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Grey Model for Evaluation and Analysis of Competitiveness in the Packaging and Testing Industry

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The integrated circuit (IC) packaging and testing industry is an important link in the semiconductor industrial chain that may decide the success or failure of the foundry industry. The purpose of this study was to compare the competitiveness of the packaging and testing industry in the rear section of the foundry process in Taiwan. Starting from the financial data of six listed companies and using Grey theory, this study summarizes their five factors of competition: scale, growth, profit, efficiency and risks. The study confirmed that the model is able to effectively compare the competitiveness of corporations in the same industry.

Keywords: Competitiveness, foundry, outsourced assembly and test, financial analysis, grey theory

JEL: C02, C60

Semiconductor refers to a substance that can conduct electric current under some circumstances, while it can be used as an insulator under other circumstances (Bouguezzi *et al.*, 2016; Tirkel, 2013). An integrated circuit (IC) means that on a semiconductor substrate, many electronic circuits are combined into various electronic components, such as diodes and transistors through oxidation, etching, and diffusion, and laminated onto a small area to complete certain logic functions (AND, OR, NAND etc.) and to further achieve pre-set circuit functions (Wang and Pan, 2016; Zhao and Wu, 2016). The raw material of a semiconductor is "silicon" of sand. Silicon itself is an insulator, but if we add a small amount of impurity atoms, it will become a little conductive, but not too conductive, semiconductor (Li and Schlichtmann, 2015). If we further divide a small silicon into several areas and add different impurity atoms into each area, the semiconductor turns into a very small volume of a current switch through this special design. After combining different kinds of switches, a firm can produce a chip used for mobile phones or computers with various zoom and control functions.

The semiconductor industry chain includes the IP (Intellectual Property) design industry and the IC design industry in the upstream; IC manufacturing, wafer fabrication and related production processes and testing equipment, photo mask, and other businesses in the mid-stream; and the IC packaging and testing industry in the downstream (Cesaroni and Piccaluga, 2013). The most important industry here is IC

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packaging and testing, because it ultimately may decide the success or failure of a semiconductor product. IC packaging uses a plastic, ceramic, or metal substance to coat the grain of a finished wafer so that the grain can avoid contamination and be easily assembled. This industry also helps to design for achieving better effects of electrical connection and heat radiation from the wafer and electronic system.

IC testing can be divided into two stages. One is the wafer testing before packaging, which mainly tests the electric properties. The other is the IC finished product test, which mainly tests IC functions and whether the electric properties and heat radiation are normal so as to ensure product quality. The IC packaging and testing industry in Taiwan is the global industry leader. Its yearly output value of over $10 billion makes a great contribution to the economic development of Taiwan. Therefore, this study establishes a Grey theory model to compare the competitiveness of Taiwan's IC packaging and testing industry.

Grey Competitive Model

Prior research indicates that Grey theory can be effectively applied to overcome unpredictability problems in cases of discrete data and deficient information (Rajesh *et al.*, 2015). The key advantage of grey theory is that it is reliable to generate satisfactory consequence utilizing a relatively small amount of data or with great factors variability (Thakur and Anbanandam, 2015). Lin *et al.* (2012) used the TOPSIS model to analyze the competitiveness of five automakers in Taiwan. Following that, Lin *et al.* (2013) employed a Grey theory model to compare the competitiveness of ten semiconductor manufacturing firms in Taiwan. Both models obtained good results. Thus, this study once more utilizes Deng's (1989) Grey theory to analyze the competitiveness of the packaging and testing industry in the rear section of foundry process in Taiwan. The study steps are given below:

– Construction of Decision Matrix

A decision matrix is a list of values that helps decision makers to identify and analyze sets of information and further develops a list of options (Cao *et al.*, 2015; Gul and Guneri, 2016). A list of weighted criteria were established in this study and each option against those criteria was evaluated. After evaluating each alternative, performance values of each attribute were obtained and with them we construct a decision matrix shown in Table 1.

Alternative	C_1	C_2	C_3	…	C_n
A_1	a_{11}	a_{12}	a_{13}	…	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2n}
A_3	a_{31}	a_{32}	a_{33}	…	a_{3n}
:	:	:	:	:	:
A_m	a_{m1}	a_{m2}	a_{m3}	…	a_{mn}

Table 1: Decision Matrix

Each alternative has *n* appraisal index and could be written as:

$$A_i = [a_{i1}, a_{i2}, a_{i3}, ..., a_{ij}, ..., a_{in}] \qquad (1)$$

In the A_i study, is the i^{th} corporation that was appraised and compared, C_j is the j^{th} competitiveness indicator, and a_{ij} is the performance value of the j^{th} competitiveness indicator of the i^{th} corporation.

– Normalized Decision Matrix

Because the magnitude order of each comparison index is different, if we put them on the same standard for comparison, then it is not fair and justified. Hence, we have to first normalize the values. In this study, we make a reference to the method introduced by Jiang *et al*. (1988) and separately use “the higher the better” and “the lower the better” models to process each element of various comparison indices according to the attribute of the index.

The target model of “the higher the better” is:

$$x_{ij} = \frac{a_{ij} - \underset{\forall i}{\min}\, a_{ij}}{\underset{\forall i}{\max}\, a_{ij} - \underset{\forall i}{\min}\, a_{ij}} \qquad (2)$$

The target model of “the lower the better” is:

$$x_{ij} = \frac{\underset{\forall i}{\max}\, a_{ij} - a_{ij}}{\underset{\forall i}{\max}\, a_{ij} - \underset{\forall i}{\min}\, a_{ij}} \qquad (3)$$

In this study, except for the equity multiplier that is the target model of “the lower the better”, all the other comparison indices are target models of “the higher the better.” Therefore, we are able to obtain the normalized value x_{ij} of the j^{th} competitiveness index of the i^{th} corporation. Here, x_{ij} is the competition comparison index value after the normalization process.

– Determine the Object Weight

Because the importance of each comparison index is different, we have to give each index a weight w_j and have to satisfy the rule that the total value of all weights should be equal to 1.

$$\sum_{j=1}^{n} w_j = 1 \qquad (4)$$

Diakoulaki *et al*. (1995) argued that when the looser the results measured by a group of indices are, the higher the importance will be for the group of measurement indices, and so when the standard deviation is higher, the greater the weight will be. Therefore, when determining the weight value, one must first obtain the standard deviation σ_j of each measurement index. The weight value of each measurement index can then be obtained with the following formula.

$$w_j = \frac{\sigma_j}{\sum_{j=1}^{n} \sigma_j} \qquad (5)$$

– Establish Standard Alternative A_0

The standard alternative is the alternative with the values of the best condition picked from each comparison index. It is defined as:

$$A_0 = [x_{01}, x_{02}, x_{03}, ..., x_{0n}] \qquad (6)$$

In this study, the best index value is the maximum value of each competitiveness comparison index after the normalization process – that is:

$$x_{0j} = \underset{\forall i}{\max}\, x_{ij} \quad i = 1,2,3,\ldots,m \qquad (7)$$

– **Establish a Difference Matrix**

We now calculate the difference between each index and standard alternative index to the following difference matrix:

$$\Delta = \begin{bmatrix} \Delta_{11} & \Delta_{12} & \Delta_{13} & \ldots & \Delta_{1n} \\ \Delta_{21} & \Delta_{22} & \Delta_{23} & \ldots & \Delta_{2n} \\ \Delta_{31} & \Delta_{32} & \Delta_{33} & \ldots & \Delta_{3n} \\ . & . & . & .. & . \\ \Delta_{m1} & \Delta_{m2} & \Delta_{m3} & \ldots & \Delta_{mn} \end{bmatrix}$$

Note that Δ_{ij} is the difference between the j th competitiveness comparison index of the i th corporation and the standard alternative index after the normalization process – that is:

$$\Delta_{ij} = \left| \, x_{ij} - x_{0j} \, \right| \qquad (9)$$

– **Calculate Grey Relational Coefficient**

The Grey relational coefficient of the j th competitiveness index of the i th corporation and standard alternative index is obtained by following formula:

$$\gamma_{ij} = \frac{\Delta_{\min} + \xi\, \Delta_{\max}}{\Delta_{ij} + \xi\, \Delta_{\max}} \qquad (10)$$

In which:

$$\Delta_{\min} = \underset{\forall i \;\; \forall j}{\min\min} \Delta_{ij} \quad i = 1,2,3,\ldots,m, \quad j = 1,2,3,\ldots,n \qquad (11)$$

Here, $\Delta_{\min}$ is the minimum value of the difference matrix.

$$\Delta_{\max} = \underset{\forall i \;\; \forall j}{\max\max} \Delta_{ij} \; i = 1,2,3,\ldots,m\,, \quad j = 1,2,3,\ldots,n \qquad (12)$$

Here, $\Delta_{\max}$ is the maximum value of the difference matrix.

Note that $\xi \in [\,0,1\,]$ is the identification coefficient designed to adjust the difference between the values of the individual Grey relation coefficients. It usually takes the value of 0.5.

– **Obtain Grey Relational Grade**

The correlation between each alternative and standard alternative is obtained through the following formula:

$$R_i = \sum_{j=1}^{n} \gamma_{ij} w_j \qquad (13)$$

Here, R_i is the Grey relational grade between the i th corporation and the standard alternative. A greater value represents that the corporation is closer to the standard alternative, and the performance value of their competitiveness comparison will be higher.

Selection for Competitiveness Indicators' Evaluation

Jin (2004) pointed out that the comparisons of enterprise competitiveness in China should include four factors: scale, growth, profit, and brand. However, because the measurement value of the indicator of a brand factor does not easily establish an objective standard measurement, this study therefore makes a reference to the model of Lin *et al*. (2012, 2013), who divided the comparison index into five factors: scale, growth, profit, efficiency, and risks. Table 2 shows the evaluation indicators of each factor and calculation.

Category	Ratio	Formula
Scale Factor	Revenue Scale	2014 Revenue / Total 2014 Revenue of all Enterprises
	Profit Scale	2014 Profit / Total 2014 Profit of all Enterprises
	Equity Scale	2014 Equity / Total 2014 Equity of all Enterprises
Growth Factor	Revenue Growth Rate	(2014 Revenue / 2013 Revenue) - 1
	Profit Growth Rate	(2014 Profit / 2013 Profit) – 1
	Equity Growth Rate	(2014 Equity / 2013 Equity) - 1
Profit Factor	ROA	2014 Net Profit / 2014 Average Asset
	ROE	2014 Net Profit / 2014 Average Equity
	Profit Margin	2014 Net Profit / 2014 Revenue
Efficiency Factor	Asset Turnover	2014 Revenue / 2014 Average Asset
	Accounts Receivable Turnover	2014 Revenue / 2014 Average Accounts Receivable
	Inventory Turnover	2014 Cost / 2014 Average Inventory
Risk Factor	Equity Multiplier	2014 Assets / 2014 Equity
	Current Ratio	2014 Current Assets / 2014 Current Liability

Table 2: Definitions of Evaluation Indicators for the Five Factors

Application of Grey Competitiveness Model

In this study we selected six listed packaging and testing firms from the foundry industry of Taiwan. They are Advanced Semiconductor Manufacturing Co. (ASE), Siliconware Precision Industry Co., Ltd. (SPIL), Powertech Technology Co., Ltd. (PTI), ChipMos Technologies Ltd. (Chip MOS), Chipbond Science and Technology Co., Ltd. (Chipbond), and King Yuan Electronics Co., Ltd. (KYEC Group). We extracted data from their public financial statements (see Table 3) to explore each corporation's competitiveness.

Enterprise	Revenue	Profit	Asset	Equity	Cost	Accounts Receivable	Inventory	Current Assets	Current Liabilities
ASE Group	8,465,652	799,153	11,018,630	5,227,239	6,699,230	1,746,002	1,456,615	5,277,358	3,668,774
SPIL	2,740,754	387,044	4,280,860	2,379,179	2,048,521	612,604	144,546	1,821,460	859,901
PTI	1,321,011	146,048	2,291,449	1,304,597	1,101,340	138,633	85,191	943,342	350,779
Chip MOS	726,009	126,302	1,142,706	688,389	555,384	158,872	56,242	676,660	275,284
Chipbond	583,412	87,210	1,322,765	790,618	442,857	158,561	33,990	635,134	351,269
KYEC Group	537,048	84,453	1,310,549	757,475	375,986	115,308	9,445	426,377	185,143

Table3: Data on Enterprises' Operational Performances in 2014 (US$ thousand)

Calculating the financial data of the six listed companies in Table 3 according to the methods shown in Table 2, we obtained the decision matrix shown in Table 4.

According to the target methods of "the higher the better" and "the lower the better" as shown in formula (2) and formula (3), we next normalized the data as shown in Table 4. Except for the equity multiplier evaluation indicator in the risk factor that has to be calculated according to the target method of "the lower the better" as given in formula (3), the rest of the evaluation indicators are the greater the more competitive, which have to be calculated according to the target method of "the higher the better." Thus we obtained the normalized data as shown in Table 5. We further calculated the standard deviation of each evaluation indicator from the normalized data and then substitute them into formula (5) to obtain the weight value of each evaluation indicator.

Enterprise	Scale Factor			Growth Factor			Profit Factor			Efficiency Factor		Risk Factor	
	Revenue Scale	Profit Scale	Equity Scale	Revenue Growth Rate	Profit Growth Rate	Equity Growth Rate	ROA	ROE	Profit Margin	Asset Turnover	Accounts Receivable Turnover	Inventory Turnover	Equity Multiplier	Current Ratio
ASE Group	0.5890	0.4902	0.4689	0.1671	0.4994	0.2459	0.0780	0.1696	0.0944	0.8267	5.3370	5.1392	2.1079	1.4385
SPIL	0.1907	0.2374	0.2134	0.1978	0.9909	0.1544	0.1013	0.1743	0.1412	0.7175	4.8978	15.4285	1.7993	2.1182
PTI	0.0919	0.0896	0.1170	0.0647	-2.3811	0.0669	0.0626	0.1156	0.1106	0.5663	9.1435	13.2464	1.7564	2.6893
Chip MOS	0.0505	0.0775	0.0618	0.1365	0.4167	0.1626	0.1184	0.1973	0.1740	0.6804	4.9682	10.4424	1.6600	2.4580
Chipbond	0.0406	0.0535	0.0709	0.1184	0.0139	0.0584	0.0675	0.1134	0.1495	0.4515	3.9587	11.6628	1.6731	1.8081
KYEC Group	0.0374	0.0518	0.0680	0.1077	0.4084	0.0583	0.0664	0.1147	0.1573	0.4225	2.2967	42.5408	1.7302	2.3030

Table 4: Decision Matrix of Business Competitiveness Comparison Indices

Enterprise	Scale Factor			Growth Factor			Profit Factor			Efficiency Factor		Risk Factor	
	Revenue Scale	Profit Scale	Equity Scale	Revenue Growth Rate	Profit Growth Rate	Equity Growth Rate	ROA	ROE	Profit Margin	Asset Turnover	Accounts Receivable Turnover	Inventory Turnover	Equity Multiplier	Current Ratio
ASE Group	1.0000	1.0000	1.0000	0.7692	0.8542	1.0000	0.2766	0.6702	0.0000	1.0000	0.4440	0.0000	0.0000	0.0000
SPIL	0.2779	0.4234	0.3725	1.0000	1.0000	0.5119	0.6943	0.7264	0.5884	0.7299	0.3799	0.2751	0.6890	0.5435
PTI	0.0989	0.0862	0.1358	0.0000	0.0000	0.0459	0.0000	0.0255	0.2031	0.3559	1.0000	0.2168	0.7846	1.0000
Chip MOS	0.0238	0.0586	0.0000	0.5396	0.8297	0.5559	1.0000	1.0000	1.0000	0.6381	0.3902	0.1418	1.0000	0.8151
Chipbond	0.0058	0.0039	0.0225	0.4033	0.7103	0.0002	0.0876	0.0000	0.6923	0.0719	0.2427	0.1744	0.9707	0.2955
KYEC Group	0.0000	0.0000	0.0152	0.3233	0.8272	0.0000	0.0685	0.0145	0.7899	0.0000	0.0000	1.0000	0.8433	0.6911
Standard Deviation	0.3554	0.3602	0.3558	0.3200	0.3258	0.3716	0.3690	0.4058	0.3427	0.3580	0.3018	0.3236	0.3366	0.3316
Weighting	0.0732	0.0741	0.0732	0.0659	0.0671	0.0765	0.0760	0.0835	0.0705	0.0737	0.0621	0.0666	0.0693	0.0683

Table 5: Normalized Comparing Indices

Because the optimal value after normalization should be 1, the value of each element in standard alternative A_0, which was established by formula (6), is 1. We now substitute them into formula (8) and formula (9) and establish the difference matrix as shown in Table 6.

Enterprise	Scale Factor			Growth Factor			Profit Factor			Efficiency Factor		Risk Factor	
	Revenue Scale	Profit Scale	Equity Scale	Revenue Growth Rate	Profit Growth Rate	Equity Growth Rate	ROA	ROE	Profit Margin	Asset Turnover	Accounts Receivable Turnover	Inventory Turnover	Equity Multiplier	Current Ratio
ASE Group	0.0000	0.0000	0.0000	0.2308	0.1458	0.0000	0.7234	0.3298	1.0000	0.0000	0.5560	1.0000	1.0000	1.0000
SPIL	0.7221	0.5766	0.6275	0.0000	0.0000	0.4881	0.3057	0.2736	0.4116	0.2701	0.6201	0.7249	0.3110	0.4565
PTI	0.9011	0.9138	0.8642	1.0000	1.0000	0.9541	1.0000	0.9745	0.7969	0.6441	0.0000	0.7832	0.2154	0.0000
Chip MOS	0.9762	0.9414	1.0000	0.4604	0.1703	0.4441	0.0000	0.0000	0.0000	0.3619	0.6098	0.8582	0.0000	0.1849
Chipbond	0.9942	0.9961	0.9775	0.5967	0.2897	0.9998	0.9124	1.0000	0.3077	0.9281	0.7573	0.8256	0.0293	0.7045
KYEC Group	1.0000	1.0000	0.9848	0.6767	0.1728	1.0000	0.9315	0.9855	0.2101	1.0000	1.0000	0.0000	0.1567	0.3089

Table 6: Difference Matrix with Standard Index Difference

From Table 6, we can see that $\Delta_{\min} = 0$ and $\Delta_{\max} = 1$. Substituting each Δ value into formula (10), we next obtain the Grey relational coefficient in Table 7. We then multiply the Grey relational coefficient by the weight value in Table 1 and sum them up through formula (13) to figure out the Grey relational grade given in Table 7. A higher value represents being closer to the standard alternative and denotes a corporation with higher competitiveness. From Table 7, we note that the top one is ASE, followed in order by

Chip MOS, SPIL, KYEC, PTI, and Chipbond.

Enterprise	Scale Factor			Growth Factor			Profit Factor			Efficiency Factor			Risk Factor		Grey Relational Grade	Rank
	Revenue Scale	Profit Scale	Equity Scale	Revenue Growth Rate	Profit Growth Rate	Equity Growth Rate	ROA	ROE	Profit Margin	Asset Turnover	Accounts Receivable Turnover	Inventory Turnover	Equity Multiplier	Current Ratio		
ASE Group	0.0000	0.0000	0.0000	0.2308	0.1458	0.0000	0.7234	0.3298	1.0000	0.0000	0.5560	1.0000	1.0000	1.0000	0.6701	1
SPIL	0.7221	0.5766	0.6275	0.0000	0.0000	0.4881	0.3057	0.2736	0.4116	0.2701	0.6201	0.7249	0.3110	0.4565	0.5895	3
PTI	0.9011	0.9138	0.8642	1.0000	1.0000	0.9541	1.0000	0.9745	0.7969	0.6441	0.0000	0.7832	0.2154	0.0000	0.4676	5
Chip MOS	0.9762	0.9414	1.0000	0.4604	0.1703	0.4441	0.0000	0.0000	0.0000	0.3619	0.6098	0.8582	0.0000	0.1849	0.6442	2
Chipbond	0.9942	0.9961	0.9775	0.5967	0.2897	0.9998	0.9124	1.0000	0.3077	0.9281	0.7573	0.8256	0.0293	0.7045	0.4399	6
KYEC Group	1.0000	1.0000	0.9848	0.6767	0.1728	1.0000	0.9315	0.9855	0.2101	1.0000	1.0000	0.0000	0.1567	0.3089	0.4883	4

Table 7: Matrix of Grey Relational Coefficient and Grey Relational Grade

DISCUSSION

ASE, ranked top on the list, has been aggressive in the global IC packaging and testing industry by expanding capacity. The firm is ranked number one on four factors: scale, growth, efficiency and risks. Although ASE's factor of profit is not the highest, it is able to rapidly respond to changes in the external operating environment, allowing them keep the number title in the global packaging and testing industry. Therefore, this research ranks ASE as being No. 1 in comprehensive competitiveness.

In second place is Chip MOS, with a scale factor of four. However, because Chip MOS is able to precisely foresee investment planning and strictly control costs, its profit factor is the best among the six firms. Because it maintains steady profit growth, its overall competitiveness is in second place.

Third place is for SPIL. It has rapidly expanded its capacity and ranks at the top for three factors: scale, growth, and profit. Its risk factor is ranked in the middle. SPIL's operation strategy is steady growth, and hence its comprehensive competitiveness is ranked third.

In fourth place is for KYEC. Despite its scale factor being ranked in last place, it has continuously invested in the expansion of new plants to increase the production of CMOS sensors, consumer electronic components, MEMS, and the capacity of part logic IC testing. Hence, KYEC's growth, profit, efficiency, and risk factors are ranked in the middle. It has also adopted an operation strategy of steady growth. Therefore, its comprehensive competitiveness is in fourth place.

PTI is on fifth number. Due to over-reliance on orders from Japanese DRAM giant Elpida, when Elpida shocked the DRAM industry and unexpectedly filed for bankruptcy on February 27, 2012, all of PTI's scale, growth, and profit factors slid to last place. As a result, its overall competitiveness slid to fifth place.

Last place is for Chipbond, as its four factors of scale, growth, profit, and efficiency are all at the bottom. This shows that Chipbond has been unable to rapidly respond to changes in the external operating environment. As a result, its pace of capacity expansion and vertical technology integration is slower compared to the other firms. Thus, Chipbond's overall competitiveness is ranked last.

CONCLUSION

Extracting data from the public financial statements issued by six listed packaging and testing corporations in 2013 and 2014, this study employed the characteristics of Grey theory to analyze their competitiveness. The results were then compared with their actual operating situation in the first half of 2015. We are able to confirm that using Grey theory to establish a competitiveness comparison model can truly reflect a corporation's future competitiveness.

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