16,643,989	8,330,090	6,144,467

The Unit is NT Dollars (thousands).

More interestingly, prior researches point out that the unique virtual integration structure in Taiwan IC industry is distinctly different from the integrated device manufacturer (IDM) structure of the IC industry in U.S., Japan and Korea (Chu, Teng, Huang and Lin 2005; Sher and Yang 2005). Under this virtual integration structure, all Taiwan IC firms in different production stages, including not only upstream IC design but also downstream IC packaging and testing firms can provide us public FDI data from separate firms. The unique setting enables the article to highlight the FDI characteristic difference of various production stages along IC industry. This study formulates the FDI dynamic model to capture the difference in the internal and external influence on FDI diffusion among various production levels along IC industry. According to diffusion theory, the internal influence is driven by the interpersonal communications among FDI members in Taiwan. Previous FDI adopters (experienced firms) exercise influence on potential FDI adopters (successive firms) by persuading potential FDI adopters to imitate previous FDI adopters in the FDI decision. On the other hand, the external influence includes investment advertising or political announcements from the representatives of the host country (China). As a result, our analysis of dynamic growth model is able to compare the extents of the internal and external influence between upstream IC design and downstream IC packaging and testing industries.

In regards to IC packaging and testing industry, the process include hundreds of standard steps and each step is fixed with standardized machinery and equipments. In this condition, IC packagers and testers highly rely on the support from the material and equipment suppliers. Only when Taiwan IC packing and testing firms construct factories in China, their suppliers can possibly implement their channels in China. In this condition, such suppliers' channels enable successive FDI firms to free-ride suppliers' support much easier. Since clustering theory (Porter 1998, 2000) hints that firms can collaborate with the available materials and basic equipment to obtain related resources in neighboring areas, the manifest cooperation enables IC packaging and testing firms to successively follow the experienced FDI firms to set up plants abroad. IC packagers and testers tend to imitate other firms to invest in China. The internal influence of IC packaging and testing industry is expected to be profound.

In contrast to IC packaging and testing production, the IC design products are designed differently according to their final applications in electronic products (such as CPU, chipset, mobile phone, power supply management and cartography). The production processes are much less similar among IC design firms; therefore the free-riding of up-stream equipment or material suppliers are much more difficult for IC design firms than IC packaging and testing ones, resulting in less imitating inclination for IC design firms. Thus, the internal influence of IC design industry is likely to be smaller than that of IC packaging and testing industry.

From the aforementioned arguments, the purpose of this paper is to apply dynamic growth model under ODE framework to interpret FDIs of Taiwan IC industry into China. This article further compares the external and internal influence extents of FDIs between IC design and IC packaging and testing industries. Finally, the prediction performance of our numerical model which incorporates FDI restrictions, numerical model without FDI limits, and regression model are compared to ascertain which model is the most accurate. The contributions of this research can be stated in two aspects. First, this research is a new application of dynamic diffusion theory in the evolution of FDI flows, which is the critical field of investment innovation. Although previous studies explore FDI flows based upon diffusion theory, the regulatory limits is ignored (Tsai 2009). In contrast to prior research, our simulation incorporates the time-varying regulatory FDI limits. Second, this article for the first time highlights the magnitude difference in internal and external influence of FDI evolutions for different industries. The results invoke us insights concerning the FDI features among differential industrial production processes, thus benefiting enterprises' strategies in management, investment and operational planning.

This paper is organized as follows. In Section 2, we propose the dynamic growth model for FDI flow. In Section 3, we define the solution method. As for Section 4, we discuss the results on FDI flow from Taiwan to China. Finally, we draw conclusions and suggest future possibilities of the elaboration of this theme.

2. BASIC ASSUMPTION AND MODEL FORMULATION

There are two origins of diffusion theory, one comes from the British and German-Austrian schools of growth in anthropology and the other comes from the S-shaped growth curve proposed by a French sociologist. According to the dynamic theory, a growth function N capturing the capital flow's dynamic pattern, given the fact that the pattern is time-dependent, we can denote a growth function of $N(t)$. The growth function is usually modelled as the solution of a differential equation $dN/dt = f(N, t)$ where the function f determines the shape of the curve of dynamic growth (Mahajan et al. 1990). To explain the dynamics of FDI behaviour, we state a FDI growth model based upon the theory of dynamic growth with the following assumptions (Kalish and Sen 1986; Mahajan and Schoeman 1977).

Assumption 1: There are only two countries in the system. Also, only the FDI capital outflow from the parent country (Taiwan) to the host country (China) is considered. We limit our discussion to a two-countries, multi-periods and one-way-capital-flow model.

Assumption 2: There is a FDI capital outflow restriction in the parent country side. Also, the potential capital size of FDI outflow, $M(t)$, remains constant over the time period. In other words, we assume that the size of the amount of capital is finite and known or can be estimated when the FDI market was opened.

Assumption 3: There is no supply restriction on the capital inflow of FDI in the host country (here, China).

Assumption 4: The process of FDI capital outflow from the parent country is independent of other kinds of capital flow, for instance, foreign portfolio investment (FPI) flows. In other words, we assume no interactions among FDI, FPI and other capital flows in the system.

Assumption 5: The increment of capital outflow from the parent country at any given point of time is directly proportional to the amount of remaining potential at that time. Mathematically, this can be represented as:

$$N(t+\Delta t) - N(t) = gN(t)\Delta t \tag{1}$$

where *N(t)* is the cumulative amount of FDI capital at time *t*, *Δt* is the increment of time and *g(t)* is the FDI growth rate. Dividing by *Δt* on both sides, we have

$$\frac{N(t+\Delta t)-N(t)}{\Delta t}=gN(t) \tag{2}$$

Taking *Δt→0* in Eq. (2), we have

$$\lim_{\Delta t\to 0}\frac{N(t+\Delta t)-N(t)}{\Delta t}=\lim_{\Delta t\to 0} gN(t) \tag{3}$$

thus,

$$\frac{dN(t)}{dt}=gN(t) \tag{4}$$

Eq. (4) can be further modified by considering the effect of the upper bound of the cumulative amount of capital on *N(t)*,

$$\frac{dN(t)}{dt}=g(t)(M-N(t)) \tag{5}$$

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*.

Assumption 6: The growth rate of the capital outflow depends on time through a linear function of *N(t)*.

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

$$g(t)=(a+bN(t)) \tag{6}$$

Substituting Eq. (6) into Eq. (5), 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:

$$\frac{dN(t)}{dt}=(a+bN(t))(M-N(t)) \tag{7}$$

We notice that the amount of capital at time t can be calculated by the following equation:

$$n(t) = \frac{dN(t)}{dt} \tag{8}$$

The difference (*M – N(t))* could be referred to as the remaining potential size of FDI capital flow into China. If cumulative FDI amounts in Eq. (6) are deflated by potential FDI size *M*, the growth rate in Eq. (6) can be written as Eq. (9).

$$g(t) = (p + q\frac{N(t)}{M}) \tag{9}$$

We can now express the developed model as Eqs. (10) and (11). Eq. (10) illustrates the diffusion behavior of Taiwan IC industry's FDI into China. In Eq. (11), the FDI diffusion is presented in terms of probability density function, *f(t),* and cumulative probability density function (CDF), *F(t)*.

$$\begin{aligned} n(t) &= \frac{dN(t)}{dt} = (p + q\frac{N(t)}{M})(M - N(t)) \\ &= pM + (q-p)N(t) - \frac{q}{M}[N(t)]^2 \end{aligned} \tag{10}$$

$$f(t) = \frac{n(t)}{M} = p + (q-p)F(t) - q[F(t)]^2 \tag{11}$$

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 deal with FDIs in China. In other words, the external influence *p* affects the innovative behaviour of FDI, especially in the first step of the FDI process. On the other hand, *q* illustrates the impact of the previously experienced firm's FDIs on the growth rate of FDIs into China. The internal influence, *q*, represents the impact on the FDI involvement through the contact with previous experienced FDI firms, namely, the imitating behaviour of FDI flow. Such internal communication as interpersonal communication (interpersonal communication, interaction among members of a social system) is more suited to influencing behaviour when the FDI process has already started and more interestingly, this imitating behaviour helps to explain the acceleration of the diffusion process as a logic process. Furthermore, these two coefficients, *p* and *q*, can be used to compare the differential internal and external influences among various stages along the IC industry value chains.

3. SOLUTION METHODS

As far as we know, at least two approaches can be applied to solve the Eq. (7). One is the analytical solution technique for statistical computation and the other is the numerical solution. These two methods are described in the following subsections.

3.1 NUMERICAL SOLUTION

Conventionally, the coefficient of external and internal influence is estimated by Bass (1969) ordinary least squares (OLS) regression. However, regression model has some shortcomings, such as the likely multicollinearity between variables. Besides, FDI restriction cannot be considered in OLS regression models. Hence, the numerical model that incorporates FDI limits is employed to solve Eq. (10) in our research. Under current regulations, FDI amount cannot exceed the maximum permitted amounts approved by the Taiwanese government, so the maximum permitted amounts are equivalent to upper bounds for the potential FDI size. Therefore, the maximum permitted amounts (8,330,090 and 18,367,663 thousand NT dollars for IC design and IC packing and testing industries, respectively) are specified as the potential size of FDI outflows into China in the numerical model incorporating maximum FDI limits.

In addition, the government sets up variant levels of the FDI upper bound over time. Because the potential FDI size is confined to the time-variant restrictive bounds, so we establish the models incorporating time-varying FDI upper bound. This model specifies potential FDI size as stepwise forms according to the trajectory of realistic FDI upper bounds. The parameters are numerically solved under the assumption of time-dependent potential FDI size. Although models incorporating time-varying limits are expected to be more accurate since the specification corresponds with the actual situation, the model's forecast ability should be still investigated through empirical investigation.

The computational procedure for the simulation-based optimization method is adopted (Li and Chiang 2007), as shown in Fig. 1. The process of computer simulation extracts parameters using the least square method. To solve the ODE numerically, a 4th-order Runge-Kutta algorithm (Burden and Faires 2005) is implemented in the proposed scheme. Once the computed solution is obtained, it is calibrated with realistic data to yield an accurate simulation. If the tolerance of the result is greater than the error, the optimal parameters and results are outputted. Otherwise, a least square optimization technique enables the updating of modifying parameters for the next simulation. To calculate the numerical solution of ODE, a 4th-order Runge-Kutta algorithm (Richard and Faires 2005) is implemented. For the accuracy of simulation, once the computed solution is obtained, we calibrate it with the realistic data. If the result is acceptable, the simulation will be terminated. Otherwise, a least square optimization technique will enable us to update the newer parameters *p* and *q* for the next simulation.

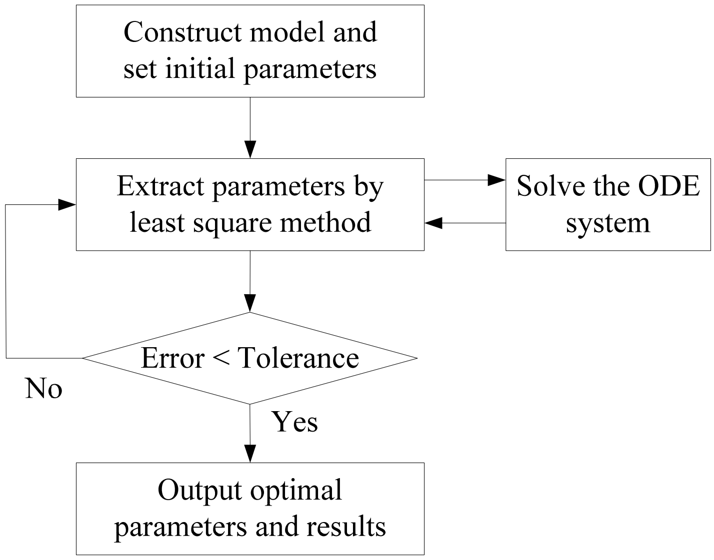

Figure 1 A Computational Procedure for the Simulation-based Optimization Methodology to Solve and Extract the Dynamic System in this Work.

To further demonstrate the performance of the model incorporating FDI limits, we also use the numerical model without FDI limits or analytical regression model to be compared with the numerical model incorporating FDI limits. For the numerical model without FDI limits, a multiple of the maximum permitted amount (16,660,180 and 36,735,326 thousand NT dollars for IC design and IC packing and testing industries, respectively) are chosen as the potential size of FDI outflows into China since such huge amount in our simulation resembles no upper bound in FDI potential size.

3.2 REGRESSION MODEL

Bass (1969) regression model $n(t) = pM + (q-p)N(t) - \frac{q}{M}[N(t)]^2$ is from equation (10). In estimating the parameters *p*, *q and M* from discrete time series data, we use the following regression: $n_{ti} = \alpha + \beta N(t_{i-1}) + \gamma [N(t_{i-1})]^2 + e_t$. In this analytical regression, n_{ti} represents the FDI amount during the interval (*t-1*, *t*). $N(t_{i-1})$ represents the cumulative FDI amount through period t_{i-1}, and e_i is the error term. α estimates *pM*, β estimates (*q-p*) and γ estimates $-q/M$, so the parameters *p* and *q* can be obtained, namely, $q=-M\gamma$ *and* $p=\alpha/M$.

3.3 CALCULATION OF CUMULATIVE FDI AMOUNTS

After the parameters *p*, *q*, and *M* are estimated, the cumulative FDIs can be obtained through the following process. Since $f(t) = p + (q-p)F(t) - q[F(t)]^2$, in order to find *F(t)*, we must solve this non-linear differential equation: $dt = dF(t)/(p + (q-p)F(t) - q[F(t)]^2)$. The solution is as Eq. (12):

$$F(t)=(q - pe^{-(t+C)(p+q)})/q(1 + e^{-(t+C)(p+q)}) \tag{12}$$

where C is the arbitrary constant. In this work, the initial FDI value is equal to zero at the beginning (*t=0*), namely, *F(0)=0*, so this integration constant may be evaluated as Eq. (13) and the cumulative FDI amount can be calculated as Eq. (14):

$$-C=(1/(p+q))Ln(q/p). \tag{13}$$

and

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}}. \tag{14}$$

For discrete-time series data, cumulative probability of FDI into China by time *ti*, $F(t_i)$ can be calculated according to Eq. (14). Hence, cumulative FDI amount by time *ti*, $N(t_i)$ can be computed by $N(t_i)= F(t_i)\times M$ and the FDI amount into China during the interval (t_{i-1}, t_i), n_{ti}, can be further obtained through $n_{ti} = N(t_i) - N(t_{i-1})$.

3.4 COMPARISON OF PREDICTION ABILITY

This article further utilizes the mean absolute prediction error (MAPE) to compare the performance among the alternative models: regression model, numerical model incorporating maximum FDI limits, numerical model incorporating time-varying FDI limits, and numerical model without FDI limits. This MAPE is calculated by $MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{|Y_t - \hat{Y}_t|}{Y_t}$, where Y_t and $\hat{Y}_t$ represent the realistic and predicted FDI at time *t*. The prediction ability is compared among the four models. To do so, the parameters of these models are estimated with the quarterly FDI amount to China up to the fourth quarter of 2006. The forecasts of quarterly FDI amount from the first quarter of 2007 to the fourth quarter of 2007 are compared with the actual realistic quarterly FDI amount.

4. APPLICATION OF THE FDI MODEL FROM TAIWAN TO CHINA

4.1 SAMPLE AND DATA

The collected realistic data visible in our study include 59 integrated circuit (IC) public firms of Taiwan: 46 IC design firms and 13 IC packaging and testing firms. None of IC foundry manufacturing firms are permitted by Taiwanese government until the second quarter in 2001. Except for Winbond Corporation, no other IC manufacturing firms are approved to engage in FDI into China before 2002. Because the IC foundry manufacturing firms lacks too much FDI data into China, the IC manufacturing industry is excluded from our sample. The sample period covers from 2000 to 2007 and the sample data are measured in New Taiwan (NT) dollars (thousands). In regards to the data sources, the data of actual 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. Taiwan government only allows IC factories to produce low-end semiconductor chips (below 8-inch wafers) in China. The FDI investment in high-end products is precluded from our sample. In other words, FDI data in our article are all confined under the regulatory restrictions.

4.2 EMPIRICAL RESULTS

4.2.1 Results of Dynamic Growth Model

Table 2 exhibits the descriptive statistics of net FDI amount to China for IC design and IC packaging and testing industries in this study. The estimated coefficients and statistical significance of the regression are listed in Table 2. The results exhibit that the coefficient γ is significantly non-zero for the IC packaging and testing industry, but not in the IC design industry. Since q is estimated based on γ ($-M\gamma=q$), the statistical difference of the coefficient γ implies that the internal influence of IC packaging and testing industries is more influential than that of IC design industry. By the estimated regression coefficients α, β, and γ, the impact parameters of imitation (q), innovation (p) and potential FDI size (M) are calculated and listed in Table 3.

Table 2 Descriptive Statistics of Variables and Results of Regression Coefficient

Panel A: Descriptive Statistics of Net FDI Amount to China

	Design	Packaging and Testing
Mean	219,445.25	573,930.66
Median	194,468.00	202,170.00
Maximum	635,028.00	2,468,413.00
Minimum	18,148.00	4,766.00
Standard Deviation	170424.89	659,249.91

(*Notes*: The unit is NT dollars (thousands))

Panel B: The results of the regression coefficient

Industry	Variable	Coefficient	*t*-Statistics
Design	α	210,112.10	2.1769*
	β	0.0124	0.1617
	γ	-1.91×10^{-9}	-0.1524
Packaging and Testing	α	25,348.72	0.1417
	β	0.2452	3.3465**
	γ	-1.35×10^{-8}	-2.7849**

**: $p \leqq 0.05$; *: $p \leqq 0.1$.

The results of the regression model, numerical model incorporating maximum FDI limits, numerical model incorporating time-varying FDI limits, and numerical model without FDI limits are shown in Table 3. The regression results show that the potential size of FDI capital flow into China is greater for IC packaging and testing enterprises than IC design corporations. Consistent with product life cycle theory (Vernon 1966), 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 packaging and testing firms to engage in large amount of FDI in China. Although recent plant expansions of Chinese IC packagers and testers are expected to hinder Taiwan's enterprises incentives to engage in FDIs to China, our findings of the realistic FDIs and estimated potential FDI size still disclose the strong FDI inclination into China for IC packaging and testing industry.

In regard to the alternative models, the coefficients of internal influence q are all estimated positive for IC design and IC packaging and testing industries. The positive effects of internal influence exist for both the two types of industries. Owing to the results of regression model, numerical model incorporating FDI limits and numerical model without FDI limits, the relationship of $p < q$ is always held for both IC design and IC packing and testing industries. This suggests that the internal influence is larger than the external one. Thus, the imitating behavior of Taiwanese IC firms dominates the dynamics of FDI flow in China. Because of the economical high-risk and uncertainty in China, most Taiwanese avoid investing in China under the premise that no previous experienced firms has ever undertaken FDIs in China. After successive firms attain to the FDI experiences from the incumbent FDI enterprises in China, these successive firms would 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 FDI members.

Table 3 The Results of the Four Models

Industry		Regression model	Numerical model incorporating constant FDI limits	Numerical model incorporating time-varying FDI limits	Numerical model without FDI limits
Design	*p*	0.0148	0.0192	0.0219	0.0117
	q	0.0272	0.0764	0.0319	0.0290
	M	14,228,009	8,330,090	Time-varying	16,660,180
Packaging and Testing	*p*	0.0014	0.0016	0.1154	0.0029
	q	0.2466	0.2402	0.2439	0.1320
	M	18,324,111	18,367,663	Time-varying	36,735,326

a.The unit of potential size of FDI capital amount (*M*) is NT dollars (thousands).
b.The potential FDI size is time-dependent for the numerical model incorporating time-varying FDI limits, because potential FDI size is assumed to be confined to the regulatory limit trend.

Particularly for all the alternative models, the coefficient of internal influence *q* is larger for IC packaging and testing industry, which suggests that the internal influence of FDI flows into China is more profound for IC packagers and testers than that of IC design houses. Since IC packaging and testing industries depend on the supplier’s supports for advanced materials, basic equipment and production resources, their suppliers will implement their channels in the region where IC packagers and testers are located. If more and more IC packagers and testers move to China, their suppliers also converge toward China. This enables the packagers and testers to easily access the available materials, basic equipment and suppliers’ resources, thus attracting more IC packagers and testers into China. On the contrary, IC design houses are less likely to gain support from their equipments or material suppliers. As a result, few IC design houses would actively respond to the FDI decisions of other IC design firms. The internal effect of IC design firms is not as great as that of IC packaging and testing firms.

The purpose of Taiwan’s IC design companies to invest in China is to establish a trading base and access business opportunities in mainland China. The IC packagers and testers are driven by their customers to move into China. The upstream international integrated device manufacturers (IDMs), the clients of Taiwanese IC manufacturing and IC packaging and testing firms, have set up business centers in China. Hence, Taiwanese IC firms actively responded to these clients to move into China and provide timely services for these IDMs. Regardless of different conditions among IC design houses, packagers and testers, both IC design houses and IC packers and testers keep pace with their competitors to implement FDIs into China to maintain their competitive advantages. Once many Taiwanese IC firms have invested in China, the other IC firms successively implement FDIs into China. The current FDI amount in China is related to the cumulative FDI flows into China for Taiwan's semiconductor industry. As expectations, the findings exhibit that the current FDI amount *n(t)* is positively related to the cumulative FDI amount *N(t)* in Eq. (10). When the cumulative FDI amount increases, the current FDI amount into China is also higher.

4.2.2 Forecast Accuracy Analysis

Two series of the predicted FDI amount are calculated by using these alternative models for the two sample industries. The actual FDI and predicted FDI amount for the two sample industries by regression model, numerical model incorporating maximum FDI limits, numerical model incorporating time-varying FDI limits and numerical model without FDI limits all exhibits an increase. The increasing presence of the FDI flow into China once again supports the industrial clustering tendency of Taiwanese IC enterprises into China. Also, the evidence refutes the claim that Taiwan government closes its country's gate to international intercourse or prohibits its enterprises from foreign investment in China.

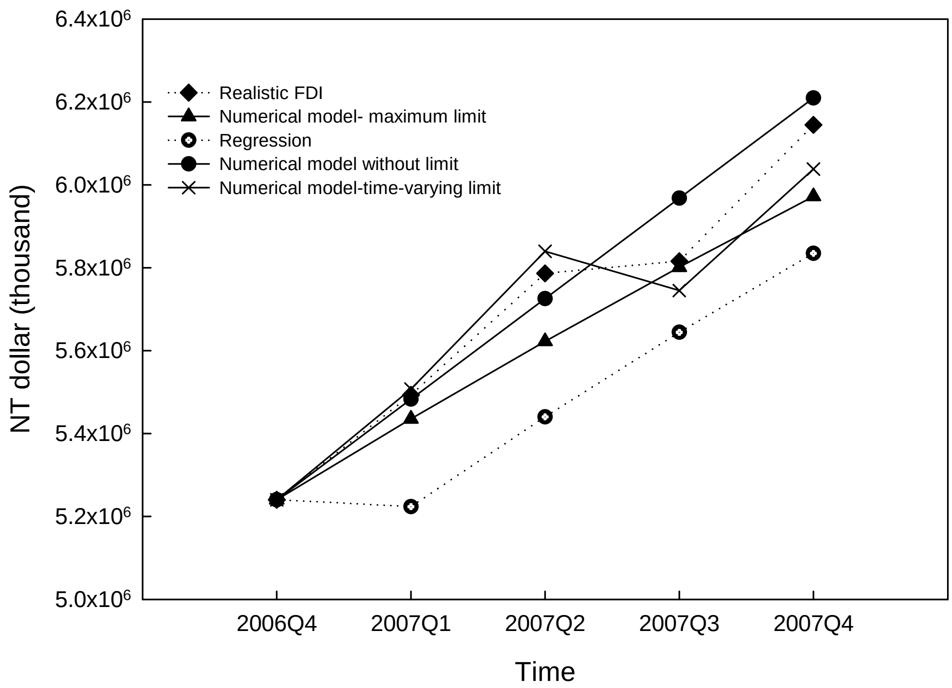

Figure 2 Actual and Simulated FDI in IC Design Industry

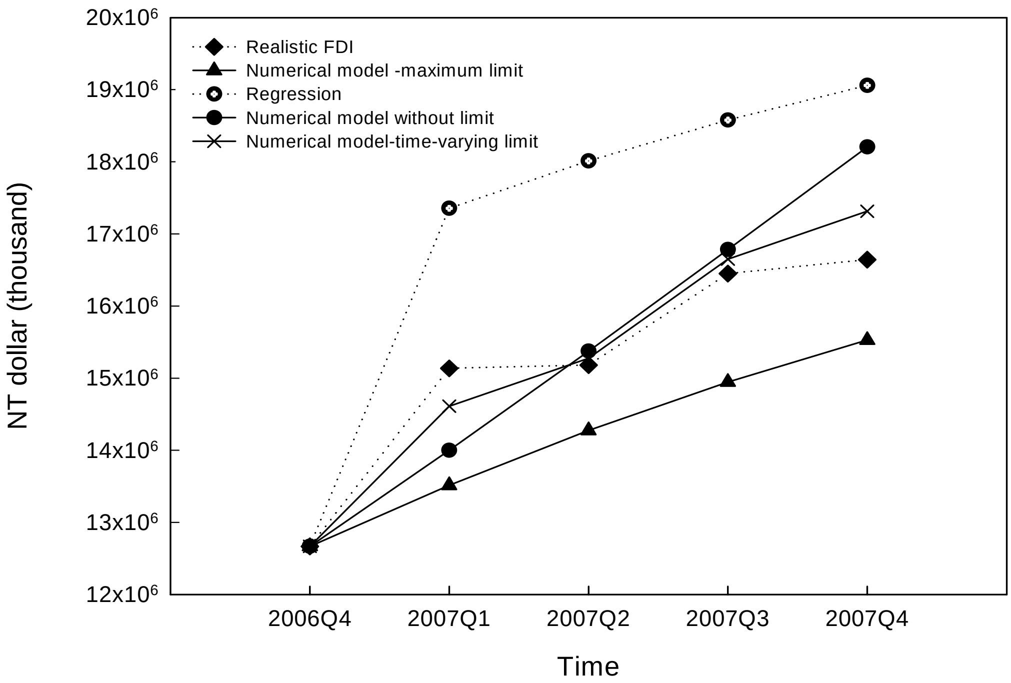

Figure 3 Actual and Simulated FDI in IC Packaging and Testing Industry

Comparison between the simulated and realistic FDIs is shown in Figs. 2-3 for IC design houses and IC packagers and testers. The computed FDIs versus the time for the calculation among the four models are plotted accordingly. It is axiomatic from these figures that the results computed by the analytical regression model shift away from the realistic data. Simulated FDIs by numerical models are closer to the actual FDIs than the simulated FDIs by analytical regression model. In particular, the numerical model incorporating time-varying FDI limits predict the most accurate FDI trajectory.

The results of forecast accuracy are shown in Table 4. From the forecasting results, displayed in Table 4, it is evident that, in both IC design and IC packaging and testing industries, the mean absolute prediction errors (MAPEs) are the lowest for the numerical model incorporating time-varying FDI limits factors. MAPEs of Bass (1969) regression model are 0.0405 and 0.1524 for IC design and IC packaging and testing industries, respectively. In contrast to the result of the regression model, MAPEs are only 0.0083 and 0.0187 for the IC design or IC packaging and testing industry, respectively, based upon the numerical models incorporating time-varying FDI limits. In addition, the MAPEs of numerical models without FDI limits are not as low as those of time-varying numerical models incorporating FDI limits. Thev reason behind this is because both the regression model and numerical model without FDI limits do not take regulatory FDI limits into account. As a result, these two models are not as accurate as the numerical model incorporating time-varying FDI limits. This implies that the dynamic growth model, which takes account of time-varying regulatory FDI limits, performs superior predictions in Taiwan's IC industry FDI into China. We can obtain a set of parameters p and q to integrate the real FDI data when the FDI restrictions are considered.

Table 4 Results of Mean Absolute Prediction Errors (MAPEs) Investigation

Industry	Regression model	Numerical model incorporating constant FDI limits	Numerical model incorporating time-varying FDI limits	Numerical model without FDI limits
Packaging and Testing	0.1524	0.0651	0.0187	0.0404
Design	0.0405	0.0139	0.0083	0.0098

Taiwan's IC industry is subject to regulatory investment limits. In other words, the government bans the high-end levels for IC design and IC packaging and testing industries to directly invest in China. Therefore, such corporations as ASE, SPIL, Lingsen listed companies successively apply for the establishment of offshore subsidiaries or strategic alliances in the third country, rather than in China. These subsidiaries or strategic alliances declare to the public that they plan to produce low-end products, for instances, transistors. Since these subsidiaries or strategic alliances are not set up in Taiwan, they may avoid the supervisions imposed by Taiwan government to build up IC factories and engage in production in China. In other words, the Taiwan IC corporations can indirectly invest in China through these offshore subsidiaries or strategic alliances in the third countries. Because the Taiwan government hardly audits the capital flows of the indirect investment, this type of investment through the third place is not as transparent as the direct investment.

On the other hand, Taiwanese firms are legitimate to apply for FDI into China. According to the statistics of Investment Commission, Ministry of Economic Affairs (MOEA), R.O.C., ASE, SPIL, Lingsen listed companies have all applied to MOEA for foreign direct investment into China, so the type of "direct investment in China" may be strictly supervised by Taiwan government. Due to the aforementioned discussions, the features of the direct and indirect investment in China are fairly diverse, so it is reliable to separately forecast these two kinds of foreign investment. In this study, we mainly focus on the analysis of "foreign direct investment" into China. Our analysis does not incorporate indirect investment by the third place. The future discussion may analyze the indirect investment in China by means of subsidiaries or strategic alliances from the third places.

5. CONCLUSIONS

Since prior researches have not effectively considered the regulatory restriction effect on foreign direct investment (FDI), this study elaborately applies numerical simulation that incorporates FDI limits to explore the FDI dynamics of Taiwan's IC industry into China. To compare forecast accuracy, estimates from the regression model and numerical model without FDI limits (two models which ignore the FDI limits) are included in the research. According to the results of these alternative models, the internal influence dominating the growth of FDI flow from Taiwan to China range from 2000 to 2007 for IC industries. This implies that the internal influence through intra-industry communications or intra-industry interactions is the key factor of FDI flow. Because of high economical risk and uncertainty in China, promotion communications from the host country (China) fails to inspire investment desire and motivation to firms from the parent country (Taiwan). Taiwanese enterprises will only undertake FDI in China once they have acquired reliable information from experienced firms (who have previously been engaged in FDIs) that confirm the safety of the Chinese investment environment. Hence, the imitation behaviour takes a more prominent position than the innovative behaviour in FDIs for Taiwan's IC industry.

Specifically, industrial differences in FDI characteristic have been empirically compared between IC design and IC packaging and testing industries. This article points out the tendency of imitation behavior for IC packaging and testing firms. IC packaging and testing firms prefer to follow and pursue FDI into China since these IC foundry firms can easily free-ride the up-stream vendors' supports set up by incumbent FDI firms. Thus, the dynamic growth model has accurately predicted the gradual increase of FDI amounts. Once more and more IC corporations build up production sites in specific locations, the other IC firms are likely to mimic and construct bases to share the available materials, basic equipment and suppliers' resources. Following from the mean absolute prediction errors (MAPEs) of the regression model, numerical model incorporating FDI limits, and numerical model with FDI limits, we conclude that the numerical model incorporating time-varying FDI limit factors perform better than those without considering FDI restrictions. The FDI restriction is critical for the capital flow behaviour of the Taiwan IC industry into China.

So far, we have simulated FDI flow based on dynamic growth model. However, other variables such as: the FDI evolutionary interrelations among Taiwan's IC design, testing and packaging industries, the interactions between the internal and external influence of FDI diffusion in Taiwan's IC industry, and plant expansions of Chinese IC firms should be considered in further researches. Besides, investors are not necessarily constrained by FDI regulatory limits. In fact, there are several ways to bypass these regulation limits. For example, some Taiwanese IC firms can invest in China in the following ways: they may invest in China through subsidiary firms; set up a separate company or joint venture to invest in China; issue comfort letters by the parent company in Taiwan (Comfort Letter) to allow subsidiaries to obtain loans from foreign banks to invest in China. In this paper, we do not consider the above mentioned situations. Perhaps further research on FDI of Taiwan's IC industry in China may incorporate these scenarios.

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