國立交通大學

管理學院(工業工程與管理學程)碩士班
碩士論文

台灣封裝測試廠經營績效評比

Performance Assessment of Semiconductor's Packaging and Testing Firms in Taiwan

研 究 生 ： 楊國華

指導教授 ： 劉復華　博士

中 華 民 國 九十三 年 七 月

台灣封裝測試廠經營績效評比

Performance Assessment of Semiconductor's Packaging and Testing Firms in Taiwan

研 究 生：楊國華 Student：Kuo-Hua Yang

指導教授：劉復華　博士 Advisor : Dr. Fuh-Hwa F. Liu

國 立 交 通 大 學

管理學院(工業工程與管理學程)碩士班

碩 士 論 文

A Thesis

Submitted to Department of Industrial Engineering and Management

College of Management

National Chiao Tung University

in Partial Fulfillment of the Requirements

for the Degree of Master of Science

in

Industrial Engineering and Management

July 2004

Hsinchu, Taiwan, Republic of China

中 華 民 國 九十三 年 七 月

國立交通大學

研究所碩士班

論文口試委員會審定書

本校管理學院碩士在職專班工業工程與管理組　楊國華　君

所提論文　台灣封裝測試廠經營績效評比

Performance Assessment of Semiconductor's Packaging and Testing Firms in Taiwan

合於碩士資格水準、業經本委員會評審認可。

口試委員：

指導教授：

工管組組長：＿＿＿＿＿＿教授

中華民國 93 年 7 月 27 日

台灣封裝測試廠經營績效評比

學生：楊國華　　　　　　　　　　　指導教授：劉復華 博士

國 立 交 通 大 學

管理學院(工業工程與管理學程)碩士班

摘 要

本研究主要是以資料包絡分析法(DEA)來評比台灣十五家半導體封裝測試廠 2000 年至 2003 年的績效。主要分為三大部份及其結論：其一為封裝測試廠每一年經營績效狀況皆因各廠家的經營式不同而且持續不斷變化；其次為透過 Malmquist Productivity Index (MPI)分析得知各家封裝測試廠連續 4 年的進步程度與僅單一年的變化不同；最後，我們比較這十五家封裝測試廠的整體經營績效與半導體整體的營業額之相依變化趨勢。

透過本研究結果，我們可清楚的瞭解半導體封裝測試廠每年的競爭皆非常激烈及各公司的經營者在過去的經營決策中，是否做了對公司最佳的決定；且由指標來看，營業額、營業額的成長率或獲利率皆無法直接代表其經營績效。而本研究實證結果不僅可提供銀行團、企業者及想要投資該企業之投資者在經營及投資時須注意該公司的經營重點指標；同時也提供了就業者從另一個選擇的角度來挑選一家較適合自己的公司。最後，封裝測試廠的客戶或供應商也可藉由對該公司的績效變化或經營績效的趨勢，認識各家封裝測試廠的經營績效狀況，可做為合作時評估的參考。

關鍵字: 資料包絡法、DEA、MALMQUIST、績效評比、封裝測試。

Performance Assessment of Semiconductor's Packaging and Testing Firms in Taiwan

Student: Kuo-Hua Yang Advisor: Dr. Fuh-Hwa F. Liu

Department of Industrial Engineering and Management National Chiao Tung University

Abstract

This study evaluates the performance of the fifteen semiconductor packaging and testing firms in Taiwan, employing the Data Envelopment Analysis (DEA) method to analyze three issues in these firms from the year 2000 through 2003. First, of all the packaging/testing firms are continuously changing every year in terms of managerial performance. Secondly, there exists considerable difference between four-year improvements and one-year improvement by the MPI analysis for any company. Lastly, our test rejected the hypothesis that the yearly managerial performance of the 15 packaging/testing firms and the revenue of whole semiconductor manufacturing industry are correlated.

From this study, one would realize the keen competitions among packaging/testing firms. Through the analysis, the performance of each firm is reflecting the managerial decisions. We use five indices for performance assessments: revenue, growth rate, profitability rate, output value by employee, and liability rate. The results of this research would enable banker, enterpriser, stockholder, stakeholder, and investor to evaluate the fifteen firms.

Keywords: Data Envelopment Analysis; DEA; MALMQUIST; Semiconductor Packaging and Testing; Ranking

Acknowledgments

I would like to take the opportunity to express greatest gratitude to my advisor, Dr. Fuh-Hwa F. Liu, for his patient guidance, encouragement and support throughput the course of this research.

I would also extend sincere thanks to Dr. Jeff Li, all of my classmates and friends who help me throughput the course of this research.

At last, I would like to express gratitude to my parents and family members, for their love, encouragement and understanding.

CONTENTS

1. Introduction

Semiconductor manufacturing has emerged as one of the most important industries in the global economy. However, tremendous capital investment is required to build and equip a production line (exceeding $2.8 billion for 300 mm wafer (Andersen et al., 1993)). According to Efficiency analysis (Banker and Morey, 1986), the industry reinvested 23% of total revenue into capital expenses in 1996, with about 60%~70% of that going into tool purchases. Against this backdrop, the semiconductor manufacturing requires short order lead times with a fair degree of flexibility in the product mix and a significant periodical increase in productivity to achieve competitive prices and adequate return on the investment. Performance is not only decided its development, but also impact stockholders, loaners, employees, suppliers, customers, stakeholders, and to-be-hired employees. This research provides the performance comparison among firms. Therefore, firms could utilize the results for their improvement.

The aim of this paper is to evaluate the performance of the fifteen major semiconductor packaging and testing firms in Taiwan. We employ the Data Envelopment Analysis (DEA) method to analyze three issues in these firms from the year 2000 through 2003. The firms have considerable significant economic impact. The first issue we examine is each year's performance ranking. Second, we analyze the productivity change over the four years. Finally, we evaluate the relationship between these fifteen firms and the entire semiconductor-related industry from 2000 to 2003.

As a result of the rapid recovery for global economy, many industries are climbing out of the business cycle valley to achieve soaring levels of growth (Paradi et al., 2002). During these prosperous periods, semiconductor-related industries in Taiwan are not only reaching 100% facility utilization, but are also using large amounts of capital to expand the facilities layout and purchase new equipment. Based on the "ITIS 2003 Semiconductor Report" (Industrial Technology Research Institute 2004), the global semiconductor industry will grow continuously, especially in the Pacific Asia area. The Pacific Asia area's market value is estimated to have the highest growth rate in the world. Furthermore, the market value of packaging and testing in the IC industry is estimated to be up to 20% of the market value for IC industry in Taiwan. The total sales from the top 5 packaging firms account for over 70% of total sales, and the total revenue of the top 5 testing firms account for over 60% of the total revenue (Industrial Technology Research Institute 2004). All fifteen firms analyzed in this study were from the Top 1000 Manufacturing Firms listed in Common Wealth Magazine.

Data envelopment analysis (DEA) (Banker and Morey, 1986) has become one of the special optimization methodologies for measuring the relative efficiency of many homogenous entities (i.e. decision-making units (DMUs)). To face competitor price-cutting challenges and reduce profit margins, maintaining competitive advantages by increasing operational efficiencies and reducing operational costs is critical. DEA is a linear programming method that considers multiple inputs and outputs simultaneously to measure the relative efficiencies of evaluated entities. Unlike the traditional univariate financial analysis that considers only two activity dimensions, represented by a numerator and denominator, DEA considers multidimensional entities performance aspects. The DEA model does not require the assignment of predetermined weights to the input and output factors. In contract to the parametric approach, DEA does not require any assumptions about the model. The results can be easily understood and interpreted by practitioners because this method conforms better to evaluating and comparing performance using standard specifications.

This paper is organized as follows. Section II illustrates the literatures review for the DEA related applications. Section III describes the DEA methodologies used in this research. Section IV details the empirical study and illustrates the results about an actual case study. Section V discusses the characteristic of DEA methodologies. Section VI gives remarks and concludes this paper.

2. Literature Review

The DEA model was developed by Charnes et al. (Charnes et al., 1978), called the Charnes-Cooper-Rhodes (CCR) model, to produce an efficiency frontier based on the Pareto optimum concept. For computation convenience and examining the slack variables, the original CCR model was solved as a dual problem using the Banker-Charnes-Cooper (BCC) model developed by Banker et al. (Banker et al., 1984). To date, numerous research papers on efficiency measurement of various entities in different applications using DEA have been conducted. DEA has been applied empirically in various public and private organizations, such as schools (Cakanyildirim and Roundy, 2002), superior courts (Lewin, et al., 1982), hospitals (Mei and Patrick, 2002), pharmaceutical firms (Parad et al., 2002), vehicle maintenance sections (Clarke, 1992), and branch network of a bank (Drake and Howcroft, 1994).

Huang (2003) chose 18 IC design house, 6 foundry and 8 assembly & test firms. It picked out fixed asset per capita, common shares per capita, operation expense per capita, R&D expense per capita and average salary as input variables and sales and ROA as output variables. And use DEA to analyze output efficiency and apply MPI to investigate the interactions between productivity and efficiency spanning several periods. The result shows as below: (a) Inefficiency in overall industry, IC assembly & test and IC design mainly comes from lack of economics scales so that firms have to allocate their capacity for best scale. (b) IC makers suffer imbalance between resource input and output so that they don't utilize technical efficiency well. (c) MPI shows decrease of efficiency variation in overall semiconductor industry. IC assembly & test owns highest DEA in single time horizon but performs worst in MPI.

Feng (2002) dealed with the operational efficiency of semiconductor industry, and materials from 1997 to 2000. Moreover, the materials of 18 firms of IC designing, 11 firms of IC producing and 12 firms of IC packaging are included in my thesis. It shows, from 1997 to 2000, scale efficiency has been slowly rising and the average of every year is higher than that of pure technical efficiency. As a result, the industry of semiconductor as a whole serves as an evidence that inefficiency of variable scale is higher than constant scale. In other words, the prime reason of inefficient production is owing to the inefficiency of variable returns to scale.

Chen (2004) employed DEA-based Malmquist productivity index measures the productivity change over time. The index can be decomposed into two components: one measuring the technical change and the other measuring the frontier shift. The proposed new approach not only reveals patterns of productivity change and presents a new interpretation along with the managerial implication of each Malmquist component, but also identifies the strategy shifts of individual DMUs based upon isoquant changes.

Carbone (2000) applied the DEA methodology to measure the efficiencies of semiconductor manufacturing operations in terms of multiple inputs and multiple outputs. The inputs included the mean time between failures, scrap rate, cycle time and down time, whereas the outputs included the wafer move, overall equipment efficiencies and activity ratio. It was shown that the DEA analysis provided a measure to compare various fab areas and goals for individual areas to achieve to become more efficient with respect to the model results.

3. DEA Model and Malmquist index

3.1 DEA model

Let R be the reference set of DMUs used to assess the relative performance of a DMU, called *DMU-k*. Model (P1) is a modified DEA model, a CCR output-oriented model (Charnes et al., 1978). The right side of the objective function, equation (1), is the relative efficiency of *DMU-k*. The ratio of virtual input to virtual output is maximized, as the decision variables are determined. Yet the relative efficiency of every reference *DMU-j* is constrained as equation (2). The decision variables are constrained to greater than a very small positive number.

To avoid setting the unknown as the infinitesimally small number e, we use the two-phase method to compute the efficiency score and slacks, such as excess (s_1^-) and shortfalls ($s_1^+, s_2^+, s_3^+, s_4^+$).

Phase-one

Solve the linear program (P1) to get the optimal solutions q_k^*, also called CCR-O efficiency.

(P1) Max q_k

s.t. $x_{1k} - \sum_{j \in R} x_{1j} l_j \geq 0$

$q_k y_{rk} - \sum_{j \in R} y_{rj} l_j \leq 0, r = 1 \sim 4$

q_k free in sign; $l_j \geq 0, j \in R$

Phase-two

Enter the coefficients of q_k^* into model (P2) to compute the slacks.

(P2) Max $(s_1^- + s_1^+ + s_2^+ + s_3^+ + s_4^+)$

s.t. $\sum_{j \in R} x_{1j} l_j + s_1^- = x_{1k}$

$$\sum_{j \in R} y_{rj} l_j - s_r^+ = q_k^* y_{rk}, r = 1 \sim 4$$

$$l_j \geq 0,\ j \in R; \quad s_1^- \geq 0; \quad s_r^+ \geq 0, r = 1 \sim 4$$

In model (P2), adding one constraints equation, $\sum_{j \in R} l_j = 1,\ j \in R$, changes the model into model (P6). This is the BCC-O model (Banker et al. 1984). To avoid setting the unknown as the infinitesimally small number e, we use the two-phase method to compute the efficiency score and slacks, such as excess (s_1^-) and shortfalls ($s_1^+, s_2^+, s_3^+, s_4^+$). q_k^* obtained from (P3) is the optimal solution.

Phase-one

(P3) Max q_k

s.t. $\sum_{j \in R} x_{1j} l_j \geq x_{1k}$

$$q_k y_{rk} - \sum_{j \in R} y_{rj} l_j \geq 0, r = 1 \sim 4$$

$$\sum_{j \in R} l_j = 1$$

q_k free in sign; $l_j \geq 0,\ j \in R$

Phase-two

(P4) Max $(s_1^- + s_1^+ + s_2^+ + s_3^+ + s_4^+)$

s.t. $\sum_{j \in R} x_{1j} l_j + s_1^- = x_{1k}$

$$\sum_{j \in R} y_{rj} l_j - s_r^+ = q_k^* y_{rk}, r = 1 \sim 4$$

$$\sum_{j \in R} l_j = 1$$

$$l_j \geq 0,\ j \in R; \quad s_1^- \geq 0; \quad s_r^+ \geq 0, r = 1 \sim 4$$

3.2 Malmquist productivity index

Suppose we have a production function in time period t as well as period t+1. Malmquist index calculation requires two single period and two mixed period measures.

The two single period measures can be obtained by using the CCR DEA model (Charnes et al., 1978).

(P5) $D^t(x^t{}_k, y^t{}_k) = \min \ q_k{}^a$

$$\text{s.t.} \quad x^t_{1k} q_k{}^a - \sum_{j=1}^{n} x^t_{1j} l_j \ge 0$$

$$\sum_{j=1}^{n} l_j y^t_{rj} \ge y^t_{rk} \qquad r = 1, 2, 3, 4$$

$$\text{all} \quad \boldsymbol{\lambda}_j \ge 0, \quad q_k{}^a \ge 0$$

(P6) $D^t(x^{t+1}{}_k, y^{t+1}{}_k) = \min \ q_k{}^b$

$$\text{s.t.} \quad x^{t+1}_{1k} q_k{}^b - \sum_{j=1}^{n} x^t_{1j} l_j \ge 0$$

$$\sum_{j=1}^{n} l_j y^t_{rj} \ge y^{t+1}_{rk} \qquad r = 1, 2, 3, 4$$

$$\text{all} \quad \boldsymbol{\lambda}_j \ge 0, \quad q_k{}^b \ge 0$$

(P7) $D^{t+1}(x^t{}_k, y^t{}_k) = \min \ q_k{}^c$

$$\text{s.t.} \quad x^t_{1k} q_k{}^c - \sum_{j=1}^{n} x^{t+1}_{1j} l_j \ge 0$$

$$\sum_{j=1}^{n} l_j y^{t+1}_{rj} \ge y^t_{rk} \qquad r = 1, 2, 3, 4$$

$$\text{all} \quad \boldsymbol{\lambda}_j \ge 0, \quad q_k{}^c \ge 0$$

(P8) $D^{t+1}(x^{t+1}{}_k, y^{t+1}{}_k) = \min \ q_k{}^d$

$$\text{s.t.} \quad x^{t+1}_{1k} q_k{}^d - \sum_{j=1}^{n} x^{t+1}_{1j} l_j \ge 0$$

$$\sum_{j=1}^{n} l_j y^{t+1}_{rj} \ge y^{t+1}_{rk} \qquad r = 1, 2, 3, 4$$

$$\text{all} \quad \boldsymbol{\lambda}_j \ge 0, \quad q_k{}^d \ge 0$$

Now we can define Malmquist productivity index by equations (P5) ~ (P8):

$$\text{(P9)} \quad M_k^t = \left[\frac{D^t(x_k{}^{t+1}, y_k{}^{t+1})}{D^t(x_k{}^t, y_k{}^t)} \frac{D^{t+1}(x_k{}^{t+1}, y_k{}^{t+1})}{D^{t+1}(x_k{}^t, y_k{}^t)} \right]^{1/2} = \left[\frac{q_k^b}{q_k^a} \times \frac{q_k^d}{q_k^c} \right]^{1/2}$$

4. Illustration

4.1 Data collection and index description

In recent years, many 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, to analyze their relative performance over the past four years. The profile of the firms in the recent four years is listed in Table 1 and Table 2.

Table 1. The profile of the firms in the recent four years

	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

Table 2. Base data from 2000 to 2003

DMU	Firm \ Index	Growth rate (%) Y_1	Net profit after tax ($100 million NT dollars) Y_2	Profitability ratio (%) Y_3	Output value by employee ($million/people) Y_4	Liability ratio (%) 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			

16	ASE	80.35	18.57	89.55	3.40	41.46
17	SIPIN	87.71	28.17	92.84	2.50	38.11
18	OSE	75.04	8.10	70.14	1.98	56.19
19	ChipMos	65.79	24.91	72.58	3.24	31.91
20	KYEC	92.71	32.08	79.57	1.44	53.48
21	ASE Chung Li	64.80	40.57	101.16	2.66	38.12
22	Sharp in Taiwan	78.55	37.60	94.05	2.75	25.01
23	Greatek	89.43	42.48	107.48	2.74	41.80
24	Lingsen	71.17	41.25	105.34	1.87	20.73
25	PowerTech	234.47	41.73	105.56	3.57	43.30
26	UTC	38.25	31.10	33.83	2.43	24.64
27	KingPak	33.53	39.17	96.14	7.68	48.35
28	Hi-Sincerity	70.15	40.21	102.02	11.32	37.24
29	Formosa	59.51	41.22	111.86	1.76	58.27
30	Sigurd	82.70	40.08	100.93	1.91	26.29
			Year 2002			
31	ASE	125.00	41.29	100.50	4.20	42.50
32	SIPIN	134.90	44.25	101.91	2.79	43.28
33	OSE	119.56	7.00	74.16	2.65	64.18
34	ChipMos	118.57	27.92	81.49	3.21	44.48
35	KYEC	137.94	36.97	94.33	1.76	49.08
36	ASE Chung Li	105.22	43.66	107.09	2.29	30.66
37	Sharp in Taiwan	118.37	37.99	95.79	2.74	32.12
38	Greatek	134.67	46.34	114.19	3.36	36.48
39	Lingsen	125.40	36.33	87.51	2.13	25.67
40	PowerTech	90.74	41.87	106.63	2.80	34.86
41	UTC	159.26	36.73	84.73	3.17	22.31
42	KingPak	98.79	38.87	94.68	4.38	54.26
43	Hi-Sincerity	96.83	39.64	96.43	11.59	39.12
44	Formosa	162.59	40.92	105.50	2.51	55.16
45	Sigurd	143.22	42.38	120.12	2.31	43.77
			Year 2003			
46	ASE	122.85	67.43	108.71	3.11	41.08
47	SIPIN	122.80	68.39	110.37	2.99	45.06
48	OSE	105.91	5.64	74.60	2.72	66.88
49	ChipMos	129.77	48.61	110.17	3.36	39.43
50	KYEC	126.91	47.73	111.39	2.38	33.89
51	ASE Chung Li	116.65	41.83	103.04	2.08	34.23
52	Sharp in Taiwan	140.26	51.91	117.79	2.68	34.58
53	Greatek	116.10	49.27	117.88	3.42	35.63
54	Lingsen	133.22	43.69	109.43	2.43	30.28
55	PowerTech	155.44	50.40	123.72	3.21	45.67
56	UTC	107.53	39.92	99.63	2.93	19.95
57	KingPak	59.82	40.94	107.40	2.87	44.82
58	Hi-Sincerity	101.98	39.35	93.68	11.05	40.29
59	Formosa	122.77	41.91	109.30	2.90	54.62
60	Sigurd	149.37	44.18	123.66	2.47	34.16

The following notations are used to represent the above data:

x_{ij} represents the data of *DMU-j* of the index X_i.

y_{rj} represents the data of *DMU-j* of the index Y_r.

In this paper, each row of Table 2 is treated as a decision-making unit (DMU). DMUs 1~15, 16~30, 31~45 and 46~60 are the firms' performances in 2000, 2001, 2002 and 2003, respectively. The twelve indices used by Common Wealth Magazine (2004) are depicted in Table 3. As recommended by Golany and Roll(1989), the number of DMUs should be at least twice the total number of input and output factors. The total number of DMUs is 15, i.e. the number of performance measures should not be larger than 7. We deleted some of the highly positive correlated indices by correlation analysis illustrated in Table 4 ~ Table 7. Among those indices, 7 correlation coefficients are higher than 0.9 as well as very close each other. Thus, these 7 performance indices will be deleted in the following section. The remaining five indices were retained for performance assessment: growth ratio, net profit after tax, profitability ratio, output value by employee, and liability ratio.

Table 3. Index descriptions

No	Index	Description
A	Total assets ($100 million NT dollars)	Total assets, including buildings, equipment, inventory, capital and accounts receivable. Represents business scale.
B	Capital	Capital for this year.
C	Liability rate (%)	If the rate of liability is acceptable, businesses can apply capital performance by finance level. If liability is too high, the interest will be higher. $Liability\ rate = \dfrac{total\ liability}{total\ assets}$
D	Number of employees	The actual number of employees at the end of the year.
E	Revenue ($100 million NT dollars)	Net operating income for products and services for the whole year. It excludes non-operating income, such as interest and grants.
F	Growth rate (%)	Compares operating income gowth ratio of this year to last year.
G	Net profit after tax ($100 million NT dollars)	Deducts business tax from income.
H	Stockholder's equity ($100 million NT dollars)	$stockholder's\ equity = total\ assets - total\ liability$
I	Profitability ratio (%)	$Profitability\ ratio = \dfrac{net\ profit\ after\ tax}{Revenue}$

J	Rate of assets return (%)	$Rate\ of\ assets\ return = \frac{net\ profit\ after\ tax}{total\ assets}$
K	Rate of stockholder's equity (%)	$Rate\ of\ stockholder's\ equity = \frac{net\ profit\ after\ tax}{stockholder's\ equity}$
L	Output value by employee ($million/people)	$output\ value\ by\ employee = \frac{revenue}{number\ of\ employee}$

Table 4. Correlation Analysis for year 2000 (underline indicate over 0.9)

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
(A)	1	0.98	-0.22	0.93	0.97	-0.14	0.90	0.99	0.22	0.15	0.12	-0.22
(B)	0.98	1	-0.21	0.88	0.96	-0.19	0.90	0.98	0.16	0.12	0.09	-0.17
(C)	-0.22	-0.21	1	-0.24	-0.19	0.58	-0.19	-0.27	-0.24	-0.32	-0.08	0.24
(D)	0.93	0.88	-0.24	1	0.92	-0.08	0.71	0.88	0.10	0.07	0.07	-0.32
(E)	0.97	0.96	-0.19	0.92	1	-0.15	0.84	0.95	0.07	0.06	0.03	-0.06
(F)	-0.14	-0.19	0.58	-0.08	-0.15	1	-0.08	-0.17	0.23	0.08	0.25	-0.11
(G)	0.90	0.90	-0.19	0.71	0.84	-0.08	1	0.94	0.49	0.44	0.39	-0.22
(H)	0.99	0.98	-0.27	0.88	0.95	-0.17	0.94	1	0.29	0.21	0.16	-0.21
(I)	0.22	0.16	-0.24	0.10	0.07	0.23	0.49	0.29	1	0.85	0.77	-0.55
(J)	0.15	0.12	-0.32	0.07	0.06	0.08	0.44	0.21	0.85	1	0.96	-0.63
(K)	0.12	0.09	-0.08	0.07	0.03	0.25	0.39	0.16	0.77	0.96	1	-0.66
(L)	-0.22	-0.17	0.24	-0.32	-0.06	-0.11	-0.22	-0.21	-0.55	-0.63	-0.66	1

Table 5. Correlation Analysis for year 2001 (underline indicate over 0.9)

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
(A)	1	0.99	0.16	0.91	0.98	-0.02	-0.72	0.99	-0.19	-0.32	-0.35	-0.20
(B)	0.99	1	0.13	0.88	0.97	-0.04	-0.72	0.98	-0.20	-0.32	-0.34	-0.17
(C)	0.16	0.13	1	0.26	0.17	0.11	-0.26	0.05	0.16	0.01	-0.09	0.03
(D)	0.91	0.88	0.26	1	0.95	0.03	-0.77	0.87	-0.17	-0.35	-0.44	-0.31
(E)	0.98	0.97	0.17	0.95	1	0.04	-0.70	0.97	-0.11	-0.27	-0.32	-0.18
(F)	-0.02	-0.04	0.11	0.03	0.04	1	0.15	-0.03	0.31	0.40	0.35	-0.11
(G)	-0.72	-0.72	-0.26	-0.77	-0.70	0.15	1	-0.66	0.58	0.77	0.84	0.21
(H)	0.99	0.98	0.05	0.87	0.97	-0.03	-0.66	1	-0.18	-0.29	-0.30	-0.19
(I)	-0.19	-0.20	0.16	-0.17	-0.11	0.31	0.58	-0.18	1	0.92	0.83	0.17
(J)	-0.32	-0.32	0.01	-0.35	-0.27	0.40	0.77	-0.29	0.92	1	0.97	0.14
(K)	-0.35	-0.34	-0.09	-0.44	-0.32	0.35	0.84	-0.30	0.83	0.97	1	0.14
(L)	-0.20	-0.17	0.03	-0.31	-0.18	-0.11	0.21	-0.19	0.17	0.14	0.14	1

Table 6. Correlation Analysis for year 2002 (underline indicate over 0.9)

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
(A)	1	0.98	0.19	0.91	0.98	0.08	-0.09	0.99	-0.13	-0.13	-0.16	-0.11
(B)	0.98	1	0.17	0.86	0.96	0.06	-0.12	0.97	-0.15	-0.15	-0.18	-0.06
(C)	0.19	0.17	1	0.26	0.22	0.01	-0.49	0.06	-0.15	-0.22	-0.37	-0.01
(D)	0.91	0.86	0.26	1	0.95	0.08	-0.18	0.87	-0.16	-0.16	-0.23	-0.23
(E)	0.98	0.96	0.22	0.95	1	0.04	-0.11	0.96	-0.11	-0.11	-0.17	-0.10
(F)	0.08	0.06	0.01	0.08	0.04	1	0.07	0.08	0.08	0.14	0.19	-0.41
(G)	- 0.09	-0.12	-0.49	-0.18	-0.11	0.07	1	0.04	0.79	0.79	0.90	0.09
(H)	0.99	0.97	0.06	0.87	0.96	0.08	0.04	1	-0.06	-0.05	-0.05	-0.10
(I)	-0.13	-0.15	-0.15	-0.16	-0.11	0.08	0.79	-0.06	1	0.97	0.93	-.04
(J)	-0.13	-0.15	-0.22	-0.16	-0.11	0.14	0.79	-0.05	0.97	1	*0.96*	-0.08
(K)	-0.16	-0.18	-0.37	-0.23	-0.17	0.19	0.90	-0.05	0.93	0.96	1	-0.05
(L)	-0.11	-0.06	-0.01	-0.23	-0.10	-0.41	0.09	-0.10	-0.04	-0.08	-0.05	1

Table 7. Correlation Analysis for year 2003 (underline indicate over 0.9)

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
(A)	1	0.98	0.22	0.98	0.99	0.07	0.45	0.99	-0.12	-0.18	-0.18	-0.18
(B)	0.98	1	0.20	0.94	0.95	0.02	0.40	0.97	-0.17	-0.22	-0.21	-0.15
(C)	0.22	0.20	1	0.26	0.25	-0.17	-0.41	0.12	-0.43	-0.37	-0.39	0.04
(D)	0.98	0.94	0.26	1	0.99	0.09	0.42	0.97	-0.14	-0.18	-0.18	-0.22
(E)	0.99	0.95	0.25	0.99	1	0.08	0.46	0.97	-0.11	-0.15	-0.15	-0.17
(F)	0.07	0.02	-0.17	0.09	0.08	1	0.32	0.09	0.55	0.55	0.52	-0.23
(G)	0.45	0.40	-0.41	0.42	0.46	0.32	1	0.52	0.70	0.60	0.65	-0.07
(H)	0.99	0.97	0.12	0.97	0.97	0.09	0.52	1	-0.06	-0.13	-0.13	-0.18
(I)	-0.12	-0.17	-0.43	-0.14	-0.11	0.55	0.70	-0.06	1	0.97	0.98	-0.29
(J)	-0.18	-0.22	-0.37	-0.18	-0.15	0.55	0.60	-0.13	0.97	1	0.99	-0.32
(K)	-0.18	-0.21	-0.39	-0.18	-0.15	0.52	0.65	-0.13	0.98	0.99	1	-0.28
(L)	-0.18	-0.15	0.04	-0.22	-0.17	-0.23	-0.07	-0.18	-0.29	-0.32	-0.28	1

4.2 Performance ranking in each year

Super-efficiency DEA models are very useful (Mei and Patrick, 2002). To compute each DMU's relative super-efficiency in 2000, 2001, 2002, and 2003, the reference set *R* of models (P3) and (P4) are composed by the DMUs listed in Table 2: {1, 2, …, 15}, {16, 17, …, 30}, {31, 32, …, 45}, and {46, 47, …, 60}. According to the method presented by Andersen and Petersen (1993), the objective *DMU-k* (the firm) is excluded from the reference set *R*. The solutions $q_k^*(2000)$, $q_k^*(2001)$, $q_k^*(2002)$, and $q_k^*(2003)$ are listed in Table 8.

Table 8. Performance measurement

DMU(k)	Object Name	$q_k^*(2000)$	$q_k^*(2001)$	$q_k^*(2002)$	$q_k^*(2003)$
1	ASE	1.3623	0.8368	0.9329	1.0556
2	SIPIN	1.0014	0.8666	0.9718	1.0149
3	OSE	0.8040	0.6430	0.7651	0.7018
4	ChipMos	0.9020	0.6911	0.7971	0.9400
5	KYEC	1.0011	0.7582	0.8842	0.9463
6	ASE Chung Li	1.0142	0.9608	1.0490	0.8593
7	Sharp in Taiwan	1.0756	0.9122	0.8999	1.0261
8	Greatek	0.8562	1.0188	1.0832	1.0050
9	Lingsen	0.9821	3.7011	0.9336	0.9806
10	PowerTech	1.2095	2.6095	0.9502	1.0800
11	UTC	2.4653	0.7547	1.7163	1.8301
12	KingPak	1.8506	0.9536	0.8646	0.8717
13	Hi-Sincerity	0.9098	2.1179	2.8790	3.2310
14	Formosa	0.8228	1.0407	1.0645	0.8853
15	Sigurd	0.8467	0.9654	1.0550	1.0702

As shown in Table 9, the top three DMUs in the packaging and testing industry are completely different each year. Some firms, however, display improvement every year, such as Hi-Sincerity and Sigurd. The stockholder, employees, and customers of OSE are disappointed in the past years.

Table 9. Performance measurement ranking of the evaluated firms

DMU(k)	Object Name	2000	2001	2002	2003
1	ASE	3	11	10	5
2	SIPIN	7	10	7	7
3	OSE	15	15	15	15
4	ChipMos	11	14	14	11
5	KYEC	8	12	12	10
6	ASE Chung Li	6	7	6	14
7	Sharp in Taiwan	5	9	11	6
8	Greatek	12	5	3	8
9	Lingsen	9	1	9	9
10	PowerTech	4	2	8	3
11	UTC	1	13	2	2
12	KingPak	2	8	13	13
13	Hi-Sincerity	10	3	1	1
14	Formosa	14	4	4	12
15	Sigurd	13	6	5	4

4.3 Productivity change over the four years

The Malmquist productivity index can be decomposed into two components measuring the change in the technology frontier and technical efficiency(Chen and Ali, 2004). In this section, we further examine the two components to reveal sources and patterns of productivity change that are obscured by the aggregated nature of the Malmquist index. It is shown that more information can be derived from the individual Malmquist components. Our proposed new approach not only reveals patterns of productivity change and presents a new interpretation along with the managerial implication of each Malmquist component, but also identifies the strategy shifts of individual DMUs in a particular time period. We can make judgments on whether or not such strategy shifts are favorable and promising.

We compute Malmquist Productivity Index by (P5)~(P9), as below.

Table 10. Efficiency score definition

Models	Efficiency scores	Objective firm-*k*'s x_{ik} and y_{rk} *are extracted from*	Set *R* in (P8) model is composed by
a	q_k^{a}	in year *t*	All DMUs in year *t*
b	q_k^{b}	in year *t*	firm-*k* in year *t* and all firms in year *t+1*
c	q_k^{c}	in year *t+1*	All DMUs in year *t+1*
d	q_k^{d}	in year *t+1*	firm-*k* at year *t+1* and all firms in year *t*

To compute the Malmquist coefficient of firm 2 between 2000 and 2001, M_2^{2000}, substitute *t* by 2000 and substitute k by 2 in Table 10. Then, for example, to compute q_2^{b}, take the data from the *DMU-2* row in Table 2 and use them for the y_{1k}, y_{2k}, y_{3k}, y_{4k}, and x_{1k}. The reference set *R* is composed of DMUs {2, 16, 17, …, 30}.

The solutions are shown in Table 11. Using the same process, we obtained the Malmquist coefficients of years (2001, 2002) and (2002, 2003), shown in Table 12 and Table 13, respectively.

Table 11. Malmquist Productivity Analysis of (2000, 2001)

DMU (k)	Object Name	q_k^{a}	q_k^{b}	q_k^{c}	q_k^{d}	M_k^{2000}
1	ASE	1	1	0.8368	0.6780	0.9001
2	SIPIN	1	1	0.8666	0.6887	0.8915
3	OSE	0.8040	1	0.6430	0.5215	1.0044
4	ChipMos	0.9020	1	0.6911	0.5562	0.9447
5	KYEC	1	1	0.7582	0.5876	0.8804

6	ASE Chung Li	1	1	0.9608	0.7495	0.8832
7	Sharp in Taiwan	1	1	0.9122	0.7280	0.8934
8	Greatek	0.8562	1	1	0.7951	0.9636
9	Lingsen	0.9821	1	1	1	1.0091
10	PowerTech	1	1	1	0.9181	0.9582
11	UTC	1	1	0.7547	0.5728	0.8712
12	KingPak	1	1	0.9536	0.7839	0.9066
13	Hi-Sincerity	0.9098	1	1	0.8989	0.9940
14	Formosa	0.8228	1	1	0.8259	1.0019
15	Sigurd	0.8467	1	0.9654	0.7679	0.9693

Aggregate the data from Tables 11 and compute the mean and the variance of the Malmquist coefficients in the three consecutive years. We ranked the firms according to the ratio of mean and standard deviations. The data are displayed in Table 12.

Table 12. Ranking according to the Malmquist coefficients

Firm k	Object Name	M_k^{2000}	M_k^{2001}	M_k^{2002}	$\mu(M_k)$	$s(M_k)$	$\mu(M_k)/s(M_k)$	Rank
1	ASE	0.9001	0.9940	0.9694	0.9545	0.0487	19.60	9
2	SIPIN	0.8915	0.9769	0.9540	0.9408	0.0442	21.27	8
3	OSE	1.0044	0.9172	1.0091	0.9769	0.0517	18.88	10
4	ChipMos	0.9447	0.9913	1.0298	0.9886	0.0426	23.20	7
5	KYEC	0.8804	0.9558	1.0299	0.9553	0.0748	12.78	13
6	ASE Chung Li	0.8832	0.9581	1.0040	0.9484	0.0610	15.55	12
7	Sharp in Taiwan	0.8934	1.0555	0.9784	0.9758	0.0811	12.03	14
8	Greatek	0.9636	0.9654	0.9826	0.9705	0.0105	92.42	2
9	Lingsen	1.0091	1.0349	1.0451	1.0297	0.0186	55.37	3
10	PowerTech	0.9582	1.0259	0.9689	0.9843	0.0364	27.05	6
11	UTC	0.8712	1.0336	1.0000	0.9683	0.0858	11.29	15
12	KingPak	0.9066	1.0218	1.0017	0.9767	0.0615	15.88	11
13	Hi-Sincerity	0.9940	1.0000	1.0000	0.9980	0.0035	287.93	1
14	Formosa	1.0019	0.9631	1.0304	0.9985	0.0338	29.58	5
15	Sigurd	0.9693	1.0178	0.9854	0.9908	0.0247	40.12	4

For Table 12, the MPI best firms are Hi-Sincerity, Greatek and Lingsen. The small scale firm Hi-Sincerity, and median scale firms Greatek and Lingsen are well known for their efficient performance. UTC, Sharp in Taiwan, and KYEC are the MPI worst firms. UTC and Sharp in Taiwan are fall out of market competition.

4.4 Relationship between the fifteen firms and the entire semiconductor-related industry

The entire semiconductor-related industry's revenue from 2000 to 2003 was $7,144, $5,269, $6,529, and $8,166, respectively, in hundred million Taiwan (NT) dollars (ITRI, 2004). Their yearly revenue in decedent order is years: 2003, 2000, 2002, and 2001. We explored the relationship between the fifteen firms and the entire semiconductor-related industry by calculating the relative efficiencies of firms in the following pairs of years: (2000, 2001), (2000, 2002), (2000, 2003), (2001, 2002), (2001, 2003), and (2002, 2003).

To evaluate the performance of years (2000, 2001), set R in models (P3) and (P4) are composed of DMUs 1, 2, 3,…30 from Table 2. Solve (P3) and (P4), then rank the 30 DMUs according to their efficiency scores. The first 15 DMUs' rankings are listed in the second row of Table 13. The next 15 DMUs are listed in the third row.

If the order of the data has more than two of the same order, the average order will be calculated. For example, the second through fifth order have the same efficiency score, so we calculate the average order, which is (2+3+4+5)/4 = 14/4 = 3.5. The summation of the second row is represented by S. T is the value computed according to the Wilcoxon-Mann-Whitney equation (Lehmann, 1977). m and n denote the amount of data in groups 1 and 2, respectively. In this example, n=15 and m=15. The two tails tolerance of t-test a is set to 0.05.

$$T = \frac{S - m(m+n+1)/2}{\sqrt{mn(m+n+1)/12}}$$

Therefore, S=138, T=-3.92, and $t_{a/2}$=1.96.

The test hypothesis is (Performance of 2000) = (Performance of 2001). If $T \geqq -t_{a/2}$ or $T \leqq t_{a/2}$, the hypothesis is accepted.

The results for (2000, 2002), (2000, 2003), (2001, 2002), (2001, 2003), and (2002, 2003) are depicted in Tables 13 and 14.

Table 13. Ranking firms in each pair years' comparison

Firm-*k*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
year 2000	3	7	19	13	8	6	5	15	9	4	2	1	12	18	16
year 2001	26	25	30	29	27	23	24	20	10	11	28	21	14	17	22
year 2000	3	9	20	12	8	7	6	15	10	4	2	1	11	18	17
year 2002	25	24	30	29	28	21	27	16	23	22	5	26	14	19	13
year 2000	2	7	27	14	8	6	5	18	9	3	4	1	13	23	20
year 2003	19	17	30	22	24	29	16	15	25	11	10	28	21	26	12
year 2001	24	23	30	28	27	20	18	13	3	2	25	15	6	10	14
year 2002	16	9	29	26	22	8	19	5	17	11	1	21	4	12	7
year 2001	25	24	30	27	28	23	19	20	8	2	26	17	3	16	15
year 2003	7	10	28	15	17	18	9	14	12	8	2	26	5	21	6
year 2002	23	21	29	28	24	17	26	14	20	18	1	27	3	7	12
year 2003	6	9	30	16	15	25	8	11	13	4	2	22	10	19	5

Table 14. Summary of performance analysis

Hypothesis(H_0)	DMUs in set R	S value	T value	Reject/Accept	conclusion
$P_{2000} = P_{2001}$	1~15, 16~30	138	-3.92	Reject	$P_{2000} < P_{2001}$
$P_{2000} = P_{2002}$	1~15, 31~45	143	-3.71	Reject	$P_{2000} < P_{2002}$
$P_{2000} = P_{2003}$	1~15, 46~60	160	-3.01	Reject	$P_{2000} < P_{2003}$
$P_{2001} = P_{2002}$	16~30, 31~45	258	1.06	Accept	$P_{2001} = P_{2002}$
$P_{2001} = P_{2003}$	16~30, 46~60	283	2.09	Reject	$P_{2001} > P_{2003}$
$P_{2002} = P_{2003}$	31~45, 46~60	270	1.56	Accept	$P_{2002} = P_{2003}$

From Table 14, we can conclude the performance in decedent order is: 2002, 2001, 2003, and 2000. The yearly revenue in decedent order is: 2003, 2000, 2002, and 2001. Apparently, the performance rankings and the revenue rankings are not consistent in years.

5. Conclusion

In this study, the conclusion will be illustrated as follows. Firstly, the packaging/testing firms are continuously changing every year in terms of managerial performance. Secondly, there exists considerable difference between four-year improvements and only one-year improvement by the MPI analysis for any one firm. Lastly, the trend of managerial performance of these 15 packaging/testing firms is not completely consistent with the trend of sales in semiconductor manufacturing industry.

In the semiconductor manufacturing industries, the back-end is much more varied than the front-end. The threshold for establishing a packaging and testing firm is considerably low and specialist back-end firms tend to end up as turn-key contractors. Obviously, the competition between back-end firms is becoming increasingly intense. Performance measurement is not only influenced by the net profit after tax and profitability, but by many other indices, such as growth rate, value created by employees, and liability ratio. One may apply these findings not only to packaging and testing firms, but also to other businesses, such as IC manufacturing, spinning and weaving, and car manufacturing.

References

1. Andersen, P. and Petersen, N. C. (1993), "A procedure for ranking efficient units in data envelopment analysis," Management Science, Vol. 39, No. 10, pp. 1261-1264.
2. Banker, R. D. and Morey, R. C. (1986), "Efficiency analysis for exogenously fixed inputs and outputs," Operations Research, Vol. 34, No. 4, pp. 513-521.
3. Banker, R. D. and Morey, R. C.(1986), The use of categorical variables in data envelopment analysis, Management Science, Vol. 32, No. 12, pp.1613-1627.
4. Banker, R. D., Charnes, A., and Cooper, W. W. (1984), "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis," Management Science, Vol. 30, No. 9, pp. 1078-1092.
5. Cakanyildirim, M. and Roundy, R. O. (2002), "Evaluation of capacity planning practices for the semiconductor industry", IEEE Transactions on semiconductor manufacturing, Vol. 15, No. 3, pp. 331-340.
6. Carbone, T. A. (2000), "Measuring efficiency of semiconductor manufacturing operations using data envelopment analysis (DEA)," IEEE/SEMI advanced semiconductor manufacturing conference, pp. 56-62.
7. Charnes, A., Cooper, W. W. and Rhodes, E. (1981), "Evaluating program and managerial efficiency: An application of data envelopment analysis to program follow through," Management Science, Vol. 27, pp. 668-697.
8. Charnes, A., Cooper, W. W., and Rhodes, E. (1978), "Measuring the Efficiency of Decision Making Units," Journal of Operational Research, Vol. 2, pp. 429-444.
9. Clarke, R. L. (1992), "Evaluating USAF vehicle maintenance productivity over time: An application of data envelopment analysis," Decision Science, Vol.23, No.2, pp. 376-384.
10. Common Wealth Magazine (2001), "Manufacture 1000," Vol. 30, pp. 118-157 (in Chinese).
11. Common Wealth Magazine (2002), "Manufacture 1000," Vol. 36, pp. 122-161 (in Chinese).
12. Common Wealth Magazine (2003), "Manufacture 1000," Vol. 274, pp. 138-177 (in Chinese).
13. Common Wealth Magazine (2004), "Manufacture 1000," Vol. 298, pp. 158-196 (in Chinese).
14. Drake, L. and Howcroft, B. (1994), "Relative efficiency in the branch network of a UK bank: An empirical study," OMEGA, Vol. 22, No. 1, pp. 83-90.
15. Feng, Hsiu-feng (2002), "A Study of Operational Efficiency in Semiconductor Industry— An Application of DEA Approach", Chung Yuan Christian University, master's thesis.
16. Golany, B. and Roll, Y. (1989), "An application procedure for DEA," OMEGA, Vol. 17, No. 3, pp. 237-250.
17. Golany, B., Yaakov, R., and Rybak, D. (1994), "Measuring Efficiency of Power Plants in Israel by Data Envelopment Analysis," IEEE Transactions on Engineering Management,

Vol. 41, No. 3, pp. 291-301.

18. Halme, M., Tarja, J., and Matti, K. (2002), "Dealing with interval scale data in Data Envelopment Analysis," European Journal of Operational Research, 137, pp. 22-27.
19. Huang, S. J., "The Empirical Study of Production Efficiency in Taiwan's Semiconductor Industry–An Application of DEA Approach", Shih Hsin University, master's thesis, 2003.
20. Industrial Technology Research Institute (2004), The semiconductor Industry in 2003, Taiwan. (In Chinese).
21. Lehmann, E. L. (1977), Nonparametrics: Statistical Methods Based on Ranks, McGraw-Hill international book Co., New York.
22. Lewin, A. Y., Morey, R. C. and Cook, T. J. (1982), "Evaluating the administrative efficiency of courts," OMEGA, Vol. 10, pp. 401-411.
23. Mei X. and Patrick T.H. (2002), "Notes: Ranking DMUs with Infeasible Super-Efficiency DEA Models," Management Science, Vol. 48, No. 5, pp. 705-710.
24. Parad I, J. C., Smith, S., and Claire, S. C. (2002), "Knowledge Worker Performance Analysis Using DEA: An Application to Engineering Design Teams at Bell Canada," IEEE Transactions on Engineering Management, Vol. 49, No. 1, pp. 161-173.
25. Smith, P. (1990), "Data envelopment analysis applied to financial statements," OMEGA, Vol. 18, No. 2, pp. 131-138.
26. Weir, J., Ed. (1998), Annual Report & directory, Semiconductor Industry Association, San Jose, CA.
27. Yao Chen and Agha Iqbal Ali (2004), "DEA Malmquist productivity measure: New insights with an application to computer industry," European Journal of Operational Research, Vol. 159, pp. 239–249.

Authors' Biographies

Kuo-Hua Yang received his B. S. degree major in Industrial Engineering from the Chung Yuan Christian University, Taoyuan, Taiwan, in 1988. He has several years of working experience in San Yang Industry, Acer computer company, King Yuan electronic Inc. Currently, he is a manager of manufacturing division in Winstek Semiconductor Engineer Company, focusing in project planning and improvement, new facility planning, efficiency improvement and aggregated corporation planning.