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Full Length Research Paper

Efficiency evaluation of Asian large scale printed circuit board firms

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The rapid growth of semiconductor foundries in Asia has lead to increased demand for printed circuit boards (PCBs), and thus the region has become the main production site of the PCB industry. Because maintaining a high level of performance can enhance competitiveness, it is important for PCB firms to measure their comparative performance. In this work, a survey is conducted to obtain the operating data of Asian large roach in data envelopment analysis is applied to identify the benchmark firm. We interview the managers of firms to obtain retails of the relevant outstanding strengths and strategies, from which some management insights are obtained. The contributions of this study are that it can not only compare the strengths and advantages among this areas in the PCB industry, but also the management insights thus obtained can be used as a reference for the management of PCB firms in a challenging economic climate.

Key words: Data envelopment analysis, efficiency, printed circuit board, slack analysis.

INTRODUCTION

Semiconductors are the basis of integrated circuits (IC), and printed circuit boards (PCB) are the platforms upon which microelectronic components, such as semiconductor chips and capacitors, are mounted, as well as providing the electrical interconnections between such components. PCB are found in virtually all electronic products, and are thus an essential part of various businesses with combined sales of about one trillion US dollars a year. Many of the firms that produce PCB are located in Asia, and the region currently produces three-fourths of the world's PCB (LaDou, 2006).

Although global competition and shorter product life cycles have contributed to the challenges faced by businesses, better performing firms can still develop and maintain a high level of competitiveness. Performance is conventionally defined either as organizational inputs or outputs, or as a relationship between these, usually stated as efficiency. However, because the evaluation characteristics are generally multi-dimensional, the basic problem of performance measurement is how to evaluate the relative efficiency of business units. To overcome this difficulty, data envelopment analysis (DEA) is a widely utilized methodology for such evaluations within a group of business units, and is often found in the management literature (Chang and Chen, 2008;Kao and Hung, 2008; Kao and Hwang, 2008).

Because maintaining a high level of performance can enhance competitiveness, it is important for business units to measure their comparative performance. In this study, an efficiency evaluation of Asian large scale printed circuit board firms is carried out, with the aim of dealing with the questions that which are the benchmark PCB firms in Asia, and what are their respective management strengths. Therefore, this study applies the DEA analysis to deal with this issue. In DEA, the selection of relevant assessment factors is perhaps the most difficult part of evaluating the management performance of firms, since it involves understanding the specific characteristics of an industry and often overcoming problems with regard to the accessibility of data. In this work, we studied the literature about the factors of performance evaluation in manufacturing industries, discussed these with experts, and derived five inputs and five outputs relevant to the PCB industry. For the efficiency evaluation of PCB firms, this study applies the slack analysis approach (Bao et al., 2008) in DEA to identify the benchmarks, since it can deal with the small sample size problem and ensure a full ranking of units. In addition, this study discusses several management insights that can be used as a reference for the management of PCB firms in a competitive environment.

METHODOLOGY

DEA is a mathematical programming approach that uses multiple inputs and outputs to measure relative efficiencies within a group of units. The relative efficiency of a unit within the DEA framework is defined as the ratio of multiple weighted outputs to multiple weighted inputs.

If we use *s* outputs and *m* inputs to evaluate *n* units, y_{ik} is denoted as the observed level of output *i* and x_{rk} as that of input *r* of unit *k*, the efficiency measurement for unit *j* is the optimal value of the objective function of the following linear programming model, referred to as the CCR model (Charnes et al., 1978).

$$\text{Max} \quad h_j = \sum_{i=1}^{s} u_i y_{ij}$$

$$\text{s.t.} \quad \sum_{r=1}^{m} v_r x_{rj} = 1 \qquad (1)$$

$$\sum_{i=1}^{s} u_i y_{ik} - \sum_{r=1}^{m} v_r x_{rk} \le 0, \; k = 1,2,\ldots,n$$

$$u_i, v_r \ge \varepsilon > 0, \; i = 1,2,\ldots,s, \; r = 1,2,\ldots,m$$

Where u_i and v_r are decision variables associated with output *i* and input *r*, respectively, and ε is a positive non-Archimedean infinitesimal. This model allows each business unit to effectively select the weights that best maximize the weighted outputs, but at the same time the constraints prevent the efficiencies of the *n* units calculated by these weights from exceeding a value of one. If the efficiency score of unit *j* is equal to one, then it is classified as efficient, and inefficient otherwise.

For efficiency measurement, if additional useful information for the decision maker is obtained during the efficiency evaluation of units, the weight-restricted DEA models can be utilized (Charnes et al., 1990; Kao and Hung, 2005; Roll et al., 1991; Thompson et al., 1990; Wong and Beasley, 1990). In situations when no additional useful information is obtained, Adler et al. (2002) classified the ranking methods in DEA into six groups, and argued that the mean cross-efficiency is more representative than self-evaluation of a unit. In addition, Doyle and Green (1994) argued that decision makers do not always have a reasonable mechanism from which to determine weight restrictions, and thus recommended the cross-efficiency matrix for efficiency measurement.

Cross-evaluation method

The cross-evaluation technique is to use DEA in peer-evaluation logic instead of self-evaluation. A peer-evaluation means calculating the efficiency score of a business unit by evaluating it using the best weights of other units, and thus there are $(n-1)$ cross efficiencies for each one.

Cross-efficiency matrix

The cross-efficiency method calculates $(n-1)$ efficiency scores for each unit, using the optimal weights obtained by the linear programs associated with the other $(n-1)$ business units, and averaging these cross-efficiencies to get the mean cross-efficiency. To be specific, let u_{ij}^* and v_{rj}^*, $i = 1,2,...,s$, $r = 1,2,...,m$, be the optimal weights associated with output *i* and input *r* of unit *j*, respectively. The cross efficiency of unit *k*, using the weights of unit *j* is shown as Equation (2).

$$E_{kj} = \frac{\sum_{i=1}^{s} u_{ij}^* y_{ik}}{\sum_{r=1}^{m} v_{rj}^* x_{rk}}, \; k \ne j. \qquad (2)$$

The mean cross-efficiency of unit *k* is defined as $\phi_k = \sum_{j=1, j\ne k}^{n} E_{kj} \Big/ (n-1)$ and is an efficiency index of it. However, the cross-efficiency matrix is an empirical approach, and thus Bao et al. (2008) introduced the slack analysis approach to provide an interpretation of it. Moreover, they showed that the ranking result is the same as that of the cross-efficiency matrix.

Slack analysis approach

In solving Model (1), there are *n* slack variables s_{kj}, $k = 1,2,\ldots,n$, are added to the constraints. The s_{kj} value is the difference between the total weighted inputs and the total weighted outputs of unit *k* using the best weights of unit *j*, that is, larger the s_{kj}, the poorer the performance of unit *k*. Therefore, Bao et al. used s_{kj} to rank business unit. However, the value of s_{kj} may be influenced by the total weighted inputs or outputs of unit *k*. To avoid this, Bao et al. (2008) scaled the s_{kj} by the total weighted inputs or the total weighted outputs of unit *k* shown as Equations (3a) and (3b), respectively.

$$s_{kj}^{I*} = \frac{s_{kj}}{\sum_{r=1}^{m} v_{rj}^* x_{rk}}, \; k = 1,2,...,n \qquad (3a)$$

$$s_{kj}^{O*} = \frac{s_{kj}}{\sum_{r=1}^{m} u_{ij}^* y_{ik}}, \; k = 1,2,...,n \qquad (3b)$$

Based on Equation (3a), they proposed an efficiency index for unit *k*, shown as Equation (4).

$$\theta_k = \sum_{j=1, j\ne k}^{n} s_{kj}^{I*} \Big/ (n-1), \qquad (4)$$

If $\theta_k < \theta_l$,then the efficiency of unit *k* is better than that of unit *l*, and thus unit *k* should receive a prior rank than unit *l*. Bao et al. (2008) show that the efficiency scores and the ranking result of business units derived from the slack analysis approach are the same as those produced by the cross-efficiency matrix, no matter whether s_{kj} is scaled by the total weighted inputs or outputs of unit *k*. The advantages of the slack analysis are that not only that the s_{kj} values can be derived from the CCR model, and thus ranking business units is an easy task, but also that it is an appropriate method to deal with the efficiency evaluation for a small sample size. Consequently, this study applies the slack analysis approach to the efficiency ranking of PCB firms located in Asian areas.

EFFICIENCY EVALUATION OF PCB FIRMS

Manufacturing printed circuit boards is highly complicated, requiring significant investment in equipment and over fifty process steps. In 2003, the United States produced 15% of the world's PCB, trailing Japan, the largest producer at 29%, and China, the second largest at 17%. Taiwan was the fourth largest producer at 13%, EU countries produced only 10%, and South Korea 8%. In 2006, China overtook Japan as the leader in PCB production, producing US$10.6 billion worth of PCB and accounting for 25% of the world total. Consequently, there is every reason to believe that the center of gravity of this industry has now moved to Asia, which produced three-fourths of the world's PCB in 2009. More specifically, the production value of PCB from China, Japan, and Taiwan accounted for 28, 23 and 14% of the world total, respectively, and thus about two-thirds of the world's PCB was produced in these three areas in 2009.

THE PCB MANUFACTURING PROCESSES

Printed circuit boards are important components in electronic products, and their production can be categorized in several ways. Of these, the layer count is widely used because it relates to the overall technological level of the related processes, in that a higher layer counts require more sophisticated technology. The most commonly produced type of PCB is double-sided boards, and the multilayer boards represent two-thirds of these. Multilayer boards may have between 2 to 40 layers, and each with its own circuit patterns. Another way to categorize PCB is whether their substrates are flexible (sometimes referred to as flex) or rigid, although the manufacturing processes for these are similar. Other common ways of considering the production process include the minimum via size (the smallest hole that is drilled and plated successfully) and minimum trace width (the smallest feature that can be imaged and etched successfully).

THE SAMPLES AND THE INPUT/OUTPUT FACTORS

Since about two-thirds of the world's PCBs are produced in China, Japan, and Taiwan, this study focuses on firms in these areas. Because the PCB industry is capital-intensive, favoring large manufacturers with considerable financial resources, this study focuses on the large scale PCB firms to identify the benchmark firms and to investigate their management strengths. Consequently, the sample firms were selected by the following criteria: (1) The manufacturing processes of the firms consist of drilling, image transfer, and electroplating; and (2) Firm capital should be at least 350 million US dollars. Twelve large scale PCB manufacturers satisfy both these criteria in Asia.

The relative efficiency of a unit in the DEA framework is defined as the ratio of multiple weighted outputs to multiple weighted inputs, so that the input and output factors are essential for this study. We studied the literature on factors of management performance evaluation in manufacturing industries, as well as consulting experts, who were the managers of PCB firms, and select five inputs and five outputs as the candidate evaluation factors. The input factors are defined as follows:

1. Capital (X_1): The book value of capital at the year end.
2. Cost of goods sold (X_2): The total cost of goods sold in the year.
3. Number of employees (X_3): The average number of full-time employees in the year.
4. Book value of equipment (X_4): The total book value of operating equipment and tooling at the year end.
4. Research and development expense (X_5): The total expenditure on research and development in the year.

The outputs are defined as follows:

1. Sales revenue (Y_1): The total net sales revenue in the year.
2. Customer satisfaction index (Y_2): The average index of the customer satisfaction in a year, as derived from questionnaires.
3. Average yield rate (Y_3): The average value of the ratios of the actual finished goods quantities to the equivalent input PCB quantities in the year.
4. Technology level index (Y_4): The index derived from the number of patents, board thickness, and trace space.
5. Inventory turnover rate (Y_5): The ratio of cost of goods sold to average inventory amount.

There are eleven effective samples (that is, firms) obtained, and the managerial data are presented in Tables A1 and 2 in Appendix. For these samples, firms A, B, C, and D are located in Japan, firms E, F, and G are planted in Taiwan, and H, I, J, and K are located in China. The only Korean company, Samsung, was excluded from the sample because we could not acquire its operating data.

Dyson et al. (2001) argued that problems may occur when the volume measures are mixed with indices, ratios or percentages in the input/output sets. To avoid this, we scale the original data of each factor by dividing each value using its sample mean. The scaled data of these sample firms are presented in Tables A3 and 4 in Appendix.

FACTOR SELECTION

There is an assumption in DEA that the inputs and outputs should be *isotonic*, that is, increased input reduces efficiency, whilst increased output increases it. Moreover, if the subsets of inputs or outputs are highly correlated, it is often tempting to delete some correlated variables in the DEA evaluation. This is generally unlikely to have a large impact on the results, as with highly correlated variables weight can often be moved from one factor to another without having a significant effect on the efficiency score. Therefore, this study calculates the Pearson correlation coefficients of factors for variable selection, and they are presented in Table 1.

Because Y_4 and Y_5 are not so correlated with the inputs that they violate the isotonic characteristic, we first exclude them since most of their correlation coefficients are negative. Moreover, X_5 is not highly correlated with the retained outputs after excluding Y_4 and Y_5, so this factor is also excluded. In addition, there are two sets of factors that are highly correlated, $S_1 = \{X_2, X_3, X_4\}$ and $S_2 = \{Y_1, Y_3\}$, and thus we retain X_2 in S_1, and retain Y_1 in S_2, since the input factor X_2 and the output factor Y_1 have the highest correlation coefficients compared to those of X_3 and X_4. Based on the isotonic and strong correlation characteristics, this study utilizes *capital* (X_1) and *cost of goods sold* (X_2) as the assessment inputs, and *sales*

Table 1. Pearson correlation matrix of factors

	X_1	X_2	X_3	X_4	X_5	Y_1	Y_2	Y_3	Y_4	Y_5
X_1	1.000	0.389	0.125	0.506	0.435	0.374	0.564	-0.137	0.284	-0.103
X_2		1.000	0.866	0.896	-0.563	0.986	0.265	0.752	-0.507	0.017
X_3			1.000	0.888	-0.786	0.883	0.194	0.873	-0.831	-0.367
X_4				1.000	-.0521	0.904	0.324	0.669	-0.633	-0.348
X_5					1.000	-0.583	0.252	-0.891	0.904	0.224
Y_1						1.000	0.343	0.768	-0.533	-0.036
Y_2							1.000	0.028	0.199	-0.017
Y_3								1.000	-0.777	-0.120
Y_4									1.000	0.560
Y_5										1.000

Table 2. The scaled data of factors of sample PCB firms.

Firm	Input		Output	
	X_1	X_2	Y_1	Y_2
A	1.501	0.929	0.900	1.008
B	1.359	0.755	0.711	1.041
C	0.947	0.531	0.501	1.008
D	0.670	0.406	0.381	1.019
E	1.154	1.447	1.346	0.986
F	0.887	1.032	1.095	0.975
G	0.554	0.755	0.678	0.942
H	1.248	1.709	1.822	1.041
I	1.016	1.348	1.535	1.052
J	0.878	1.303	1.287	0.997
K	0.785	0.786	0.744	0.931

revenue (Y_1) and *customer satisfaction index* (Y_2) as the assessment outputs, and the scaled data are presented in Table 2.

DATA ANALYSIS AND THE RESULTS

In this study, the value of ε was setting as equal to 10^{-4} and LINGO software was utilized, and the weight sets of factors and efficiency scores for individual firms using the CCR model are presented in Table 3. For efficiency ranking of these sample firms, we apply Equations (3a) and (4), and the ranking result is presented in the last column of Table 4. The ranking result indicates that firm I, located in China, has the best management performance, since it receives the smallest ranking index, $\theta_{\mathrm{I}} = 0.078$. Note that there are nine slacks of zero for firm I under the most favorable weights of the eleven firms. Since smaller slack means better performance, firm I is a benchmark among the sample PCB firms. Notably, two Japanese PCB firms are ranked as the last, and thus this study compares the strengths and weaknesses of firms in these areas.

DISCUSSION

From the financial perspective, we define the gross profit rate (GPR) as Equation (5), and the GPRs obtained for the firms are presented in Table 5. By associating the GPRs with the ranking result, some findings can be summarized, as follows.

Gross profit rate =

$$\frac{(\text{Sales revenue} - \text{Cost of goods sold})}{\text{Sales revenue}} = 1 - \frac{X_2}{Y_1} \quad (5)$$

Finding 1

Firm I not only attains the best management performance (with a rank of 1) but also it has the highest GPR (a value of 28.65%). Consequently, there might be some management insights to be gained by examining this firm. Therefore, we interviewed the CEO of firm I, and two conclusions were derived.

Table 3. The set of weights and the efficiencies of the sample PCB firms.

Firm	Inputs		Outputs		CCR efficiency
	v_1^*	v_2^*	u_1^*	u_2^*	
A	10^{-4}	1.076	0.876	0.101	0.890
B	10^{-4}	1.324	1.077	0.125	0.896
C	10^{-4}	1.883	1.532	0.177	0.949
D	1.351	0.233	10^{-4}	0.381	1.000
E	10^{-4}	0.691	0.562	0.065	0.821
F	0.433	0.597	0.609	0.295	0.954
G	1.462	0.252	10^{-4}	1.061	1.000
H	0.801	10^{-4}	0.530	10^{-4}	0.966
I	10^{-4}	0.742	0.651	10^{-4}	1.000
J	1.139	10^{-4}	0.582	0.251	0.999
K	0.535	0.738	0.752	0.365	0.899

Table 4. The scaled slacks and ranking indices of all firms.

Rated firm	Rating firm											Index θ_k	Ranking
	A	B	C	D	E	F	G	H	I	J	K		
A	-	0.110	0.011	0.560	0.109	0.298	0.559	0.603	0.149	0.546	0.298	0.324	10
B	0.103	-	0.104	0.493	0.103	0.288	0.492	0.654	0.173	0.564	0.288	0.326	11
C	0.054	0.054	-	0.295	0.054	0.172	0.295	0.650	0.173	0.495	0.171	0.241	8
D	0.000	0.000	0.000	-	0.000	0.000	0.000	0.624	0.176	0.375	0.000	0.117	3
E	0.179	0.179	0.179	0.490	-	0.186	0.490	0.228	0.183	0.216	0.186	0.252	9
F	0.048	0.048	0.048	0.335	0.048	-	0.335	0.183	0.068	0.127	0.046	0.128	4
G	0.151	0.152	0.152	0.000	0.151	0.000	-	0.189	0.211	0.000	0.000	0.101	2
H	0.075	0.075	0.075	0.510	0.075	0.092	0.067	-	0.638	0.070	0.093	0.177	6
I	0.000	0.000	0.000	0.388	0.000	0.000	0.388	0.000	-	0.000	0.000	0.078	1
J	0.124	0.124	0.124	0.343	0.124	0.070	0.343	0.030	0.132	-	0.070	0.148	5
K	0.118	0.118	0.118	0.265	0.118	0.101	0.265	0.372	0.168	0.254	-	0.190	7

First, the highest GPR indicates that firm 1 attains the lowest ratio of cost of goods sold to sales revenue. The major reason is that firm 1 produces a niche product, known as IC substrate. This substrate needs high-end manufacturing technology, and thus the unit price of IC substrate is relatively higher than those of other PCB products. In addition, firm 1 has a high enough technological level, the line space/line width is about 2.5/2.5 micron miles, compared to the other Chinese PCB firms. Therefore, it is able to produce IC substrate with a relatively low defect ratio, and thus this product can make a significant contribution to its profit margins.

Second, in order to reduce the response time for customer orders and improve the customer service level, a third party logistics provider was introduced to incorporate services such as inventory management, warehousing, procurement, transportation, systems administration, information systems, material subassembly, contract manufacturing, kitting, and import and export assistance. Meanwhile, an enterprise resource planning system was set up to integrate manufacturing and management information.

Finding 2

As can be seen in Table 5, the GPR of firm G is the lowest, with a value of 9.57%, although it is ranked as second by the ranking index. From the expert interview, the firm G produces a high mix of PCB in order for it to increase the yield rate for the equipment, even though the unit profits may be low. Because of the high mix production and considerable setup time, the manufacturing cost of firm G increases, and this reduces the gross profit. We examine the original operating data and find that its level of capital is the lowest of all the sample firms. Moreover, its inputs are all under the average levels, since the scaled values of inputs are all less than one (Table A3), meaning that firm G has well-controlled inputs. Therefore, the major reason for this

Table 5. The gross profit rates of firms.

Firm	Gross profit rate (%)
A	16.12
B	13.76
C	13.88
D	13.31
E	12.70
F	23.47
G	9.57
H	23.75
I	28.65
J	17.77
K	14.10

situation is that the unit prices of PCB products for firm G are relatively low compared to those of other firms, even though it has relatively good management efficiency.

Finding 3

The inventory turnover rate (Y_5) data indicates that most of the PCB firms in China and Japan achieve a low level of inventory turnover compared to those in Taiwan. A low inventory turnover rate will increase the book value of the inventory, and thus more operating cash is needed. Moreover, because the life cycle of electronic products is very short, a high book value of inventory will produce a high operating risk in the future. This study investigates this issue and finds that most large scale high-technology firms in Taiwan are located in science parks, and thus the upstream semiconductor firms and downstream electronic product firms are all located close to one another, which shortens both transportation distance and purchase lead time. In addition, each sample PCB firm examined in Taiwan had set up an enterprise resource planning system to integrate manufacturing and management information. Consequently, they have a relatively high inventory turnover rate.

Finding 4

The PCB products can be classified into five categories, namely high layer count, thin board, gold finger, LCD board and mass market, and the complexity of the techniques required moves from high to low in that order. The high layer count (more than 14 layers) is generally utilized in computer servers, since they need high reliability, while the thin boards (less than 2 micron miles) are generally utilized in mobile products and enhance the design and production of high density interconnections. Most of the Japanese firms examined in this study focus on these two types of PCB. Specific manufacturing equipment is generally required to produce the gold finger PCB, and they are usually utilized in the connectors of electronic components. PCB board products need well controlled enlargement or reduction of their dimensions, and mass market PCB are from two to six layers, which require a relatively low level manufacturing technique, and most of the Chinese firms produce this type of PCB. Consequently, the major production characteristic of the mass market PCB is their lower cost. Most of the Taiwanese firms are able to produce all five of these PCB. Based on the analysis of technology levels presented in this work, a better strategy for Japanese firms is to make strategic alliances or cooperate with Chinese firms so that the high layer count and thin board PCB are manufactured in Japan, while the mass market ones are produced in China. For the Chinese firms, they should strengthen their training programs, since they can then enhance both the capabilities and productivity of their employees. For Taiwanese firms, they should focus on niche products, such as IC substrates, even though they have the capability to produce every type of PCB, and thus increase the gross profit rate.

Because of the global financial crisis that started in 2008, there is likely to be a decline in the sales revenue for each firm. To maintain competitiveness and a high level of profit, these firms should thus reduce unnecessary expenses during periods of economic contraction, taking such steps as freezing the hiring of new personnel, since these can reduce the operating expenses. These efforts will help to improve efficiency in a challenging economic climate.

Conclusions

The rapid growth of the semiconductor industry in Asia has seen a rising demand for PCB, and thus Asia has quickly become the center of the global PCB industry. This study progresses in characterizing performance via a slack analysis that provides an assessment of the relative performance of large scale PCB firms in China, Japan, and Taiwan. According to the performance indices, a benchmark firm is identified, and then several management insights are obtained that can be applied to aid other PCB firms in improving their efficiency.

In many real world situations, an industry may contain a few of large scaled firms, and thus the slack analysis approach is an appropriate technique for efficiency measurement and ranking. The advantage of this approach is that it utilizes the available information from the CCR model to calculate the efficiency indices and ensures a full ranking, and thus the process is a relatively easy task.

Performance improvement is one of the most serious concerns for managers, since it can enhance the competitiveness of a firm. In future work, researchers can identify the improvement targets of factors for inefficient firms so that input wastages and/or output shortfalls can be eliminated. To this end, the assessment factors obtained in this study can be applied for the performance evaluation of related firms and industries of interest.

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APPENDIX

In this appendix we present the operational data and the scaled data of factors.

Table A1. The original inputs data of the sample PCB firms.

Firm	Input				
	Capital X_1 (10^6)	Cost of goods sold X_2 (10^6)	Number of employees X_3	Book value of equipments X_4	R & D expenditure X_5 (10^6)
A	1,000	640	3,863	406	17.7
B	905	520	2,979	332	14.3
C	631	366	2,055	225	11.0
D	446	280	1,656	182	12.5
E	769	997	6,250	440	6.7
F	591	711	4,677	314	5.7
G	369	520	3,950	215	4.3
H	831	1,178	12,300	649	0.9
I	677	929	10,080	514	0.7
J	585	898	11,400	458	0.3
K	523	542	6,900	428	0.3

Table A2. The original outputs data of the sample PCB firms.

Firm	Outputs				
	Sales revenue Y_1 (10^6)	Customer satisfaction index Y_2	Average yield rate Y_3	Technology level index Y_4	Inventory turnover rate Y_5
A	763	92	88	92	13
B	603	95	91	94	14
C	425	92	89	91	14
D	323	93	88	90	15
E	1,142	90	93	88	18
F	929	89	92	87	15
G	575	86	94	85	16
H	1,545	95	96	75	13
I	1,302	96	97	76	14
J	1,092	91	96	73	12
K	631	85	93	70	11

Table A3. The scaled inputs data of the sample PCB firms.

Firm	Inputs				
	Capital	Cost of goods sold	Number of employees	Book value of equipments	R&D expenditure
A	1.501	0.929	0.643	1.073	2.617
B	1.359	0.755	0.496	0.877	2.114
C	0.947	0.531	0.342	0.595	1.626
D	0.670	0.406	0.276	0.481	1.848
E	1.154	1.447	1.040	1.163	0.991
F	0.887	1.032	0.778	0.830	0.843
G	0.554	0.755	0.657	0.568	0.636
H	1.248	1.709	2.047	1.715	0.133
I	1.016	1.348	1.677	1.358	0.103
J	0.878	1.303	1.897	1.210	0.044
K	0.785	0.786	1.148	1.131	0.044

Table A4. The scaled outputs data of the sample PCB firms.

Firm	Outputs				
	Sales revenue	Customer satisfaction index	Average yield rate	Technology level index	Inventory turnover rate
A	0.900	1.008	0.952	1.099	0.923
B	0.711	1.041	0.984	1.123	0.994
C	0.501	1.008	0.963	1.087	0.994
D	0.381	1.019	0.952	1.075	1.065
E	1.346	0.986	1.006	1.051	1.277
F	1.095	0.975	0.995	1.039	1.065
G	0.678	0.942	1.017	1.015	1.135
H	1.822	1.041	1.038	0.896	0.923
I	1.535	1.052	1.049	0.908	0.994
J	1.287	0.997	1.038	0.872	0.852
K	0.744	0.931	1.006	0.836	0.781