Using DEA to Evaluate R&D Performance in the Integrated Semiconductor Firms -- Case Study of Taiwan

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Abstract

The evaluation of research & development (R&D) performance has been an important problem of both academic interest and practical need. An effective R&D operation is a major source of competitive advantage in today’s rapidly globalizing economy. Current economic situations are forcing high-tech companies to compete with each other through increasing R&D performance and decreasing cost simultaneously. To make decisions on R&D activity should be based on economic considerations more strongly, in order to estimate the opportunity cost and revenues of in-house R&D and to take these into account in costing [9].

There are a number of studies and abundant literature about the R&D topics, such as: (1) the organization of R&D [24] (2) evaluation of R&D projects [38][42] (3) the principle or guidelines for measuring R&D process [20][37][48] (4) the factors which affect R&D results [9][37] (5) the measurement of R&D performance [9][10][20][29][37][48] etc. Such researches have focused on one aspect of R&D activities in the micro-level views. However, little research has been done on evaluating the performance of R&D activities in the high-tech firms.

Keywords: R&D performance, efficiency, Data Envelopment Analysis, high-tech firm

1. Introduction

The evaluation of research & development (R&D) performance has been an important problem of both academic

interest and practical need. An effective R&D operation is a major source of competitive advantage in today’s rapidly globalizing economy. Current economic situations are forcing high-tech companies to compete with each other through increasing R&D performance and decreasing cost simultaneously. To make decisions on R&D activity should be based on economic considerations more strongly, in order to estimate the opportunity cost and revenues of in-house R&D and to take these into account in costing [9].
of high risks and high investment rewards. Because of the nature of R&D activities such that cumulative, uncertainty, external and depend on the industry, evaluating R&D performance has been a difficult task. However, most of the managers of the high-tech companies rely on their experiences to evaluate R&D activities. In particular, the managers can hardly specify which factors contributing more or less R&D activities. Therefore, the managers do not know which factors they should enhance to increase the R&D performance of their firms.

This paper presents an empirical study in which we apply Data Envelopment Analysis (DEA) to evaluate the relative R&D efficiencies of 52 integrated semiconductor firms located at Hsinchu Science-based Industrial Park in Taiwan. Taiwan is now one of the world’s leading suppliers of integrated semiconductor. This industry is comprised of companies with high flexibility and the ability to react quickly to a changing environment and to adjust the product line to reflect the customers’ needs. The rest of this paper is organized as follows. Section II reviewed existing literature on the subject of R&D performance measurements. Section III describes the data envelopment analysis applied in this study. Section IV is the data and factors. Section V discussed the result and analysis. Summary is made in section VI.

2. Literature Review

There are a number of quantitative and qualitative techniques and methods have been developed for R&D evaluation. For example, financial analysis methods such as profit/earning ratio, return of investment, marginal rate of return and earnings/sales [22][26][46]; simple ratio way such as R&D intensity (R&D expenditure/sales) for screening and evaluation performance [7][36][46]. However, these methods focus on a single point of view, e.g., R&D expenditure, paid-in-capital, and patents. Managers need a method to understand the overall R&D performance and directions for improvement.

Considering the multiple attributes for evaluating R&D efficiencies, some researchers developed empirically derived methods such as regression models for investigating R&D productivity. For example, Gilman [26] studied stock price and optimum R&D spending, and pointed out P/E ratio is positive correlation referred to R&D intensity. Morbey and Reithner [37] used regression models to study the relation among R&D effects, productivity, and profitability. Zif et al. [50] investigated the characteristics of business with high R&D investment used multiple regression models.

In addition, researchers also constructed subjectively derived models, grounded in decision sciences, such as the analytic hierarchy process (AHP), for priority setting and resource allocation in R&D management. For example, Liberatore [33] developed a framework for applying AHP and supporting methods in the R&D evaluation. Werner and Souder [48-49] reviewed the measurement of R&D performance. Rouse and Boff [40] summarized the state of knowledge of R&D/technology management. Meanwhile, Cordero [18] studied an overview on the measurement of R&D performance in the firms.

However, as for the evaluation of R&D performance, the relations between inputs and outputs are usually not obvious. Data Envelopment Analysis (DEA) model [14] does not require the predetermination of the relative weights of the inputs and outputs, as do other approaches such as AHP. DEA has...
been effectively applied for measuring the relative efficiency in many fields, including schools and universities, hospitals, and banks. These special properties just suit the characteristics of R&D activities. However, little research has been done to apply DEA to evaluate the R&D efficiency.

3. Methodology

Data Envelopment Analysis (DEA) computes the efficiency of a firm in transforming inputs into outputs in relation to its peer group. Charnes et al. [14] first developed the DEA approach based on the concept of technical efficiency of Farrel [23]. DEA in essence is a linear programming technique that converts multiple inputs and outputs into a scalar measure of efficiency. This conversion is accomplished by comparing the mix and volume of outputs provided and the inputs used by each firm compared with all other firms. Each firm is evaluated against a hypothetical firm with an identical output mix that is constructed as a combination of efficient firms. DEA identifies the most efficient firms in a population and provides a measure of inefficiency for all others. The most efficient firms are rated to have an efficiency score of one, while the less efficient institutions score between zero and one. Through DEA does not give a measure of optimal efficiency, it however differentiates the least efficient firms from the set of all firms. Thus the efficient institutions calculated using DEA establish the best practice frontier.

In this study, the use of DEA for evaluating the relative efficiencies of R&D activities shows a good understanding of resources utilization of each firm in the high-tech industry. In particular, the results distinguish between efficient and inefficient firms and also provide improvement directions for individual companies.

Two DEA formulations, i.e., the CCR model [14], and the BCC model [5] are employed in the present study. For the CCR model, the total efficiency is obtained. For the BCC model, technical scale and return to scale are measured. A comparison of the two allows the determination of the extent to which inefficiencies can be attributed to increasing and decreasing returns to scale, in addition to potential resource-allocation discrepancies. Detailed formulations of the CCR model, and BCC model are stated as follows:

A. The CCR Model

The CCR model proposed by Charnes et al. [14] is applied for measuring the efficiency of DMUs. A DMU is said to be efficient if it is impossible to increase (decrease) the value of an output (input) without increasing the use of at least one other input or decreasing the generation of at least one other output.

For each DMUo, the CCR model is:

Max $h_o = \sum_r u_r y_{ro}$ for $r=1,2,...,s$  \hspace{1cm} (1)

s.t. $\sum_i v_i x_{io} = 1$ for $i=1,2,...,m$

$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \leq 0$

for $r=1,2,...,s$, $i=1,2,...,m$, and $j=1,2,...,n$

The dual program for each DMUo is

Min $h_o = \theta_o - \varepsilon (\sum_r S_r + \sum_i S_i)$

for $r=1,2,...,s$, $i=1,2,...,m$  \hspace{1cm} (2)

s.t. $\sum_j y_{ij} \lambda_j - S_r = y_{ro}$

for $j=1,2,...,n$

$\sum_j x_{ij} \lambda_j - \theta_o x_{io} + S_i = 0$

for $j=1,2,...,n$

where $y_{rj}$: the value of the $r$-th output
of the j-th DMU
\[ x_{ij} : \text{the value of the i-th output of the j-th } \]
DMU
\[ u_i, v_i: \text{virtual multipliers for output } r, \]
input i respectively (\( \geq \varepsilon \))
\[ S_i, S_r: \text{slack corresponding to input } i, \]
and output r, respectively
\[ h_o: \text{relative efficiency of specified DMU}_o \]
\[ \theta_o: \text{the potential of a proportional } \]
reduction in all the inputs of specified DMU
\[ \lambda_j: \text{weight of DMU}_j \text{ in the facet for the } \]
evaluated DMU(\( \geq 0 \))
\[ \varepsilon: \text{a small non-Archimedean quantity} \]

The subscript is defined as:
\[ i: \text{ inputs, } i=1,2,\ldots,m \]
\[ j: \text{ DMUs, } j=1,2,\ldots,n \]
\[ o: \text{ specified DMU}, \ o=1,2,\ldots,n \]
\[ r: \text{ outputs, } r=1,2,\ldots,s \]

B. The BCC Model [5]

For each DMUo, the BCC model is:
Max \[ h_o = \sum_{r} u_r y_{ro} - \mu_o \]
for \( r=1,2,\ldots,s \) \[ \sum_{i} v_i x_{io} = 1 \text{ for } i=1,2,\ldots,m \]
(3)
\[ \sum_{r} u_r y_{ro} - \sum_{i} v_i x_{io} - \mu_o \leq 0 \]
for \( r=1,2,\ldots,s, \ i=1,2,\ldots,m \)

The dual program for each DMUo is
Min \[ h_o = \theta_o - \varepsilon(\sum_{r} S_r + \sum_{i} S_i) \]
for \( r=1,2,\ldots,s, \ i=1,2,\ldots,m \) \[ \sum_{j} y_{ij} \lambda_j - S_r = y_{ro} \]
(4)
\[ \sum_{j} x_{ij} \lambda_j - \theta_o x_{io} + S_i = 0 \text{ for } j=1,2,\ldots,n \]

4. Case Study

This empirical study involves: (1) the selection of input and output factors, (2) the evaluation of total efficiency by CCR model, the evaluation of technical efficiency and scale efficiency by BCC model, and (3) the discussion of improvement directions of the inefficient DMUs.

4.1 Selection of input and output factors

On the basis of the existing studies ([7][12][31][36][43][46-47][50]), main factors affect R&D results are: (1) R&D expenditure (2) R&D employees (2) paid-in-capital (4) sales (5) industrial classification (6) companies’ size (7) the age of company (8) the percent of market share (9) the number of patents. In this study, four input factors and two output factors are selected. The four input variables are:

\[ A: \text{ the age of the firm} \]
\[ P: \text{ paid-in-capital of the firm} \]
\[ R&D: \text{ annual R&D expenditure of the firm, contains R&D current} \]
\[ \text{expenditure and R&D capital expenditure.} \]
\[ R: \text{ number of R&D employees in R&D department/section of the firm} \]
\[ \text{and two output variables are:} \]
\[ S: \text{ annual sales of the firm} \]
\[ T: \text{ number of patents approved by domestic and foreign patent office} \]

Researchers have found the relationship have been found between R&D expenditure and the numbers of patents generated, the use of patent counts in measuring R&D performance [8][21][35][39][47]. Thus, patents are useful indicators for identifying
the fields where technological advances are been made in comparing high-tech firms. In addition, combining the data with sales, R&D expenditure, and R&D employees of the firms provides a basis for assessing the firm’s R&D performance. The data of 52 integrated semiconductor firms located at HSIP in Taiwan are collected for the period of year 1995 (Science Park Annual Report, 1995). For the confidential reasons, these firms are coded as DMU1 to DMU 52, respectively.

Table 1 Correlation between Inputs and Outputs

<table>
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<tr>
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<th>R&amp;D</th>
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<td>S</td>
<td>0.882</td>
<td>0.616</td>
<td>0.813</td>
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</tr>
<tr>
<td>T</td>
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<td>0.665</td>
<td>0.728</td>
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</table>

To estimate the construct validity, we use correlation analysis to check the isotonicity [6][27-28] among inputs and outputs for validation. Significantly positive correlation among the inputs and outputs are found, as shown in Table 1. Thus, the isotonicity assumption of DEA model is validated. Also, as suggested by [6], the number of inputs and outputs must be small or equal to one-third number of DMUs. In this study, we used 6 factors to evaluate 52 DMUs. The numbers of DMUs corresponds to the number of outputs and inputs should be large enough to make sure that the measurement of efficiency is meaningful.

5. Results And Discussion

A. Total Efficiency

The CCR model is solved via computer programming and used the result to evaluate the efficiencies of the 52 integrated semiconductor firms located at Hsinchu Science-based Industrial Park in Taiwan. The efficiency values of the 52 firms are very different, as shown in Table 2 and Table 3. The efficiency ratio has an average value of 0.563, which means about 43.7% firms need to improve their efficiency. On the other hand, 10 companies have the total efficiency values to be 1 (i.e., at the efficient frontier). Among the non-efficient firms, DMU31 with a value of 0.985 is the exception. 40% firms (20 of 52) that the efficiency values are more than 0.5, and 22% of companies (11 of 42) are smaller than 0.1. Variations in the inefficient DMUs may due to various reasons such that the differences in product technologies, R&D lag, firm size and other factors might be take into account.

Table 2 Total efficiency (TOE), technical efficiency (TEE), scale efficiency(SCE), and return to scale (RTS) of DMUs

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<th>firms</th>
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<th>SCE</th>
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Note:
※ : IC manufacturing  ★ : IC design  ● : IC peripherals  □ : mask manufacturing
▲ : IC package  ⊕ : IC foundry  ☆ : IC testing

Table 3 Mean and Variance of TOE, TEE, and SCE

<table>
<thead>
<tr>
<th></th>
<th>TOE</th>
<th>SCE</th>
<th>TEE</th>
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<tbody>
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<td>0.790442</td>
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<td>variance</td>
<td>0.13147967</td>
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</table>

B. Technical efficiency and scale efficiency

Technical efficiency and scale efficiency can be obtained by BCC model. The value of total efficiency (TOE) consists of two components: technical efficiency and scale efficiency. The technical efficiency is given in the second column of Table 2 by TEE, the so-called pure technical efficiency [5] formulation. From Table 2, the technical efficiency has an average value of 0.8. It means that most companies in the present study have a good usage in technical resources. Only few companies need to improve in this way. Although DMU 17, 26, 28, 30, 40 and 41 are inefficient, their technical efficiency equal to 1. This implies their total inefficiencies are due to scales rather than their technology to make use of resources.

The scale efficiency is measured by the ratio of TOE to TEE. It is computed by the percent of actual production constitutes relative to scale efficiency output, and means the percentage of resource usage expected of a company due to its size, i.e. to its scale of operation. Hence (1 - TOE/TEE) is the percent of potential output lost due to scale inefficiency.

As shown in Table 2, the major portion of the inefficiencies is attributable to the scale component, i.e. to differences in firm size. Furthermore, the last column indicates the type of returns to scale exhibited by each firm. The number in the fourth column of Table 2 corresponds to the sum of the optimal value [16] of the firm’s weights. Then a unit is said to exhibit increasing (IRS), decreasing (DRS) or constant (CRS) returns to scale, if its RTS value is exceeding, less than or equal to 1, respectively. The significance of this column lies in the fact that it gave an indication of the direction towards which resource allocation may have to be redirected, if efficiencies are to be improved.

The efficiency DMUs must have constant returns to scale. From the last column of Table 2, only DMU 3, 5, 21, and 33 are decreasing return to scale. It means that most companies were not on the economic scale, and they should enlarge the scale of company. The scale inefficiency is the major reason for inefficiency DMUs.

There are 22 inefficient companies, among these 15 of 22 companies’ technical efficiency values are bigger than scale efficiency values (i.e., DMU 6, 7, 14, 17, 23, 26, 28-30, 32, 40, 41, 45, 48 and 52). These company’s resource inefficiencies may due to the scale factor, rather than from the technical factor. For companies with increasing return to scale, the key issues are to examine possible investment to increase the scale. DMU 3, 5, 21, and 33 are decreasing returns to scale, i.e. their technical efficiency values are smaller than scale efficiency values. Thus, they should improve their technical factors to increase the efficiency of R&D performance.
Using data envelopment analysis, this paper evaluated the R&D performance of 52 integrated semiconductor firms located at Hsinchu Science-based Industrial Park in Taiwan. Some concluding remarks are made:

1. The efficiency values of 52 integrated semiconductor firms are very different. 56.3% of firms have the total efficient values to be 1.
2. The major portion of the inefficient firms is attributed to the scale component, i.e., to differences in resource allocation/usage patterns.
3. Most of the inefficient firms have increasing return to scale. It means most inefficient firms have technical resources, but the scale efficiency should be enhance.
4. Further study should be done to apply DEA to evaluate the R&D performance of other high-tech firms to validate date of the proposed approach.

References


Using DEA to Evaluate R&D Performance in the Integrated Semiconductor Firm


[41] Science park annual reports, Hsinchu science park administration, Taiwan, 1986-1997.


