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台灣半導體廠資料包絡法 Malmquist 生產力分析

DEA Malmquist Productivity Measure:

Taiwanese Semiconductor Companies

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摘 要

我們以五個指標,應用資料包絡法 (DEA)評量十五家台灣半導體封裝測試廠從 2000 年到 2003 年之間生產力的增減變化。為能更精確的量測，我們以差額式評量之模式 (Slacks-based Measurement, SBM) 替代以放射式(Radial-based model)評量之模式。我們更以超高效模式，達成更精確量測。本研究主要在分析每跨年之間，各公司績效變化的情形，我們藉著摩科斯特(Malmquist) 的四項績效元素結構可獲取下面資訊- 技術上的變化、效率前緣正向移動與負向移動的量測、公司跨周期時的移動過程、以及綜合的生產力。我們的方法對於生產力的變化在管理意涵上有更深入的詮釋，因此能夠解析各公司相對於其他公司競爭力變化的情形。

關鍵字：資料包絡法；摩科斯特；差額式評量；超高效模式

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ABSTRACT

We use data envelopment analysis (DEA) with five indicators to measure the productivity change of 15 semiconductor packaging and testing firms in Taiwan between years 2000 to 2003. Instead of radial-based model, we use slacks-based measurement (SBM) to have more accurate measurement. Furthermore, super-SBM model is employed to measure the super efficiency. We employ Malmquist productivity measurement to analyze four events for each firm- the technical change, the frontier forward/backward shift, the productivity shift, and comprehensive productivity. Our approach excavates the deeper management implication and provides some new interpretations. Therefore, competitiveness of each firm against others would be realized.

Keywords: Data envelopment analysis; Malmquist; SBM; super efficiency

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1. Introduction

Semiconductor manufacturing plays one of the most important roles in the global economy. Tremendous capital investment is required to build and equip a production line (Andersen et al., 1993). Also, the high reinvestment of total revenue into capital expenses is required. For competitive prices and adequate return on the investment against above two issues, the strategy to shorten order lead times with a fair degree of flexibility in the product mix and a significant periodical increase in productivity is critical. In other words, managements must make a right decision in a short time after analyzing the performance. Not only that, the performance analysis can help stockholders, loaners, employees, suppliers, customers, and future employees to understand the condition they possess. Thus, one of motivations is assessing the performance accurately; another is comparing their advancement and trend from management viewpoints.

DEA is a multiple input-output efficient technique that measures the relative efficiency of decision-making units (*DMU*s) using a linear programming based model. The technique is non-parametric because it requires no assumption about the weights of the underlying production function. DEA was originally proposed by Charnes et al. (1978) and this model is commonly referred to as a CCR model. The DEA frontier *DMU*s are those with maximum output levels for given input levels or with minimum input levels for given output levels. DEA provides efficiency score θ_o^*, a *ratio efficiency* of the DMU_o. At the same time, the optimal solution reveals *slacks*, if any of excesses in inputs and shortfalls in output exists. If its full ratio efficiency, $\theta_o^*=1$, and with no slacks in any optimal solutions is called

CCR-efficient. Otherwise ($0<\theta_o^*<1$), the *DMU* has a disadvantage against the *DMU*s in its reference-set.

Färe et al. (1992, 1994a) developed the DEA-based Malmquist productivity index by CCR model. The DEA-based Malmquist productivity is a combined index that can be extended to measures the productivity change of *DMU*s over time. It has been applied in many ways, as described in Färe et al. (1994b), Löthgren and Tambour (1999a), Grifell-Tatjé and Lovell (1996), and Fulginiti and Perrin (1997) and others. The two components embedded in Malmquist productivity, measuring the changes in technology frontier and technical efficiency, are also further examined in this research. By the technology frontier shift (*FS*), the development or decline of all *DMU*s is able to measure. Technical efficiency change (*TEC*) is used to measure the change in technical efficiency. It is also a measure of how much closer to the frontier the company (DMU) is when crossing the two consecutive times. We define *TEC* and Malmquist iproductivity as R_3 and R_4 respectively in Section 4.1 for the performance measurement.

Chen and Ali (2004) applied the DEA Malmquist productivity measure to the computer industries by the CCR model to assess the four distance functions of Malmquist productivity. Moreover, they discovered more information about the two components that obscure in the Malmquist productivity index. We define them as R_1 and R_2 in Section 3 for the performance measurement in this research and account for the attributes. Their approach not only reveals patterns of productivity change and presents a new interpretation along with the managerial implication of each component, but also identifies the strategy shifts of individual *DMU*s in a particular time period. They determined whether such strategy shifts were favorable and improving. However, the ratio efficiency θ_o^* by the CCR model is not able to take account of slacks. For instance, the optimal solution $\theta_o^*=1$ might be with slacks $\neq 0$. In the DEA Malmquist productivity, the DMU_o is regarded as efficient but actually, it should be regarded as inefficient. Therefore, it is important to observe both the ratio efficiency and the slacks. Some attempts have been made to unify θ_o^* and slacks into a scalar measure.

Charnes et al. (1985) developed the additive model of DEA, which deals directly with input excess and output shortfalls. But this model has no scalar measure (ratio efficiency) per se. Thus, although this model can discriminate between efficient and inefficient *DMU*s by the existence of slacks, it has no means of gauging the depth of inefficiency, similar to θ_o^* in the CCR model.

Tone (2001) developed a slack-based measure (SBM) of efficiency in DEA, which takes account of scalar measure and slacks. Further, Tone (2002) developed a slack-based measure of super efficiency (Super-SBM) in DEA for discriminating between efficient *DMU*s. Super efficiency measures the degree of superiority that efficient DMU_o possesses against other *DMU*s.

So far, all the studies using DEA Malmquist productivity measurement are still not employing the slacks-based measurement. Using the SBM/Super-SBM model to measure Malmquist productivity is an unprecedented approach. The method could attain more accurate and complete results. Liu and Yang (2004) applied the CCR model to assess the performance of Semiconductor's packaging and testing firms in Taiwan from 2000 to 2003. Instead, we employ the SBM measurement and the Super-SBM model in this research. In addition to *TEC* (R_3) and Malmquist productivity (R_4) which existed in the traditional Malmquist productivity measurement, we also investigate the two components- R_1 and R_2 proposed by Chen and Ali (2004) to interpret a more detailed management implication.

The next section reviews how the DEA-based Malmquist productivity index works. We also present the Malmquist productivity approach.

2. DEA Malmquist productivity index

Färe et al. (1992) construct the DEA-based Malmquist productivity index as the geometric mean of the two Malmquist productivity indices of Caves et al. (1982): one measures the change in efficiency and the other measures the change in the frontier technology. The frontier technology, determined by the efficient frontier, is estimated using DEA for a set of *DMU*s.

There are *n DMU*s under comparison for their performance. Let x_{ij} and y_{rj} denote the value of the *i-th* input (i=1,…, m) and the *r-th* output (r=1,…, s) of DMU_j (j=1,…, n), respectively. The slack variables for the *i-th* input and the *r-th* output are respectively represented by s_i^- and s_r^+, which indicate the *input excess* and *output shortfall,* respectively. The variable λ_j denotes the weight of DMU_j while assessing the performance θ_o of the object DMU_o.

Instead of a radial-based model, we now use the slacks-based measuring (SBM) model and explain the reason for the substitution. The following contents show the definition of SBM.

$$\rho_o^* = \frac{1-(1/m)\sum_{i=1}^{m} s_i^- / x_{io}}{1+(1/s)\sum_{r=1}^{s} s_r^+ / y_{ro}}. \tag{1}$$

The numerator evaluates the average relative reduction rate of inputs, which is to be minimized; the denominator evaluates the average relative expansion rate of outputs, which is to be maximized. Therefore, ρ_o^* is to be minimized as the objective of SBM taking slacks into accounts directly. Constraints of the SBM model are as follows. Firstly, using the reference-set R_o is

$R_o = \{j \mid \lambda_j^* > 0\}, j=1, 2,\ldots, n,$ (2)

we can express (x_{io}, y_{ro}) by

$$x_{io} = \sum_{j \in R_o} x_{ij}\lambda_j + s_i^-, \qquad i=1, 2,\ldots, m, \tag{3}$$

$$y_{ro} = \sum_{j \in R_o} y_{rj}\lambda_j - s_r^+, \qquad r=1, 2,\ldots, s, \tag{4}$$

where the set of indices corresponding to positive λ_j^* is called the reference-set to (x_{io}, y_{ro}). From the equations (1) to (4), the SBM prototype is established. It is easy to see ρ_o^* does take slacks into account.

Because the CCR score is a radical measure, it takes no account of slacks, the particular DMU_o may have an efficiency score $\theta_o^* = 1$ although its total slacks, $\sum_{i=1}^{m} s_i^{-*} \geq 0$ and $\sum_{r=1}^{s} s_r^{-*} \geq 0$ (notations with '*' in superscript indicates it is the optimal solution). But an inefficiency score $\rho_o^* \leq 1$ in SBM when the factors is taken into account. In other words, using the CCR model overestimates the performance of each *DMU* while the SBM model does revise this weak point to attain a more accurate result. There are two theorems are proved: (I) The optimal SBM ρ_o^* is not greater than the optimal CCR θ_o^*, and (II) A *DMU* (x_{io}, y_{ro}) is CCR-efficient, if only if DMU_o is SBM-efficient. Because index ρ_o^* is defined as follows:

In this case, we can reduce the misleading result with the SBM measure. On the other hand, the SBM score ρ_o^* =1 guarantees the particular *DMU* has the more precise efficiency score.

Let $D^a(x_o^b, y_o^b)$ denote the relative efficiency of a particular DMU_o in period *b* against the performance of those *DMU*s in period *a*. There are four possible pairs (*a*, *b*) for analysis of the Malmquist productivities, (*t*, *t*), (*t*+1, *t*), (*t*, *t*+1) and (*t*+1, *t*+1). Hence, there are four distance functions to be measured, $D^t(x_o^t, y_o^t)$, $D^{t+1}(x_o^t, y_o^t)$, $D^t(x_o^{t+1}, y_o^{t+1})$, and $D^{t+1}(x_o^{t+1}, y_o^{t+1})$, and they are denoted as the efficiency score ρ_{1o}^*, ρ_{2o}^*, ρ_{3o}^* and ρ_{4o}^*, respectively. Let x_{io}^t and y_{ro}^t denote DMU_o's *i-th* input and *r-th* output respectively in time period *t*. Employing the SBM model introduced in Tone (2001), the following model (M1) is used to measure the relative efficiency of DMU_o for (*a*, *b*) = (*t*, *t*).

$$\rho_{1o}^* = D^t(x_o^t, y_o^t) = Min \quad k - \frac{1}{m}\sum_{i=1}^{m}(S_i^- / x_{io}^t),$$

$$Subject\ to \quad k + \frac{1}{s}\sum_{r=1}^{s}(S_r^+ / y_{ro}^t) = 1,$$

$$kx_{io}^t = \sum_{j=1}^{n} x_{ij}^t k\lambda_j + S_i^-, \qquad i = 1, 2, \ldots, m, \qquad \text{(M1)}$$

$$ky_{ro}^t = \sum_{j=1}^{n} y_{rj}^t k\lambda_j - S_r^+, \qquad r = 1, 2, \ldots, s,$$

$$\lambda_j \geq 0, j = 1, 2, \ldots, n;\ k \geq 0;\ S_i^- \geq 0, i = 1, 2, \ldots, m;\ S_r^+ \geq 0, r = 1, 2, \ldots, s.$$

where *k* is a scalar for transforming a ratio SBM model to a linear SBM model. The optimal solutions λ_j^*, k^*, S_i^{-*}, S_r^{+*}, ρ_{1o}^* are obtained. Further, the excess and the shortfall can be obtained indirectly: $s_i^{-*} = S_i^{-*}/k^*$, $s_r^{+*} = S_r^{+*}/k^*$. For instance, ρ_{1o}^* is the relative efficiency score. The values $\hat{x}_{io}^t = x_{io}^t - s_i^{-*}$ (i=1~m), and $\hat{y}_{ro}^t = y_{ro}^t + s_r^{+*}$ (r=1~s) are its projection points on the efficient frontier constructed by the *DMU*s performed in period t.

If ρ_{1o}^*<1, then we stop computing and use this as distance function; If ρ_{1o}^*=1, we continue to employ the Super-SBM model (Tone, 2002) to measure the super efficiency π_{1o}^*, the distance of DMU_o against to the frontier constructed by the other *DMU*s. Then the optimal value of $D^t(x_o^t, y_o^t)$ is π_{1o}^*, which is substituted for ρ_{1o}^*. The following model (M1.1) is used to compute the distance π_{1o}^*. Its projection point on the frontier is obtained ($\overline{X}_o^t, \overline{Y}_o^t$) where $\overline{X}_o^t$=($\overline{x}_{io}^t$, i=1~m) and $\overline{Y}_o^t$=($\overline{y}_{ro}^t$, r=1~s); $\overline{x}_{io}^t = \tilde{x}_{io}^{t*}/\tau^*$, $\overline{y}_{ro}^t = \tilde{y}_{ro}^{t*}/\tau^*$.

$$\pi_{1o}^* = Min\ \frac{1}{m}\sum_{i=1}^{m}\frac{\tilde{x}_{io}^t}{x_{io}^t},$$

$$Subject\ to \quad 1 = \frac{1}{s}\sum_{r=1}^{s}\frac{\tilde{y}_{ro}^t}{y_{ro}^t},$$

$$\tilde{x}_{io}^t \geq \sum_{j=1,\neq o}^{n} x_{ij}^t \Lambda_j^t, \qquad i=1, 2, \ldots, m, \qquad \text{(M1.1)}$$

$$\tilde{y}_{ro}^t \leq \sum_{j=1,\neq o}^{n} y_{rj}^t \Lambda_j^t, \qquad r=1, 2, \ldots, s,$$

$$\tilde{x}_{io}^t \geq \tau x_{io}^t, \qquad i=1, 2,\ldots, m,$$

$$0 \leq \tilde{y}_{ro}^t \leq \tau y_{ro}^t, \qquad r=1, 2,\ldots, s,$$

$$\Lambda_j^t \geq 0,\ j=1, 2, \ldots, n;\ \ \tau>0.$$

Through (M1) and (M1.1), the first single period measure for $D^t(x_o^t, y_o^t)$ is obtained. By the similar mechanism, we can obtain the other single period measure for $D^{t+1}(x_o^{t+1}, y_o^{t+1})$ where (a, b)=(t+1, t+1). The models (M4) and (M4.1) are shown in Appendix.

The first mixed period measures where (a, b)=(t+1, t), defined as ρ_{2o}^* for each DMU_o, is computed as the optimal value to the following SBM model (M2). In particular, the object DMU_o is also included in the production possibility set.

$$\rho_{2o}^* = D^{t+1}(x_o^t, y_o^t) = Min\ k - \frac{1}{m}\sum_{i=1}^{m}\left(S_i^- \big/ x_{io}^t\right),$$

$$Subject\ to \quad k + \frac{1}{s}\sum_{r=1}^{s}\left(S_r^+ \big/ y_{ro}^t\right) = 1,$$

$$kx_{io}^t = \sum_{j=1}^{n} x_{ij}^{t+1} k\lambda_j + x_{io}^t k\lambda_{n+1} + S_i^-,\ i=1, 2, \ldots, m, \qquad \text{(M2)}$$

$$ky_{ro}^t = \sum_{j=1}^{n} y_{rj}^{t+1} k\lambda_j + y_{ro}^t k\lambda_{n+1} - S_r^+,\qquad r=1, 2, \ldots, s,$$

$$\lambda_j \geq 0, j=1, 2,\ldots, (n+1);\ k\geq 0;\ S_i^- \geq 0,\ i = 1, 2,\ldots, m;\ S_r^+ \geq 0,\ r = 1, 2,\ldots, s.$$

If ρ_{2o}^*=1, we continue to employ the following Super-SBM model (M2.1) to obtain measure the super-efficiency score π_{2o}^*, substituted as $D^{t+1}(x_o^t, y_o^t)$.

$$\pi_{2o}^* = Min\ \frac{1}{m}\sum_{i=1}^{m}\frac{\tilde{x}_{io}^t}{x_{io}^t},$$

$$Subject\ to \quad 1 = \frac{1}{s}\sum_{r=1}^{s}\frac{\tilde{y}_{ro}^t}{y_{ro}^t},$$

$$\tilde{x}_{io}^{t} \geq \sum_{j=1}^{n} x_{ij}^{t+1} \Lambda_j^{t+1}, \qquad i = 1, 2, \ldots, m, \tag{M2.1}$$

$$\tilde{y}_{ro}^{t} \leq \sum_{j=1}^{n} y_{rj}^{t+1} \Lambda_j^{t+1}, \qquad r = 1, 2, \ldots, s,$$

$$\tilde{x}_{io}^{t} \geq \tau\, x_{io}^{t}, \qquad i=1, 2, \ldots, m,$$

$$0 \leq \tilde{y}_{ro}^{t} \leq \tau\, y_{ro}^{t}, \qquad r=1, 2, \ldots, s,$$

$$\Lambda_j^{t+1} \geq 0,\ j=1, 2, \ldots, n;\ \ \tau > 0.$$

For the second mixed period measures ρ_{3o}^{*} and π_{3o}^{*} where (a, b) = (t, t+1), the models (M3) and (M3.1) are shown in Appendix.

Therefore, each of four distance functions fall into one of the three ranges: >1, =1, or <1. The Malmquist productivity index (Färe et al, 1992) measures the productivity change of a particular DMU_o in period t and (t+1):

$$M_o^{t+1} = \left[\frac{D^t(x_o^{t+1}, y_o^{t+1})}{D^t(x_o^t, y_o^t)} \frac{D^{t+1}(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^t, y_o^t)} \right]^{1/2} \tag{5}$$

When $M_o^{t+1} > 1$, this signifies a productivity gain; when $M_o^{t+1} < 1$, this signifies a productivity loss; and when $M_o^{t+1} = 1$, there is no change in productivity.

The above measure is actually the geometric mean of two Malmquist productivity indices: technical efficiency change (TEC_o) and frontier shift (FS_o) (Caves et al., 1982, and Färe et al. 1992).

$$M_o^{t+1} = \left[\frac{D^t(x_o^{t+1}, y_o^{t+1})}{D^t(x_o^t, y_o^t)} \frac{D^{t+1}(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^t, y_o^t)} \right]^{1/2} = TEC_o \times FS_o. \tag{6}$$

$$TEC_o = \frac{D^{t+1}(x_o^{t+1}, y_o^{t+1})}{D^t(x_o^t, y_o^t)} = R_3. \tag{7}$$

$$FS_o = \left[\frac{D^t(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^{t+1}, y_o^{t+1})} \frac{D^t(x_o^t, y_o^t)}{D^{t+1}(x_o^t, y_o^t)} \right]^{1/2} = (R_1 \times R_2)^{1/2} \tag{8}$$

TEC_o is used to measure the change in technical efficiency; on the other hand, it is also a measure of how much closer to the boundary the company is in period (t+1) compared with period t. If TEC_o is 1.0, the particular DMU_o (maybe a company) has the same distance in periods (t+1) and t from the respective efficient boundaries. If TEC_o is over 1.0, the company has moved closer to the period (t+1) boundary than it was to the period t boundary; the converse is the case if the TEC_o is under 1.0. As for FS_o, it is used to measure the technology frontier shift between time periods t and (t+1). Färe et al. (1992, 1994a) point out that a value of FS_o less than 1.0 indicates negative shift of frontier or technical regress; FS_o greater than 1.0 indicates positive shift of frontier or technical progress; FS_o equal to 1.0 indicates no shift in technology frontier.

3. Insights from the Malmquist productivity approach

Chen and Ali (2004) further analyzed the properties of two ratios of FS_o, $\frac{D^t(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^{t+1}, y_o^{t+1})}$ and $\frac{D^t(x_o^t, y_o^t)}{D^{t+1}(x_o^t, y_o^t)}$. The former, R_1, is the relative locations of DMU_o in time (t+1) to the t-frontier and (t+1)-frontier, indicating the location of DMU_o whether the current performance of all *DMU*s is better then before; the latter, R_2, is the relative locations of DMU_o in time t to the t-frontier and (t+1)-frontier, indicating the location of DMU_o whether the future performance of all *DMU*s will be better than now.

If R_1>1, it indicates DMU_o is right in the current period that entire performance is better than the last period; If R_1<1, it indicates DMU_o is right in the current period that entire performance is worse than the last period; If R_1=1, the performances over two periods even.

On the contrary, If R_2>1, it indicates DMU_o is right in the current period that entire performance will be better than now; If R_2<1, it indicates DMU_o is right in the current period that entire performance will be worse than now; If R_2=1, the performances over two periods even.

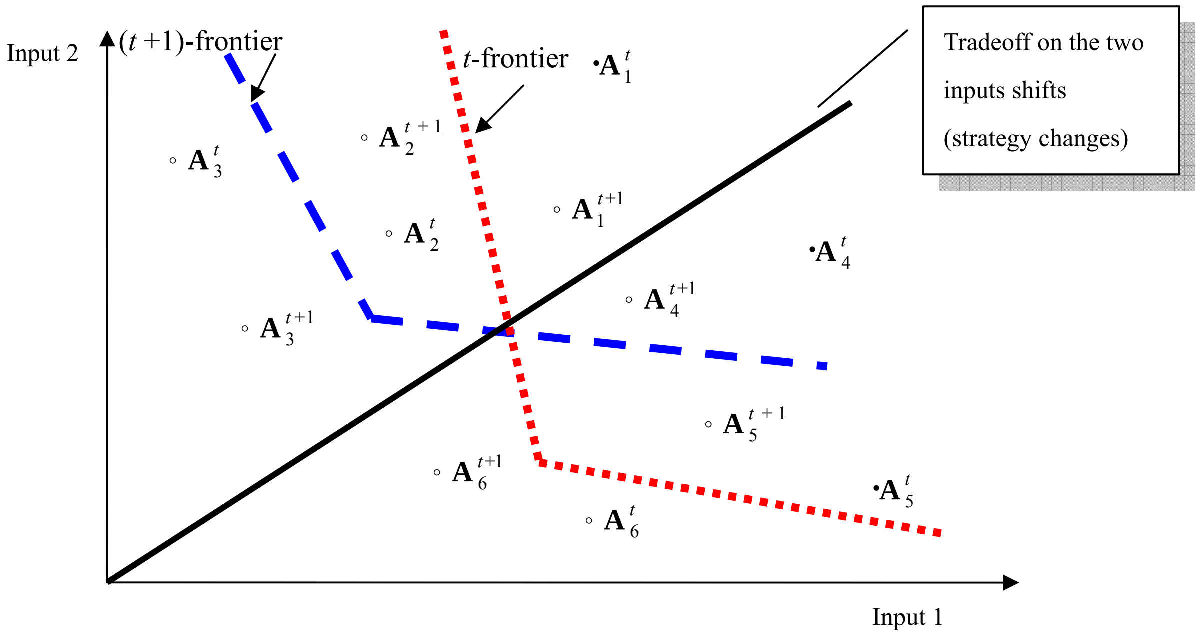

Figure 1 Frontier shift

As depicted in Figure 1, a company's performance in period t could be the six possible locations, $A_1^t \sim A_6^t$. The oblique line that connects the origin and the intersection of the two frontiers is the tradeoff on the strategy changes. A_1^t, A_2^t, and A_3^t locate on the upper part and inside the t-frontier, between the two frontiers, and outside the (t+1)-frontier respectively. The distances of A_2^t and A_3^t to the t- and (t+1)-frontiers respectively are the measurement of super-efficiencies. Similarly, A_4^t, A_5^t, and A_6^t locate on the lower part and inside the (t+1)-frontier, between the two frontiers, and outside the t-frontier respectively. The distances of A_6^t and A_5^t to the t- and (t+1)-frontiers respectively are the measurement of super-efficiencies. It is noticeable that the locations of the six points $A_1^{t+1} \sim A_6^{t+1}$ have similar occasions.

For convenience of illustration, we temporarily employ a radial model such as CCR to express the efficiency measurement of each point by the ratio of distances; for instance, by drawing a line that connects the origin and point A_1^{t+1}. The line intersects with the t-frontier and (t+1)-frontier at points α_1 and β_1, respectively. The ratio of $D^t(x_o^{t+1}, y_o^{t+1})$ to $D^{t+1}(x_o^{t+1}, y_o^{t+1})$ could be expressed as $\frac{\overline{O\alpha_1}}{\overline{OA_1^{t+1}}}$ and $\frac{\overline{O\beta_1}}{\overline{OA_1^{t+1}}}$, respectively. Thus, $\frac{D^t(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^{t+1}, y_o^{t+1})} = \frac{\overline{O\alpha_1}}{\overline{O\beta_1}}$. Similarly, drawing a line connects the origin and point A_1^t. The line intersects with the t-frontier and (t+1)-frontier at points γ_1 and δ_1, respectively. Tables 1 and 2 depict the models employed to measure the two distances. The signs of R_1 and R_2 in the last columns are visible from Figure 1.

In Figure 1, a downward frontier shift (towards the origin) from period t to (t+1) represents a positive shift. The converse situation (away from the origin) represents a negative shift. For a company, from period t to (t+1), the four possible frontier shifts are as follows in (a)~(d). The 36 possible movements are depicted in Table 3.

Table 1 The computation of ratio R_1

t+1	$D^t(x_o^{t+1}, y_o^{t+1})$	$D^{t+1}(x_o^{t+1}, y_o^{t+1})$	$R_1 = \frac{D^t(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^{t+1}, y_o^{t+1})}$	R_1
A_1^{t+1}	Use (M3) ($\rho_{3o}^* < 1$)	Use (M4) ($\rho_{4o}^* < 1$)	$\frac{\overline{O\alpha_1}/\overline{OA_1^{t+1}}}{\overline{O\beta_1}/\overline{OA_1^{t+1}}} = \frac{\overline{O\alpha_1}}{\overline{O\beta_1}}$	>1
A_2^{t+1}	Use (M3.1) ($\pi_{3o}^* > 1$)	Use (M4) ($\rho_{4o}^* < 1$)	$\frac{\overline{O\alpha_2}/\overline{OA_2^{t+1}}}{\overline{O\beta_2}/\overline{OA_2^{t+1}}} = \frac{\overline{O\alpha_2}}{\overline{O\beta_2}}$	>1
A_3^{t+1}	Use (M3.1) ($\pi_{3o}^* > 1$)	Use (M4.1) ($\pi_{4o}^* > 1$)	$\frac{\overline{O\alpha_3}/\overline{OA_3^{t+1}}}{\overline{O\beta_3}/\overline{OA_3^{t+1}}} = \frac{\overline{O\alpha_3}}{\overline{O\beta_3}}$	>1

A_4^{t+1}	Use (M3) (ρ^*_{3o}<1)	Use (M4) (ρ^*_{4o}<1)	$\frac{\overline{O\alpha_4}/\overline{OA_4^{t+1}}}{\overline{O\beta_4}/\overline{OA_4^{t+1}}}=\frac{\overline{O\alpha_4}}{\overline{O\beta_4}}$	<1
A_5^{t+1}	Use (M3) (ρ^*_{3o}<1)	Use (M4.1) (π^*_{4o}>1)	$\frac{\overline{O\alpha_5}/\overline{OA_5^{t+1}}}{\overline{O\beta_5}/\overline{OA_5^{t+1}}}=\frac{\overline{O\alpha_5}}{\overline{O\beta_5}}$	<1
A_6^{t+1}	Use (M3.1) (π^*_{3o}>1)	Use (M4.1) (π^*_{4o}>1)	$\frac{\overline{O\alpha_6}/\overline{OA_6^{t+1}}}{\overline{O\beta_6}/\overline{OA_6^{t+1}}}=\frac{\overline{O\alpha_6}}{\overline{O\beta_6}}$	<1

Table 2 The computation of ratio R_2

t	$D^t(x_o^t, y_o^t)$	$D^{t+1}(x_o^t, y_o^t)$	$R_2=\frac{D^t(x_o^t, y_o^t)}{D^{t+1}(x_o^t, y_o^t)}$	R_2
A_1^t	Use (M1) (ρ^*_{1o}<1)	Use (M2) (ρ^*_{2o}<1)	$\frac{\overline{O\gamma_1}/\overline{OA_1^t}}{\overline{O\delta_1}/\overline{OA_1^t}}=\frac{\overline{O\gamma_1}}{\overline{O\delta_1}}$	>1
A_2^t	Use (M1.1) (π^*_{1o}>1)	Use (M2) (ρ^*_{2o}<1)	$\frac{\overline{O\gamma_2}/\overline{OA_2^t}}{\overline{O\delta_2}/\overline{OA_2^t}}=\frac{\overline{O\gamma_2}}{\overline{O\delta_2}}$	>1
A_3^t	Use (M1.1) (π^*_{1o}>1)	Use (M2.1) (π^*_{2o}>1)	$\frac{\overline{O\gamma_3}/\overline{OA_3^t}}{\overline{O\delta_3}/\overline{OA_3^t}}=\frac{\overline{O\gamma_3}}{\overline{O\delta_3}}$	>1
A_4^t	Use (M1) (ρ^*_{1o}<1)	Use (M2) (ρ^*_{2o}<1)	$\frac{\overline{O\gamma_4}/\overline{OA_4^t}}{\overline{O\delta_4}/\overline{OA_4^t}}=\frac{\overline{O\gamma_4}}{\overline{O\delta_4}}$	<1
A_5^t	Use (M1) (ρ^*_{1o}<1)	Use (M2.1) (π^*_{2o}>1)	$\frac{\overline{O\gamma_5}/\overline{OA_5^t}}{\overline{O\delta_5}/\overline{OA_5^t}}=\frac{\overline{O\gamma_5}}{\overline{O\delta_5}}$	<1
A_6^t	Use (M1.1) (π^*_{1o}>1)	Use (M2.1) (π^*_{2o}>1)	$\frac{\overline{O\gamma_6}/\overline{OA_6^t}}{\overline{O\delta_6}/\overline{OA_6^t}}=\frac{\overline{O\gamma_6}}{\overline{O\delta_6}}$	<1

Table 3 The four possible frontier shifts for a company between two periods

<table>
<tr><td></td><td></td><td colspan="6">To period (t+1)</td></tr>
<tr><td></td><td></td><td>$\mathbf{A}_1^{t+1}$</td><td>$\mathbf{A}_2^{t+1}$</td><td>$\mathbf{A}_3^{t+1}$</td><td>$\mathbf{A}_4^{t+1}$</td><td>$\mathbf{A}_5^{t+1}$</td><td>$\mathbf{A}_6^{t+1}$</td></tr>
<tr><td rowspan="5">From period t</td><td>$\mathbf{A}_1^t$</td><td colspan="3" rowspan="3">(a) R_2>1 and R_1>1</td><td colspan="3" rowspan="3">(d) R_2>1 and R_1<1</td></tr>
<tr><td>$\mathbf{A}_2^t$</td></tr>
<tr><td>$\mathbf{A}_3^t$</td></tr>
<tr><td>$\mathbf{A}_4^t$</td><td colspan="3" rowspan="2">(c) R_2<1 and R_1>1</td><td colspan="3" rowspan="2">(b) R_2<1 and R_1<1</td></tr>
<tr><td>$\mathbf{A}_5^t$</td></tr>
</table>

	$\mathbf{A}_6^t$		

(a) If R_2>1 and R_1>1,

then the FS_o must be larger then 1.0, indicating the DMU_o has a positive shift and the technology of DMU_o progresses. As shown in Figure 1, the points of period *t*, A_1^t, A_2^t, and A_3^t in the *upper* part could be one of the points at period (*t*+1) in the *upper* part, A_1^{t+1}, A_2^{t+1}, and A_3^{t+1}.

(b) If R_2<1 and R_1<1,

then the FS_o must be less then 1.0, indicating the DMU_o has a negative shift and the technology of DMU_o declines. As shown in Figure 1, the points of period *t*, A_4^t, A_5^t, and A_6^t in the *lower* part could be one of the points at period (*t*+1) in the *lower* part, A_4^{t+1}, A_5^{t+1}, and A_6^{t+1}.

(c) If R_2<1 and R_1>1,

then FS_o may be larger or less then 1.0. But, certainly we can conclude DMU_o moves from a negative shift facet towards a positive shift facet. Also, there is a change in the tradeoff between the two inputs. Furthermore, FS_o <1 indicates that the change resulting from the positive shift facet is less than that of the negative shift facet; and, on average, the technology of DMU_o declines. In contrast, FS_o >1 indicates that the change resulting from the positive shift facet is lager than that of the negative shift facet; and, on average, the technology of DMU_o progresses. FS_o =1 indicates that, on average, the technology of DMU_o remains the same. As shown in Figure 1, the points of period *t*, A_4^t, A_5^t, and A_6^t in the *lower* part could be one of the points at period (*t*+1) in the *upper* part, A_1^{t+1}, A_2^{t+1}, and A_3^{t+1}.

(d) If R_2>1 and R_1<1,

then FS_o may be greater or less then 1.0. But, we can certainly conclude DMU_o moves from a positive shift facet towards a negative shift facet. Also, there is a change in the tradeoff between the two inputs. Furthermore, FS_o <1 indicates that the change resulting from the positive shift facet is less than that of the negative shift facet; and, on average, the technology of DMU_o declines. In contrast, FS_o >1 indicates that the change resulting from the positive shift facet is lager than that of the negative shift facet; and, on average, the technology of DMU_o progresses. FS_o =1 indicates that on average the technology of DMU_o remains the same. As shown in Figure 1, the points of period *t*, A_1^t, A_2^t, and A_3^t in the *upper* part could be one of the points at period (*t*+1) in the *lower* part, A_4^{t+1}, A_5^{t+1}, and A_6^{t+1}.

3.1 Definition of TEC_o

Note that $M_o^{t+1} = TEC_o \times FS_o$ and $TEC_o = D^{t+1}(x_o^{t+1}, y_o^{t+1}) / D^t(x_o^t, y_o^t)$ if (i) TEC_o >1, indicating $D^{t+1}(x_o^{t+1}, y_o^{t+1}) > D^t(x_o^t, y_o^t)$. This implies that DMU_o in time (*t*+1) is closer to the frontier in time *t,* (ii) TEC_o <1 implies DMU_o in time (*t*+1) is further away from the frontier in (*t*+1) than DMU_o in time *t* to the frontier in *t,* and (iii) TEC_o=1 implies DMU_o in time (*t*+1) is as close to the (*t*+1)-frontier as DMU_o in time *t* to the *t*-frontier.

4. An application

We employ the proposed approach to analyze the performance changes in semiconductor packaging and testing firms in Taiwan between the years 2000 and 2003. Among them, 15 companies chosen by Liu and Yang (2004) are further analyzed in this study. The calculations are based upon one input, Liability ratio, and four outputs: (i) Growth rate (%), (ii) Net profit after tax ($100 million NT dollars), (iii) Profitability ratio (%), and (iv) Output value by employee ($million/people).

4.1 Data collection and index description

In recent years, many semiconductor packaging and testing firms have been founded and their sales value has increased rapidly. This study uses the data published in the popular business magazine *Common Wealth* (2004) to analyze the relative performance of these firms between 2000 and 2003. The profile of the firms over these four years is listed in Table 4 and Table 5 that report the total profile of all firms in each year and the inputs/outputs of the 15 firms respectively.

Table 4 Profile of the firms, 2000-2003

	2000	**2001**	**2002**	**2003**
Revenue ($100 million US dollars)	33.19	25.38	31.52	38.21
Total assets ($100 million US dollars)	76.13	74.12	74.20	82.00
Capital ($100 million US dollars)	27.17	32.23	32.55	34.62

Liability ($100 million US dollars)	14.08	13.55	14.33	15.39
Number of employees	34,106	31,055	34,149	42,228

The following table shows five indices in *Common Wealth*: (i) Y_1 = Growth Rate (%), (ii) Y_2 = Net profit after tax ($100 million NT dollars), (iii) Y_3 = Profitability ratio (%), (iv) Y_4 = Output value by employee ($million/people), and (v) X_1 = Liability ratio (%). These indices have been commonly used in most of financial statements for analyzing a performance of companies or enterprises. The choice secures the reliability for the current approach in this thesis.

Table 5 Basic Data

DMU	Firm	Index				
		Y_1	Y_2	Y_3	Y_4	X_1
Year 2000						
1	ASE	145.86	98.37	122.87	3.50	38.26
2	SIPIN	158.16	72.21	117.09	3.56	32.84
3	OSE	146.85	41.04	100.73	2.19	31.12
4	ChipMos	128.82	55.39	118.71	4.11	33.80
5	KYEC	239.66	51.78	128.17	1.41	43.37
6	ASE Chung Li	284.76	55.90	121.02	3.47	50.90
7	Sharp in Taiwan	157.53	58.19	135.43	3.31	28.55
8	Greatek	154.48	45.25	114.15	2.68	44.83
9	Lingsen	153.12	43.38	110.27	2.07	26.09
10	PowerTech	344.42	42.50	118.85	1.46	56.07
11	UTC	136.54	49.02	125.65	4.49	23.01
12	KingPak	200.28	38.75	98.05	22.27	53.41
13	Hi-Sincerity	100.75	40.25	101.68	12.37	38.89
14	Formosa	143.13	41.77	110.24	2.37	58.83
15	Sigurd	135.29	41.50	114.49	1.98	32.05
Year 2001						
1	ASE	80.35	18.57	89.55	3.40	41.46
2	SIPIN	87.71	28.17	92.84	2.50	38.11
3	OSE	75.04	8.10	70.14	1.98	56.19
4	ChipMos	65.79	24.91	72.58	3.24	31.91
5	KYEC	92.71	32.08	79.57	1.44	53.48

6	ASE Chung Li	64.80	40.57	101.16	2.66	38.12
7	Sharp in Taiwan	78.55	37.60	94.05	2.75	25.01
8	Greatek	89.43	42.48	107.48	2.74	41.80
9	Lingsen	71.17	41.25	105.34	1.87	20.73
10	PowerTech	234.47	41.73	105.56	3.57	43.30
11	UTC	38.25	31.10	33.83	2.43	24.64
12	KingPak	33.53	39.17	96.14	7.68	48.35
13	Hi-Sincerity	70.15	40.21	102.02	11.32	37.24
14	Formosa	59.51	41.22	111.86	1.76	58.27
15	Sigurd	82.70	40.08	100.93	1.91	26.29
Year 2002						
1	ASE	125.00	41.29	100.50	4.20	42.50
2	SIPIN	134.90	44.25	101.91	2.79	43.28
3	OSE	119.56	7.00	74.16	2.65	64.18
4	ChipMos	118.57	27.92	81.49	3.21	44.48
5	KYEC	137.94	36.97	94.33	1.76	49.08
6	ASE Chung Li	105.22	43.66	107.09	2.29	30.66
7	Sharp in Taiwan	118.37	37.99	95.79	2.74	32.12
8	Greatek	134.67	46.34	114.19	3.36	36.48
9	Lingsen	125.40	36.33	87.51	2.13	25.67
10	PowerTech	90.74	41.87	106.63	2.80	34.86
11	UTC	159.26	36.73	84.73	3.17	22.31
12	KingPak	98.79	38.87	94.68	4.38	54.26
13	Hi-Sincerity	96.83	39.64	96.43	11.59	39.12
14	Formosa	162.59	40.92	105.50	2.51	55.16
15	Sigurd	143.22	42.38	120.12	2.31	43.77
Year 2003						
1	ASE	122.85	67.43	108.71	3.11	41.08
2	SIPIN	122.80	68.39	110.37	2.99	45.06
3	OSE	105.91	5.64	74.60	2.72	66.88
4	ChipMos	129.77	48.61	110.17	3.36	39.43
5	KYEC	126.91	47.73	111.39	2.38	33.89
6	ASE Chung Li	116.65	41.83	103.04	2.08	34.23
7	Sharp in Taiwan	140.26	51.91	117.79	2.68	34.58
8	Greatek	116.10	49.27	117.88	3.42	35.63
9	Lingsen	133.22	43.69	109.43	2.43	30.28
10	PowerTech	155.44	50.40	123.72	3.21	45.67
11	UTC	107.53	39.92	99.63	2.93	19.95
12	KingPak	59.82	40.94	107.40	2.87	44.82
13	Hi-Sincerity	101.98	39.35	93.68	11.05	40.29
14	Formosa	122.77	41.91	109.30	2.90	54.62
15	Sigurd	149.37	44.18	123.66	2.47	34.16

The measured efficiencies are depicted in the following tables.

Table 6 DEA technical efficiency from 2000 to 2003

Firms	$D^t(x_o^t, y_o^t)$			
	2000	**2001**	**2002**	**2003**
ASE	1.038	0.414	0.558	0.584
SIPIN	0.762	0.504	0.518	0.530
OSE	0.525	0.174	0.156	0.114
ChipMos	0.665	0.549	0.428	0.591
KYEC	0.349	0.250	0.342	0.618
ASE Chung Li	0.490	0.533	0.642	0.548
Sharp in Taiwan	0.807	0.864	0.638	0.664
Greatek	0.423	0.532	0.668	0.651
Lingsen	0.659	1.163	0.731	0.687
PowerTech	1.009	1.101	0.562	0.546
UTC	1.185	0.479	1.246	1.345
KingPak	1.093	0.418	0.394	0.377
Hi-Sincerity	0.734	1.161	1.150	1.131
Formosa	0.288	0.269	0.401	0.390
Sigurd	0.485	0.756	0.485	0.646
Industry average	**0.701**	**0.611**	**0.595**	**0.628**

Table 7 Technical efficiency change

Firms	***TEC***		
	2000 vs. 2001	**2001 vs. 2002**	**2002 vs. 2003**
ASE	0.399	1.349	1.046
SIPIN	0.662	1.028	1.022
OSE	0.331	0.897	0.728
ChipMos	0.825	0.781	1.380
KYEC	0.715	1.370	1.807
ASE Chung Li	1.088	1.206	0.853
Sharp in Taiwan	1.071	0.739	1.041
Greatek	1.256	1.257	0.975
Lingsen	1.764	0.629	0.939
PowerTech	1.091	0.510	0.972
UTC	0.404	2.601	1.080
KingPak	0.383	0.942	0.957
Hi-Sincerity	1.581	0.990	0.984
Formosa	0.934	1.489	0.972
Sigurd	1.557	0.642	1.331
Industry average	**0.937**	**1.095**	**1.073**

Tables 6 and 7 report the DEA technical efficiency and the associated technical efficiency changes from 2000 to 2003. From Table 6, *Hi-Sincerity* is the only one improving its performance year after year. Figure 2 shows its technical efficiency in 2000 to be less than 1.0 but larger than 1.0 afterwards. However, the technical change for *Hi-Sincerity* shown in Table 7 is larger than 1.0 only between 2000 and 2001, but less than 1.0 in the remaining years, indicating an exact definition of technical efficiency progress still needs to be investigated; all technical changes larger than or equal to 1.0 would be perfect, generally. Note that, in Table 7, only *KingPak* and *OSE* do not show technical efficiency progress from 2000 to 2003; on the other hand, we can conclude that other firms show improvement and decline in technical efficiency change. For the industry average, technical efficiency declines 6.3% from 2000 to 2001, improves 9.5% from 2001 to 2002, and improves 7.3% from 2002 to 2003.

Table 8 Frontier shift

Firms	***FS***		
	2000 vs. 2001	**2001 vs. 2002**	**2002 vs. 2003**
ASE	0.853	1.133	1.034
SIPIN	0.709	1.139	1.034
OSE	0.664	0.998	1.137
ChipMos	0.694	1.142	1.052
KYEC	0.521	1.041	0.996
ASE Chung Li	0.590	1.216	1.021
Sharp in Taiwan	0.708	1.214	1.041
Greatek	0.720	1.177	1.031

Lingsen	0.587	1.203	1.046
PowerTech	0.670	1.430	1.028
UTC	0.792	1.060	0.988
KingPak	0.771	1.323	0.997
Hi-Sincerity	0.621	1.001	0.937
Formosa	0.765	1.091	1.038
Sigurd	0.639	0.934	1.025
Industry average	**0.687**	**1.140**	**1.027**

Table 8 reports the Malmquist frontier shift component. It can be seen that on average, the industry technology frontier declines 31.3% from 2000 to 2001, improves 23.8% from 2001 to 2002, and improves 2.3% from 2002 to 2003.

As indicated by FS_o in Table 8, we can see all firms show negative shift in technology frontier from 2000 to 2001. From 2001 to 2002, only *Sigurd* and *OSE* show a negative shift in technology frontier, indicating the period has changed drastically compared with the previous period. Regarding the periods 2002 to 2003, although most of the firms declines in frontier shift compared with 2001 to 2002, they still hold a positive frontier shift (FS_o>1). Over this period, only four firms, *KYEC*, *Hi-Sincerity*, *UTC*, and *KingPak* show a negative frontier shift; the other 11 firms still show a positive shift.

In the previous section, FS_o is known as a product of two ratios, $D^t(x_o^{t+1}, y_o^{t+1}) / D^{t+1}(x_o^{t+1}, y_o^{t+1})$ and $D^t(x_o^t, y_o^t) / D^{t+1}(x_o^t, y_o^t)$. Moreover, the value of each ratio represents a different implication; thus, we still need to discuss the two components of FS_o.

Note that $R_1 = D^t(x_o^{t+1}, y_o^{t+1}) / D^{t+1}(x_o^{t+1}, y_o^{t+1})$, $R_2 = D^t(x_o^t, y_o^t) / D^{t+1}(x_o^t, y_o^t)$ in the following table (Chen and Ali, 2004).

Table 9 reports the component shifts in technical frontier. We can see that no firms show a cross-frontier shift from 2000 to 2001, corresponding with the fact that no one shows a positive frontier shift in Table 8. From 2001 to 2002, take *OSE*, *UTC,* and *Hi-Sincerity* as examples, their R_1 <1 and R_2 >1 indicate they move from a positive shift facet towards a negative shift facet. In terms of management, this situation should be avoided. However, other firms all show the pure positive shift (R_1>1, R_2 >1), indicating they stand for consistent operation strategies. From 2002 to 2003, we can find out the cause of four firms' frontier shift less than 1.0 (Table 8). Among these four firms, only the cause of *KYEC*'s frontier shift less than 1.0 is R_1>1 can not overcome the damage from R_2<1; the cause of the others' is their R_1<1 covers the positive effect from R_2>1. Except these four firms, all show the pure positive frontier shift. For the industry average, it is worth noting there is a negative frontier shift from 2000 to 2001, but that it moves to a desirable shift from 2001 to 2003. Commonly, only a minority of the firms show that moving from a good shift facet to a bad shift facet (R_1<1, R_2 >1).

Table 9 Individual shift

Firms	**Time**					
	2000 vs. 2001		**2001 vs. 2002**		**2002 vs. 2003**	
	R_1	R_2	R_1	R_2	R_1	R_2
ASE	0.760	0.957	1.144	1.122	1.022	1.045
SIPIN	0.743	0.677	1.136	1.141	1.021	1.048
OSE	0.790	0.559	0.962	1.036	1.139	1.135
ChipMos	0.734	0.656	1.102	1.185	1.037	1.067
KYEC	0.797	0.340	1.100	0.985	1.029	0.964

ASE Chung Li	0.726	0.480	1.205	1.227	1.018	1.023
Sharp in Taiwan	0.709	0.708	1.203	1.225	1.036	1.045
Greatek	0.755	0.687	1.213	1.143	1.022	1.040
Lingsen	0.566	0.609	1.392	1.039	1.041	1.052
PowerTech	0.459	0.979	1.177	1.736	1.045	1.010
UTC	0.729	0.861	0.928	1.210	0.834	1.169
KingPak	0.631	0.942	1.168	1.499	0.968	1.028
Hi-Sincerity	0.551	0.700	0.892	1.124	0.783	1.122
Formosa	0.765	0.765	1.106	1.077	1.038	1.039
Sigurd	0.696	0.587	1.158	0.754	1.041	1.009
Industry average	**0.694**	**0.700**	**1.126**	**1.167**	**1.005**	**1.053**

Table 10 Malmquist productivity

Firms	M_o^{t+1}		
	2000 vs.2001	**2001 vs.2002**	**2002 vs.2003**
ASE	0.34	1.528	1.081
SIPIN	0.469	1.170	1.057
OSE	0.220	0.895	0.828
ChipMos	0.573	0.892	1.451
KYEC	0.373	1.426	1.799
ASE Chung Li	0.642	1.467	0.871
Sharp in Taiwan	0.759	0.897	1.083
Greatek	0.904	1.480	1.005
Lingsen	1.035	0.756	0.983
PowerTech	0.732	0.729	0.999
UTC	0.320	2.757	1.067
KingPak	0.295	1.247	0.955
Hi-Sincerity	0.982	0.992	0.923
Formosa	0.715	1.625	1.009
Sigurd	0.996	0.600	1.364
Industry average	**0.624**	**1.231**	**1.098**

Table 10 reports the Malmquist productivity index M_o^{t+1}. It can be seen, on industry average, there is about a 37.6% productivity loss from 2000 to 2001, while from 2001 to 2002 there is about a 23.1% productivity gain and from 2002 to 2003 there is about a 9.8% productivity gain.

However, the Malmquist productivity index is a combined product of TEC_o and FS_o; that is, $M_o^{t+1} = TEC_o \times FS_o$. In order to analyze the performances of these firms more precisely, the information in Tables 7 and 8 is not only helpful, but essential. Fortunately, M_o^{t+1} is consistent with TEC_o and FS_o here. However, if we see that the Malmquist productivity index is larger than 1.0 on average in a certain case, this is maybe a combined effect of an average improvement in technology frontier and an average declining technical efficiency. Such a situation does not appear in this case, but it would be absolutely necessary for management to make a detailed investigation to find the real cause of productivity gains or losses.

Therefore, for the conclusion regarding productivity change of each firm, we must refer to FS_o and TEC_o. In addition, Table 11 is derived comprehensively as follows.

Next, let us examine the detailed Malmquist change information. Here, we denote R_1 (first component of *FS*) $= D^t(x_o^{t+1}, y_o^{t+1}) \big/ D^{t+1}(x_o^{t+1}, y_o^{t+1})$, R_2 (second component of *FS*) $= D^t(x_o^t, y_o^t) \big/ D^{t+1}(x_o^t, y_o^t)$, R_3 (*TEC*) $= D^{t+1}(x_o^{t+1}, y_o^{t+1}) \big/ D^t(x_o^t, y_o^t)$, R_4 (M_o^{t+1}) $= \left[\dfrac{D^t(x_o^{t+1}, y_o^{t+1})}{D^t(x_o^t, y_o^t)} \dfrac{D^{t+1}(x_o^{t+1}, y_o^{t+1})}{D^{t+1}(x_o^t, y_o^t)} \right]^{1/2}$.

Table 11 reports the component information associated with productivity change. Contents include results of CCR models and SBM/Super-SBM models. In the previous instruction, the value of each ratio presents different management implication when >1, =1, <1. Thus, differences are highlighted for readers to note them easily. "SBMs" denotes the results of SBM/Super-SBM models.

Table 11 Detailed Malmquist productivity change information

2000 vs. 2001								
	***R*₁**		***R*₂**		***R*₃**		***R*₄**	
	CCR	**SBMs**	**CCR**	**SBMs**	**CCR**	**SBMs**	**CCR**	**SBMs**
ASE	0.72	0.76	0.77	0.96	0.56	0.40	0.42	0.34
SIPIN	0.75	0.74	0.76	0.68	0.63	0.66	0.47	0.47
OSE	0.70	0.79	0.79	0.56	0.42	0.33	0.31	0.22
ChipMos	0.73	0.73	0.71	0.66	0.85	0.83	0.61	0.57
KYEC	0.73	0.80	0.85	0.34	0.44	0.72	0.34	0.37
ASE Chung Li	0.86	0.73	0.87	0.48	0.62	1.09	0.54	0.64
Sharp in Taiwan	0.78	0.71	0.73	0.71	0.95	1.07	0.71	0.76
Greatek	0.80	0.75	0.78	0.69	1.03	1.26	0.81	0.90
Lingsen	0.93	0.57	0.78	0.61	1.02	1.76	**0.87**	**1.04**
PowerTech	0.89	0.46	0.88	0.98	**1.00**	**1.09**	0.89	0.73
UTC	0.80	0.73	0.66	0.86	0.71	0.40	0.51	0.32
KingPak	0.86	0.63	0.65	0.94	0.63	0.38	0.47	0.29
Hi-Sincerity	0.89	0.55	0.80	0.70	1.10	1.58	0.93	0.98
Formosa	0.93	0.76	0.77	0.76	0.93	0.93	0.79	0.71
Sigurd	0.85	0.70	0.74	0.59	1.18	1.56	0.94	1.00

2001 vs. 2002								
	***R*₁**		***R*₂**		***R*₃**		***R*₄**	
	CCR	**SBMs**	**CCR**	**SBMs**	**CCR**	**SBMs**	**CCR**	**SBMs**
ASE	1.15	1.14	**0.98**	**1.12**	1.14	1.35	1.21	1.53
SIPIN	1.14	1.14	**0.93**	**1.14**	1.04	1.03	1.07	1.17
OSE	**1.29**	**0.96**	**1.00**	**1.04**	0.93	0.90	**1.05**	**0.90**
ChipMos	1.23	1.10	**0.99**	**1.18**	0.79	0.78	0.87	0.89
KYEC	1.16	1.10	**1.01**	**0.98**	1.27	1.37	1.38	1.43
ASE Chung Li	**0.92**	**1.21**	**0.82**	**1.23**	1.60	1.21	1.40	1.47
Sharp in Taiwan	1.08	1.20	**0.90**	**1.22**	0.88	0.74	0.87	0.90
Greatek	1.07	1.21	**0.87**	**1.14**	1.39	1.26	1.34	1.48
Lingsen	1.17	1.39	**0.75**	**1.04**	0.90	0.63	0.84	0.76
PowerTech	**0.89**	**1.18**	1.32	1.74	0.81	0.51	0.87	0.73
UTC	**1.46**	**0.93**	**0.92**	**1.21**	1.41	2.60	1.64	2.76
KingPak	1.06	1.17	**0.94**	**1.50**	0.78	0.94	**0.77**	**1.25**
Hi-Sincerity	**1.07**	**0.89**	**0.94**	**1.12**	**1.00**	**0.99**	1.00	0.99
Formosa	1.20	1.11	**0.75**	**1.08**	1.33	1.49	1.26	1.62
Sigurd	1.02	1.16	0.83	0.75	0.86	0.64	0.79	0.60

2002 vs. 2003								
	***R*₁**		***R*₂**		***R*₃**		***R*₄**	
	CCR	**SBMs**	**CCR**	**SBMs**	**CCR**	**SBMs**	**CCR**	**SBMs**
ASE	1.22	1.02	1.08	1.05	1.28	1.05	1.47	1.08
SIPIN	1.22	1.02	1.07	1.05	1.22	1.02	1.40	1.06
OSE	**1.00**	**1.14**	**0.88**	**1.14**	0.97	0.73	0.91	0.83

ChipMos	1.22	1.04	**0.99**	**1.07**	1.26	1.38	1.38	1.45
KYEC	1.23	1.03	0.97	0.96	1.39	1.81	1.52	1.80
ASE Chung Li	1.25	1.02	1.29	1.02	**0.69**	**0.85**	0.88	0.87
Sharp in Taiwan	1.21	1.04	1.15	1.05	**0.96**	**1.04**	1.13	1.08
Greatek	1.26	1.02	1.20	1.04	0.84	0.97	1.03	1.00
Lingsen	1.17	1.04	**0.99**	**1.05**	0.91	0.94	0.98	0.98
PowerTech	1.13	1.05	1.31	1.01	0.78	0.97	0.96	1.00
UTC	**1.31**	**0.83**	**0.76**	**1.17**	**1.00**	**1.08**	**1.00**	**1.07**
KingPak	**1.31**	**0.97**	1.13	1.03	0.99	0.96	**1.20**	**0.96**
Hi-Sincerity	0.95	0.78	**0.93**	**1.12**	**1.00**	**0.98**	0.94	0.92
Formosa	1.26	1.04	**0.92**	**1.04**	0.83	0.97	**0.89**	**1.01**
Sigurd	1.17	1.04	1.19	1.01	1.12	1.33	1.33	1.36

“ , the blue highlighted or the boldface”: indicates the different between radial- and slacks-based models.

In Table 11, among the 180 comparisons of two measurement methods, 39 (21.7%) are in different signs, a large percentage of total. This proves the current SBM-based approach indeed revises the weak points of the radial-based measure, leading to an appropriate result. It is obvious that applying the current approach leads to a different managerial interpretation. Theoretically, SBM/Super-SBM models have a truly specific interpretation in these 15 firms. One of the major reasons for the difference is that previous study did not measure the super-efficiency of DMU_o in a single period t or (t+1). The more explicit explanation is in Section 5. The following table shows the extracted results of SBM/Super-SBM from Table 11. (a)~(d) denote the four definitions cases of R_1 and R_2 in Section 3; *D* denotes “Decline”; *P* denotes “Progress”.

Table 12 Detailed Malmquist productivity change information of SBM/Super-SBM

	2000 vs. 2001			2001 vs. 2002			2002 vs. 2003		
	R_1, R_2	R_3	R_4	R_1, R_2	R_3	R_4	R_1, R_2	R_3	R_4
ASE	(b)	*D*	*D*	(a)	*P*	*P*	(a)	*P*	*P*
SIPIN	(b)	*D*	*D*	(a)	*P*	*P*	(a)	*P*	*P*
OSE	(b)	*D*	*D*	(d)	*D*	*D*	(a)	*D*	*D*
ChipMos	(b)	*D*	*D*	(a)	*D*	*D*	(a)	*P*	*P*
KYEC	(b)	*D*	*D*	(c)	*P*	*P*	(c)	*P*	*P*
ASE Chung Li	(b)	*P*	*D*	(a)	*P*	*P*	(a)	*D*	*D*
Sharp in Taiwan	(b)	*P*	*D*	(a)	*D*	*D*	(a)	*P*	*P*
Greatek	(b)	*P*	*D*	(a)	*P*	*P*	(a)	*D*	*P*
Lingsen	(b)	*P*	*P*	(a)	*D*	*D*	(a)	*D*	*D*
PowerTech	(b)	*P*	*D*	(a)	*D*	*D*	(a)	*D*	*D*
UTC	(b)	*D*	*D*	(d)	*P*	*P*	(d)	*P*	*P*
KingPak	(b)	*D*	*D*	(a)	*D*	*P*	(d)	*D*	*D*
Hi-Sincerity	(b)	*P*	*D*	(d)	*D*	*D*	(d)	*D*	*D*
Formosa	(b)	*D*	*D*	(a)	*P*	*P*	(a)	*D*	*P*
Sigurd	(b)	*P*	*D*	(c)	*D*	*D*	(a)	*P*	*P*

We will first expand on the managerial purpose concerning the results of SBM and Super-SBM measures in Table 12. We advice that referring to the definitions of (a) ~(d) in Section 3 and signs *D* and *P* in Table 12 could be more understandable for the following analysis. By analyzing some meaningful cases, we will determine the essential factor of each productivity result. First, the Malmquist productivity of *PowerTech* are both decline in two periods – from 2000 to 2001 and from 2001 to 2002 – yet the contents of R_1, R_2 and R_3 in each period are contrary. From 2000 to 2001, the components of FS_o display a pure negative frontier shift, and the only inferior effect on its whole performance is positive technical efficiency change. However, from 2001 to 2002, the only benefit in the performance is the technical efficiency progress, while the components of FS_o reveal purely positive.

Secondly, *PowerTech* shows a productivity loss from 2002 to 2003 due to improvement in FS_o where R_1 and R_2 are both >1 (case(a)), and the only decline in technical efficiency, representing the positive frontier shift cannot overtake the harm from technical efficiency decline. In terms of chasing a good performance, management strategy should focus on this issue.

UTC shows productivity gain with an improvement in technical efficiency from 2001 to 2002. Actually, the firm is moving to a negative shift facet because the R_1 <1 and R_2 >1. The implication of these two ratios has been discussed previously. Therefore, *UTC* demonstrates an unfavorable strategy in this period.

Hi-Sincerity from 2001 to 2002 shows the least favorable strategy for change under the scenario R_1 and R_2 performing inconsistently, case (c) and (d). Since its R_4 progresses, R_3 declines, the performance of R_1, R_2 corresponds to case (d), we can conclude that it also suffers productivity loss, technical efficiency change decline, and has moved from a positive shift facet towards a negative shift facet. This situation must be discussed because every company or industry may encounter such potential danger, and it is easily ignored.

Among the current set of performance assessments of semiconductor packaging and testing firms in Taiwan, *KYEC* is the polar opposite of *Hi-Sincerity*. It is significant to know that the most favorable strategy change occurs when R_4>1, R_3 >1, the performance of R_1, R_2

correspond to case (c) under the scenario that R_1 and R_2 perform inconsistently. In other words, the conditions demonstrate that besides the particular company showing productivity gain and progress in technical efficiency, its strategy moves from a negative shift facet towards a positive shift facet.

The last two simple cases are (i) $R_4 > 1$, $R_3 > 1$, and $R_1 > 1$, $R_2 > 1$(case(a)), which indicates the best result of all, and (ii) $R_4 < 1$, $R_3 < 1$, and $R_1 < 1$, $R_2 < 1$ (case(b)), which indicates the worst result of all. The above discussion shows that by further analyzing the Malmquist components, more insights into productivity changes can be obtained.

5. Comparisons of CCR and SBM measures

We compare our results and the results obtained by Chen and Ali (2004) employing the CCR model. As noted earlier in this thesis, θ_o^*, ρ_o^*, and π_o^* are the optimal efficiency scores of CCR, SBM, and Super-SBM models respectively. When measuring the distances $D^t(x_o^t, y_o^t)$ and $D^{t+1}(x_o^{t+1}, y_o^{t+1})$, if the object company is inefficient, the CCR score θ_o^* is greater or equal to the SBM score. If the object company is efficient, we further measure its distance to the frontier constructed by the other companies; the Super-SBM efficiency scores are greater than 1.0 and greater than the CCR scores, 1.0. In the other case, we measure the distances across two periods of $D^{t+1}(x_o^t, y_o^t)$ and $D^t(x_o^{t+1}, y_o^{t+1})$; if the object company is inefficient, the CCR score θ_o^* is greater or equal to the SBM score. If the object company is efficient, we further measure its distance to the frontier constructed by all the companies in other periods; the Super-SBM efficiency scores are greater than 1.0 and greater than the CCR scores, 1.0.

Chen and Ali (2004) do not measure the Super-CCR efficiency score (Andersen & Petersen, 1993) of DMU_o in a single period t or (t+1); therefore, $\pi_o^* \geqq 1$, $\theta_o^* \leqq 1$ and verified that $\pi_o^* \geqq \theta_o^*$. As a result, the changes in optimal efficiency score for the three models might affect the ratios R_1, R_2, R_3, and R_4.

Take R_1 for example, measuring the two distance functions of R_1 ($R_1 = D^t(x_o^{t+1}, y_o^{t+1}) \big/ D^{t+1}(x_o^{t+1}, y_o^{t+1})$) by our proposed SBM/Super-SBM models and the CCR model could be inefficient or efficient. Their values are depicted in Table 13. The ratio R_1 could be obtained by the three possible combinations as shown in Table 14, where I and E denote inefficient and efficient, respectively. Given the ratio R_1 is less than 1.0 for the SBM/Super-SBM models ($R_{1,\ SBMs}$), the ratio R_1 for the CCR model ($R_{1,\ CCR}$) could be inferred. The first and second combinations have different outcomes in two models. One could perform similar analysis for the ratios R_2, R_3, and R_4 under the two models. The current thesis provides measurement different from the CCR measure proposed by Chen and Ali (2004).

Table 13 Values of $D^t(x_o^{t+1}, y_o^{t+1})$ and $D^{t+1}(x_o^{t+1}, y_o^{t+1})$

	SBM/Super-SBM		CCR	
	Inefficient	**Efficient**	**Inefficient**	**Efficient**
$D^t(x_o^{t+1}, y_o^{t+1})$	≦1	≧1	≦1	≧1
$D^{t+1}(x_o^{t+1}, y_o^{t+1})$	≦1	≧1	≦1	1

Tabe 14 Values of $[D^t(x_o^{t+1}, y_o^{t+1}) \ / \ D^{t+1}(x_o^{t+1}, y_o^{t+1})]$ when $R_{1,\ SBM/Super\text{-}SBM} \le 1$

No.	**Combination**	$R_{1,\ SBMs} \le 1$	$R_{1,\ CCR}$
1	I/I	≦1	≦1 or ≧1
2	E/E	≦1	≧1
3	I/E	≦1	≦1

6. Conclusions

We benefited from use of the DEA Malmquist productivity approach employed by Chen and Ali (2004) to discover that in-depth information could be obtained by analyzing each individual component of the Malmquist productivity index. Further, the result is more precise using the SBM/Super-SBM measures. According to the comparison with CCR, there are numbers of differences at the end. Such analyses not only help revise the weak points in the CCR model but also provide a more in-depth management implication. It is very critical to capturing a firm's performance through an analysis of the components of the Malmquist productivity index to reveal the managerial implications of each component and limit misleading information. As a result, a firm will be aware of what kind of weaknesses they should watch out for and remedy. Furthermore, in terms of industrial management, this method allows judgments to be made concerning whether or not the strategic shift is favorable and promising.

Appendix

The relative efficiency of DMU_o for $(a, b) = (t, t+1)$.

$$\rho_{3o}^{*} = D^{t}(x_o^{t+1}, y_o^{t+1}) = Min\ k - \frac{1}{m}\sum_{i=1}^{m}\left(S_i^{-} \middle/ x_{io}^{t+1}\right),$$

$$Subject\ to \quad k + \frac{1}{s}\sum_{r=1}^{s}\left(S_r^{+} \middle/ y_{ro}^{t+1}\right) = 1,$$

$$kx_{io}^{t+1} = \sum_{j=1}^{n} x_{ij}^{t} k\lambda_j + x_{io}^{t+1} k\lambda_{n+1} + S_i^{-},\ i=1, 2, \ldots, m, \tag{M3}$$

$$ky_{ro}^{t+1} = \sum_{j=1}^{n} y_{rj}^{t} k\lambda_j + y_{ro}^{t+1} k\lambda_{n+1} - S_r^{+}, \qquad r = 1, 2, \ldots, s,$$

$$\lambda_j \geq 0, j = 1, 2, \ldots, (n+1);\ k \geq 0;\ S_i^{-} \geq 0,\ i = 1, 2, \ldots, m;\ S_r^{+} \geq 0,\ r = 1, 2, \ldots, s.$$

The relative super efficiency of DMU_o for $(a, b) = (t, t+1)$.

$$\pi_{3o}^{*} = Min\ \frac{1}{m}\sum_{i=1}^{m}\frac{\tilde{x}_{io}^{t+1}}{x_{io}^{t+1}},$$

$$Subject\ to \quad 1 = \frac{1}{s}\sum_{r=1}^{s}\frac{\tilde{y}_{ro}^{t+1}}{y_{ro}^{t+1}},$$

$$\tilde{x}_{io}^{t+1} \geq \sum_{j=1}^{n} x_{ij}^{t}\Lambda_j^{t}, \qquad i = 1, 2, \ldots, m, \tag{M3.1}$$

$$\tilde{y}_{ro}^{t+1} \leq \sum_{j=1}^{n} y_{rj}^{t}\Lambda_j^{t}, \qquad r = 1, 2, \ldots, s,$$

$$\tilde{x}_{io}^{t+1} \geq \tau\, x_{io}^{t+1}, \qquad i = 1, 2, \ldots, m,$$

$$0 \leq \tilde{y}_{ro}^{t+1} \leq \tau\, y_{ro}^{t+1}, \qquad r = 1, 2, \ldots, s,$$

$$\Lambda_j^{t} \geq 0,\ j = 1, 2, \ldots, n;\ \tau > 0.$$

The relative efficiency of DMU_o for $(a, b) = (t+1, t+1)$.

$$\rho^*_{4o} = D^{t+1}(x_o^{t+1}, y_o^{t+1}) = Min \quad k - \frac{1}{m}\sum_{i=1}^{m}\left(S_i^- \big/ x_{io}^{t+1}\right),$$

$$Subject\ to \quad k + \frac{1}{s}\sum_{r=1}^{s}\left(S_r^+ \big/ y_{ro}^{t+1}\right) = 1,$$

$$kx_{io}^{t+1} = \sum_{j=1}^{n} x_{ij}^{t+1} k\lambda_j + S_i^-, \qquad i = 1, 2, \ldots, m, \tag{M4}$$

$$ky_{ro}^{t+1} = \sum_{j=1}^{n} y_{rj}^{t+1} k\lambda_j - S_r^+, \qquad r = 1, 2, \ldots, s,$$

$$\lambda_j \ge 0, j = 1, 2, \ldots, n;\ k \ge 0;\ S_i^- \ge 0,\ i = 1, 2, \ldots, m;\ S_r^+ \ge 0,\ r = 1, 2, \ldots, s.$$

The relative super efficiency of DMU_o for $(a, b) = (t+1, t+1)$.

$$\pi^*_{4o} = Min \ \frac{1}{m}\sum_{i=1}^{m}\frac{\tilde{x}_{io}^{t+1}}{x_{io}^{t+1}},$$

$$Subject\ to \quad 1 = \frac{1}{s}\sum_{r=1}^{s}\frac{\tilde{y}_{ro}^{t+1}}{y_{ro}^{t+1}},$$

$$\tilde{x}_{io}^{t+1} \ge \sum_{j=1, \ne o}^{n} x_{ij}^{t+1} \Lambda_j^{t+1}, \qquad i = 1, 2, \ldots, m, \tag{M4.1}$$

$$\tilde{y}_{ro}^{t+1} \le \sum_{j=1, \ne o}^{n} y_{rj}^{t+1} \Lambda_j^{t+1}, \qquad r = 1, 2, \ldots, s,$$

$$\tilde{x}_{io}^{t+1} \ge \tau x_{io}^{t+1}, \qquad i = 1, 2, \ldots, m,$$

$$0 \le \tilde{y}_{ro}^{t+1} \le \tau y_{ro}^{t+1}, \qquad r = 1, 2, \ldots, s,$$

$$\Lambda_j^{t+1} \ge 0, \quad j = 1, 2, \ldots, n; \quad \tau > 0.$$

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從小培養課外才能與運動的習慣

自國小開始除了補習班與到學校上課外，由於自身興趣使然，在課外閒暇之餘也培養素描、書法、直笛以及多方面的運動例如羽毛球、游泳，由於父親是國中理化老師也兼任國中羽球教練，平常會讓我跟在旁邊學習羽球技能，並鼓勵我多元學習，因此在國小就成為游泳校隊的一員，而美術上的天分也讓我在升國中時順利考上當地明星學校道明中學美術班，也許興趣廣泛加上容易從中獲得成就感，使得培養的才藝也比平常人多一些，這些優勢伴隨著我成長，因為許多課外活動方面，這些業餘技藝都能發揮功用，也提昇我個人正當休閒的娛樂和運動潛能。

大學時熱愛 OR 並開始接觸程式語言

工業工程與管理其中的 OR 是眾所皆知的狠角色，的確剛開始接觸時帶給我不少的壓力，加上第一次考試就落個不及格的分數，讓我在之後的考試無一不是豁盡心力，逐漸的也開始熱愛這個跟以前所碰的數學很不一樣的科目，兩學期結束都以班上最高分過關，而大三下專題以 VBA 語言撰寫資料包絡法的程式，就讓我深深覺得運用程式的好處，讓程式快速地計算人所無法計算的繁複數據，可說是相當不錯的工具，雖然花了許多無法言語的心血及時間，但是也跨出原本害怕程式的心理障礙。

順利進入研究所並專研資料包絡法

在指導教授的提拔與教導之下，在研究所除了學習所裡的課程，更重要的是從老師身上學到了做研究的精神，以及對於資料包絡法更深一層的研究。研究所不比大學，其課程更為艱深，但是時間卻又較大學更能自己掌握，因此在努力之下，成績仍保持穩定，而在研究所期間，也利用額外的時間培養自己的興趣，雖然只有短短的三學期，但是收穫卻是及豐盛，一切都歸功於老師盡心盡力的教導。

對英語能力的重視

另外一項極重要的能力，就是外語能力，從高中時期，就知道英語重要性，父母也敦聘外語教師，教導我英語聽和說能力。但是現在仍覺得聽、說、寫方面，極需加強，也由於本身的興趣，從大二下開始每天有聽英文雜誌的習慣，接觸過的有 CNN 互動英語雜誌以及 Advanced 彭蒙惠英語。在大三時也利用課餘時間報名了課外的托福補習班，大四畢業時也去補 GRE，真正瞭解到自己需在英語會話能力多加強，目前仍每天撥時間在學習、未來以期能夠在英文能力方面更流利、拓展自己的視野與範疇，我希望能在國內完成碩士學位後後夠出國深造，增進語文及本科學識。