Productivity Evaluation of Taiwanese Semiconductor Companies Using a Three-stage Malmquist DEA Approach

Mei-Ying Huang* and Shu-Yu Huang**

Abstract

In this paper, we evaluate the productivity performance of Taiwanese semiconductor companies using a three-stage Malmquist DEA panel model to account for external environmental effects on firms' managerial performance over time. The empirical results have shown that the effects of external environments on firm’s efficiency performance are significant. Based on the empirical results of the proposed panel model with the adjusted inputs, in general we conclude that the semiconductor industry in Taiwan has enjoyed efficiency improvement, technical progress and productivity growth in 2002-2007. However, we also find that without considering the effects of the environmental factors, the evaluation of firms' changes in productivity and technology will be overestimated for the semiconductor industry, whereas the efficiency improvement will be mostly underestimated.

Keywords: Semiconductor Industry, Efficiency, Productivity, DEA, Malmquist Index

JEL Classification: C33, D24, L63, L86

* Professor, Department of Economics, National Taipei University. Corresponding Author. Tel: (02)26748189 ext. 67167, Email: mayin@mail.ntpu.edu.tw.

** Contract Assistant Researcher, Fair Trade Commission, Executive Yuan.
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I. Introduction

After experiencing remarkable technology development and output growth in the 1980s and 1990s, Taiwan’s semiconductor industry has become the most important and productive industry in Taiwan. However, due to the impact of the worldwide economic recession occurred in 2000, it happened that the production values and the market demand of Taiwan’s semiconductor industry had decreased in 2001. In order to maintain its leading position in the world, the government launched the “Two-trillion and Two-star industries” project in 2002 to accelerate the industrial escalation and economic growth. Semiconductor industry is one of the two-trillion industries. In 2002, government launched a national project on developing technology of “system on chip” to increase the technology advancement of Taiwanese semiconductor firms and to direct industry to be innovative and research & development oriented. In 2003, Taiwan government established a special office for promoting semiconductor industry and coordinating leading Taiwanese companies to build a common international product standard (Rosetta Net). Such B2B procedure coordination would help product sale to international market and save substantial time and communication costs with clients. In addition, a semiconductor college for cultivating skillful experts for semiconductor industry was also built by government in 2003. After such project promotion, Taiwan semiconductor had successfully achieved the aim of trillion values of sales in 2004. In 2007, Taiwan was the fourth largest semiconductor producing country in the world. Among various
selected Integrated Circuit (IC) industries, Taiwan is ranked the first in the world in the IC Foundry and IC testing industries, and is second only to the US in IC design.

The success of the development of the Taiwanese semiconductor industry has often been attributed to the adequacy of Taiwan’s industrial promotion policies over time and its unique vertically integrated production system. However, despite its important role in the global production of semiconductors, Taiwanese companies are currently confronting strong technological competition from other leading developed countries, including Japan, the US and South Korea, as well as cost competition from other newly-industrializing countries such as China and India. In the last decade, many Taiwanese semiconductor companies have moved some of their production lines to China to take advantage of the lower costs there. To accommodate such urgent international competition, Taiwanese firms must improve their productivity by advancing innovative technology or by enhancing their management efficiency to compensate for their loss of competitiveness in terms of cost.

Most of the previous research related to the semiconductor industry in Taiwan has been directed at the role of government or the industrial development strategy in improving the competitiveness of the industry (Tung, 2001; Chang and Tsai, 2002; Saha, 1998; Chen and Sewell, 1996; Chang and Hsu, 1998). Despite some studies had attempted to evaluate efficient performance of Taiwanese semiconductor firms, however, their evaluations had been conducted through the use of either the simple data envelopment analysis (DEA) (Hu and Li, 2004; Fung, 2001) or the Malmquist productivity index approach (Chen, 2005; Huang, 2005). To measure the influence of external environment on management ability, Huang (2007) adopted the concept of three-stage input-oriented DEA of Fried et al. (2002) to measure the pure management inefficiency of semiconductor firms. His study however limited to a cross sectional static analysis.

In this paper, we attempt to evaluate the dynamic productivity performance of Taiwanese semiconductor companies during 2002-2007. To serve such purposes, we adopt the static concept of three-stage input-oriented DEA of Fried et al. (2002) and extend it to a three-stage

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1 Except Hu and Li (2004), other studies are unpublished master theses.
Malmquist DEA panel model to account for some of the uncontrollable institutional and environmental factors which may affect the semiconductor firms’ managerial performance. After decoupling these effects that may be uncontrollable, the proposed Malmquist DEA model using adjusted inputs will be able to provide pure performance measures of firms’ technical and scale efficiency levels for each year, as well as of productivity (technical, scale and efficiency) changes between 2002 and 2007. The empirical results show that the efficiency scores from third-stage DEA are in general higher than those from first-stage DEA, whereas efficiencies of semiconductor firms have shown to increase from 2002 to 2007. Significant impacts of external environments on semiconductor firms’ management performance are also evidenced. The paper is structured as follows. After the introduction section, we will describe the analytical models in next section. This is followed by a section on data and variable description. In the fourth section, we will explain our empirical results. The paper will end with a section on concluding remarks.

II. Analytical Models

The multi-stage input-oriented DEA models of Fried et al. (1999, 2002) have been proposed to decouple possibly uncontrollable effects of the environment on firm performance. By using such models, one can separate the pure management inefficiency from those inefficiencies from external variables in forms of ownership, location characteristics, labor relations, and government regulations (Fried et al., 1999). However, their models are static models and good for cross-sectional analysis. In this paper, we attempt to examine the performance of the Taiwanese semiconductor industry over time. Since the performance of Taiwanese semiconductor firms are also strongly influenced by some external environmental variables (to be discussed in the later section), therefore, we extend the cross-sectional version of the Fried et al. (2002) model to a panel version model within the framework of the Malmquist productivity index. Such a three-stage Malmquist DEA model can thus account
for environmental factors that may affect the firms’ managerial performance over time. After
decoupling these possibly uncontrollable effects, the proposed Malmquist DEA model using
adjusted inputs or outputs provides pure performance measures for firms’ technical and scale
efficiency levels in each year, as well as on productivity (technical, scale and efficiency)
changes over time. It should be noticed that our proposed model differs from that of Fried et
al. (2002) in the way to estimate the slack frontier regressions. In Fried et al. (2002) models,
the simple DEA was employed in the first stage and slacks for inputs were calculated, it then
was followed by estimating the slack frontiers by stochastic frontier analysis (SFA) in the
second stage, and it finally adjusted the inputs and ran the DEA using the original outputs and
adjusted inputs in the last stage. It occurred that the slack frontier using SFA often confronted
divergence in estimation due to censored nature of input slacks. To accommodate such
problem, we propose a modified three-stage procedure where we estimated input slack
deterministic frontiers rather than stochastic frontiers in the second stage. Our modified
model can be briefly described as follows:

A. The modified three-stage DEA method

a. The stage one

Similar to those models of Fried et al. (1999, 2002), the stage one of our proposed model
is to estimate the initial technical efficiency $\theta$ using the original unadjusted inputs and outputs
in the standard DEA linear programming formulation.

Denote $\theta_i^*$ and $\lambda_i^*$ as the optimal solutions of the linear programming for the $i^{th}$
decision making unit (DMU). The stage one optimization yields the DMU($i$) input-oriented
technical efficiency $\theta_i^* \leq 1$, which has the radial $k^{th}$ input slack (radial input contraction) equal
to
radial $k^{th}$ input slack = $x_{ki} - \theta_i^* x_{ki} \geq 0, \quad k = 1, 2, \ldots, k$  \hspace{1cm} (1)

and possible non-radial input slack (non-radial input contraction) equal to

non-radial $k^{th}$ input slack = $\theta_i^* x_{ki} - \sum_{n=1}^{N} \lambda_{ni}^* x_{kn} \geq 0$.  \hspace{1cm} (2)

However, the first stage estimates of the input-oriented technical efficiency $\theta_i^* \leq 1$ are likely to be contaminated by some combination of the effects from environmental variables and statistical random noise. The influences of the environmental variables and random noise on the efficiency estimates are transmitted to the radial and non-radial input slacks in (1) and (2).

b. The stage two of Fried et al. (2002)

The objective of the stage two procedure is to decompose stage one slacks into three sources: pure DMU inefficiency, environmental influence, and statistical noise. Once the three components are identified, the environmental influence and the statistical noise are purged from the inputs in order to estimate the pure technical efficiency. In stage two, we define the total input slack as the sum of the radial and non-radial slacks, i.e.,

$$S_{ki} = (\text{radial } k^{th} \text{ input slack}) + (\text{non-radial } k^{th} \text{ input slack})$$

$$= x_{ki} - \sum_{n=1}^{N} \lambda_{ni}^* x_{kn} \geq 0, \quad k = 1, 2, \ldots, K; \quad i = 1, 2, \ldots, N$$  \hspace{1cm} (3)

Suppose DMU($i$) faces $T$ environmental variables, $z_i = (z_{i1}, z_{i2}, \ldots, z_{iT})$. With the total slack $S_{ki}$ representing the dependent variables and $z_i$ the independent variables, in Stage Two, Fried et al. (2002) estimate $K$ sets of stochastic slack frontier regressions, with one for each input, i.e.,

$$S_{ki} = F_k(z_i) + v_{ki} + u_{ki}$$

$$= F_k(z_i) + \varepsilon_{ki}, \quad k = 1, 2, \ldots, K; \quad i = 1, 2, \ldots, N$$  \hspace{1cm} (4)
where \( \varepsilon_{i} = v_{i} + u_{i} \) is the composite error. The term \( F_{K}(z_{i}) \) is the deterministic feasible slack frontier representing the influence of environmental variables. The term \( v_{i} \) represents the random noise component of the input slack, and the term \( u_{i} \), which is assumed to be non-negative, represents the input slack portion that is attributable to DMU inefficiency. We note that the positive (negative) value of \( F_{K}(z_{i}) \) implies that the environmental variable has an unfavorable (favorable) impact on efficiency, and the positive (negative) value of \( v_{i} \) is an indicator of bad (good) luck in the DMU’s operation. Any slacks in excess of the stochastic feasible frontier \( S_{i} = F_{i}(z_{i}) + v_{i} \) are attributable to the \( i^{th} \) DMU’s inefficiency in the utilization of the \( k^{th} \) input in production.

Following the stochastic frontier specification, we assume that the random noise component is normally distributed, \( v_{i} \sim N(0, \sigma^2_{v_{i}}) \), and that the distribution of the non-negative error component is half-normal, \( u_{i} \sim N^{+}(0, \sigma^2_{u_{i}}) \). The stochastic slack frontier regression can be estimated by means of the maximum likelihood method once the frontier \( F_{K}(z_{i}) \) is parametrically specified. We now have the estimates of the three components of the input-oriented slack:

\[
S_{i} = \hat{F}_{i}(z_{i}) + \hat{v}_{i} + \hat{u}_{i}.
\]  

A positive \( F_{K}(z_{i}) \) and \( v_{i} \) implies an unfavorable environmental and random noise impact on the \( i^{th} \) DMU’s production efficiency. The extent of the unfavorable impact varies with the DMUs depending on the magnitudes of \( F_{K}(z_{i}) \) and \( v_{i} \). In the worst scenario, the extent of the impact of the unfavorable environmental and random noise on efficiency is equal to \( \max_{i}(\hat{F}_{i}(z_{i})) + \max_{i}(\hat{v}_{i}) \). In comparison with the worst case, the relative advantage of the DMU(\( i \)) over the worst case is then the difference, \( \{\hat{F}_{i}(z_{i}) - \max_{i}(\hat{F}_{i}(z_{i}))\} + \{\hat{v}_{i} - \max_{i}(\hat{v}_{i})\} \leq 0 \). Thus, one way to adjust the impact of the environmental and random variables on efficiency so that all DMUs can be compared on a level playing field compared to the worst
scenario is to take away the advantage, or to upwardly adjust the inputs of the DMUs that have been at an advantage due to their relatively favorable operating environment and their relatively good luck. Therefore, the input adjustment is:

\[
x^d_{ki} = x_{ki} - \left\{ \hat{F}_k(z_i) - \max_j (\hat{F}_k(z_j)) \right\} - \left\{ \hat{v}_{ki} - \max_l (\hat{v}_{kl}) \right\}
\]

\[
= x_{ki} + \left\{ \max_j (\hat{F}_k(z_j)) - \hat{F}_k(z_i) \right\} + \left\{ \max_l (\hat{v}_{kl}) - \hat{v}_{ki} \right\}
\]  

(6)

c. The stage two of our modified model

Differ from Fried et al. (2002) who use SFA to estimate the slack frontiers, we will use the corrected ordinary least square method (COLS) to estimate deterministic form of slack frontiers for purging the effects of the environment. The underlying reason why we did not adopt the SFA model of Fried et al. (2002) is that the SFA estimation for some of the input slacks failed to converge due to the censoring problem associated with the slack dependent variables. Therefore, we have replaced the SFA model in (5) by the following COLS model.

Assume the slack to be a function of \(Z\) and the error only contains inefficiency term \(u\), and assume \(F_k() = \beta_0^* + \beta_1^* z_i\), then equation(4) can be rewritten as a deterministic slack frontier functional form:

\[
S_{ki} = F_k(z_i) + u_{ki} = \beta_0 + \beta_1^* z_i + u_{ki}
\]

(7)

Direct applying the ordinary least squares (OLS) to (7) would result in bias in intercept estimate since the mean of \(u_{ki}\) is not 0. However, one can use the following COLS procedure to estimate the unbiased intercept parameter of the deterministic slack frontier. The result of standard OLS regression for (7) is:

\[
S_{ki} = \hat{\beta}_0 + \hat{\beta}_1^* z_i + \epsilon_i
\]

(8)
where the residual $e_i$ is the estimate of regression error. A feature of the OLS estimation is that the mean of the residuals is zero, $\frac{1}{N} \sum_{i=1}^{N} e_i = 0$, which implies that some values of the OLS residual are positive and some are negative. Consequently, the OLS residuals $e_i$ in (8) are not good estimates of the positive errors ($u_i$) in (7). One way to estimate the positive errors ($u_i$) is to “correct” the OLS residuals by the following adjustment,

$$ S_{ui} = \hat{\beta}_0 + \hat{\beta}_i z_i + (e_i - \text{Min}(e_i)) $$

(9)

where $\text{Min}(e_i)$ is the minimum value of the OLS residuals. This adjustment guarantees that the corrected residuals are always positive, $(e_i - \text{Min}(e_i)) >= 0$. The corrected ordinary least squares (COLS) estimates of the regression errors ($u_i$) in (7) become:

$$ \hat{u}_i^{\text{COLS}} = e_i - \text{Min}(e_i) $$

(10)

With the OLS adjustment, the COLS estimation of the slack function (8) is:

$$ S_{ui} = \hat{\beta}_0^{\text{COLS}} + \hat{\beta}_i^{\text{COLS}} z_i + \hat{u}_i^{\text{COLS}} $$

(10)

where the COLS estimate of the intercept $\beta_0$ becomes:

$$ \hat{\beta}_0^{\text{COLS}} = \hat{\beta}_0 + \text{Min}(e_i) $$

(11)

We then use the COLS regression results to predict $\hat{F}_k(z_i)$ for the $k$-th input. Under the deterministic slack frontier framework, the input adjustment requires that the statistical noise term of (6) be dropped to make the necessary input adjustments for the environmental effects. That is, the adjustment is made only by

$$ \max_i (\hat{F}_k(z_i)) - \hat{F}_k(z_i) $$

(12)
d. The stage three

After the input adjustment for all inputs, we again apply the BCC DEA to the data of original output and 3 adjusted inputs. The Efficiencies of all semiconductor sample firms can then be measured.

B. The input-oriented Malmquist productivity index (MPI) decomposition

Once the inputs have been adjusted by “equalizing” the impact of both of the environmental variables for years of 2002 and 2007, we then perform a standard MPI evaluation based on the adjusted inputs $x_{ji}$ and original output variables in 2002 and 2007. Following the previous literature, the MPI is introduced as follows:

$$M_t(y_{i}, x_{i}, y_{i}, x_{i}) = \left( M'_t(y_{i}, x_{i}, y_{i}, x_{i}) \times M''_t(y_{i}, x_{i}, y_{i}, x_{i}) \right)^{1/2}$$

$$= \left( \frac{D_h'(y_{i}, x_{i})}{D_h'(y_{i}, x_{i})} \times \frac{D_h''(y_{i}, x_{i})}{D_h''(y_{i}, x_{i})} \right)^{1/2} \quad (13)$$

Note that

$$M_t(y_{i}, x_{i}, y_{i}, x_{i}) = 1 \quad \text{implies} \quad \text{unchanged productivity}$$

$$> 1 \quad \text{productivity improvement}$$

$$< 1 \quad \text{productivity deterioration}$$

The four input-oriented distance functions can be computed from the CCR input-oriented DEA method, as in the CCR output-oriented DEA method. The four linear programming problems are:
\[
\min_{\theta, \lambda} \quad \theta = [D'^{\prime}_{IC}(y, x)]^{-1}
\]
\[
\text{s.t.} \quad \sum_{n=1}^{N} \lambda_n y_{mnt} \geq y_{mis}, \quad m = 1, 2, \cdots, M
\]
\[
\sum_{n=1}^{N} \lambda_n x_{klt} \leq \theta x_{kis}, \quad k = 1, 2, \cdots, K
\]
\[
\lambda_1, \lambda_2, \cdots, \lambda_N \geq 0,
\]

\[
\min_{\theta, \lambda} \quad \theta = [D'^{\prime}_{IC}(y, x)]^{-1}
\]
\[
\text{s.t.} \quad \sum_{n=1}^{N} \lambda_n y_{mnt} \geq y_{mis}, \quad m = 1, 2, \cdots, M
\]
\[
\sum_{n=1}^{N} \lambda_n x_{klt} \leq \theta x_{kis}, \quad k = 1, 2, \cdots, K
\]
\[
\lambda_1, \lambda_2, \cdots, \lambda_N \geq 0,
\]

\[
\min_{\theta, \lambda} \quad \theta = [D'^{\prime}_{IC}(y, x)]^{-1}
\]
\[
\text{s.t.} \quad \sum_{n=1}^{N} \lambda_n y_{mnt} \geq y_{mis}, \quad m = 1, 2, \cdots, M
\]
\[
\sum_{n=1}^{N} \lambda_n x_{klt} \leq \theta x_{kis}, \quad k = 1, 2, \cdots, K
\]
\[
\lambda_1, \lambda_2, \cdots, \lambda_N \geq 0,
\]

and

\[
\min_{\theta, \lambda} \quad \theta = [D'^{\prime}_{IC}(y, x)]^{-1}
\]
\[
\text{s.t.} \quad \sum_{n=1}^{N} \lambda_n y_{mnt} \geq y_{mis}, \quad m = 1, 2, \cdots, M
\]
\[
\sum_{n=1}^{N} \lambda_n x_{klt} \leq \theta x_{kis}, \quad k = 1, 2, \cdots, K
\]
\[
\lambda_1, \lambda_2, \cdots, \lambda_N \geq 0,
\]
The input-oriented MPI can be decomposed into the components of technical efficiency change and technical change.

\[
M_j(y_j, x_j, y_t, x_t) = \left( \frac{D_{IC}^t(y_t, x_t)}{D_{IC}^s(y_j, x_j)} \frac{D_{IC}^t(y_t, x_t)}{D_{IC}^s(y_j, x_j)} \right)^{1/2}
\]

\[
= \Delta T_j(s,t) \times \Delta E_j(s,t).
\]

The first part measures the input-oriented efficiency change,

\[
\Delta E_j(s,t) = \frac{D_{IC}^s(y_j, x_j)}{D_{IC}^s(y_t, x_t)}
\]

\[
>\text{technical efficiency improvement} = 1 \text{ implies unchanged technical efficiency} <\text{technical efficiency deterioration}.
\]

The second part is the geometric mean of two input-oriented technical changes,

\[
\Delta T_j(s,t) = \left( \frac{D_{IC}^t(y_t, x_t)}{D_{IC}^s(y_j, x_j)} \frac{D_{IC}^t(y_t, x_t)}{D_{IC}^s(y_j, x_j)} \right)^{1/2}
\]

\[
>\text{technical progress} = 1 \text{ implies unchanged technology} <\text{technical regress}.
\]

### III. Data and Variable Description

According to the 2008 Yearbook of the Industrial Technology Research Institute (ITRI), there are 272 IC design companies, 14 IC manufacturing companies, and 67 IC packaging and
testing companies in Taiwan, that belong to the upstream, mid-stream and downstream IC industries, respectively.

The sample firms used in this study are drawn from companies listed in the Taiwan Stock Exchange and the over-the-counter Securities Exchange. These firms are major firms that are relatively sizable since they are qualified to raise funds in the open financial market of Taiwan. Our sample includes 60 IC-design firms, 10 IC-manufacturing firms, and 22 IC-packaging and testing firms from these publicly traded firms in order to ensure the consistency and reliability of the data.

The output variable used is the net value of sales. The use of sales value rather than sale quantity is to provide a uniform unit, since semiconductor firms usually produce different products with different prices by the nature of their industry. The net sale is defined as gross sale value minus product sale return and discounts. The input variables used for DEA are R&D expenditures, fixed assets, labor costs and the other operating costs. For a knowledge-based industry such as the semiconductor industry, research and development is the key to firm’s growth and survival. Therefore, R&D expenditure of firms is recognized as an essential input for production. In addition, since the semiconductor industry is in capital intensive nature, those fixed capital assets including land, building, computer and other production equipments are essential inputs for production. The net value of fixed assets is used as proxy for capital input. Labor cost defined as wage plus other fringe benefit is used to represent the labor input used in firm’s production. The last input variable is the other operating cost which is defined to be the total operating cost minus labor cost. This variable may capture firm’s other cost related to materials, marketing and product management.

The variables characterized the external environment which may affect firm’s management inefficiency include firm size, foreign investment ratio, and listed company in open financial market. The size of semiconductor firm is determined mainly by industrial technology requirement or other predetermined factors such as budget, government regulations or policies, or firm’s long-run planning, which may be beyond the control of managers at least in a short period. The value of total assets of a firm is used as the proxy for the environmental variable “firm size”. Another environmental variable used for semiconductor firms in Taiwan
is the ratio of investment from foreign owners. The foreign stock holders are usually regarded as an external force to push a good pressure for company’s governance. They may also play a role of bring in new concepts or ways related to firm operation. The higher the foreign owner ratio, the higher efficiency of a company is expected. We define such variable as the ratio of stocks held by foreign investors to the total stocks of a firm. The last environmental variable is the company which listed in the open financial market of Taiwan. The listed company is a company qualified to raising funds from the open market. While such a company can get financial support easier, it also subjects to additional requests and monitoring rules from government and stock holders. We have tried to consider other possible environmental factors such as firm location, firm characteristic in product produced, and years of operation of a firm. But these factors are shown to be insignificant to influence firm’s efficiency performance and thus are excluded from the analysis. In sum, the above mentioned 3 kinds of variables are chosen as the external environment which could affect managers’ performance.

All the data are collected from the Taiwan Economic Journal. Since we try to measure the most recent performance of semiconductor firms in Taiwan, the study period covers the years 2002 and 2007. In 2002, the Taiwan government launched the so-called “Two-trillion and Two-star industries” project where the semiconductor is one of the industries targeted. For promoting such government project, some incentive policies are provided by government. That is why the year 2002 is selected as the beginning year of this study. To make the performance comparison consistent, we tend not to cover the period strongly affected by the most recent global financial crisis in 2008, thus the end of study period is year 2007. This paper will compare the productivity and efficiency between year 2002 and year 2007 to examine the changes of performance in this project promoting period. To insure consistent comparison over time, it is noticed that the output sales are deflated by real effective exchange rate index, whereas those inputs are deflated by the producer price index with 2002 as the base year.

Table 1 and Table 2 show the descriptive statistics of the original input and output data for 2002 and 2007, respectively. Among these three sub-sectors, it is easy to find from values of both output and inputs that the IC manufacturing firms have the largest firm size in terms of operations, and these are followed by the IC packaging and testing, and then the IC design
firms. By comparing the minimum and maximum values of sales and inputs for each subsector, we also find the variation of firm size to be quite substantial for all subsectors. Table 1 also shows that the variation of Design subsector is much higher than the other two subsectors. In addition, the values of sales in Table 2 have shown to be double to those in Table 1. As for those inputs, their growth rates between 2002 and 2007 are shown to be smaller than that of sales.

Table 1  Descriptive statistics of input and output variables in 2002

<table>
<thead>
<tr>
<th>Subsector</th>
<th>2002 sales</th>
<th>R&amp;D expenditures</th>
<th>fixed assets</th>
<th>labor costs</th>
<th>operating costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>2575.61</td>
<td>264.79</td>
<td>578.10</td>
<td>67.87</td>
<td>1639.59</td>
</tr>
<tr>
<td>Number of firms</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Minimum</td>
<td>47.43</td>
<td>5.49</td>
<td>3.41</td>
<td>6.64</td>
<td>13.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>29513.15</td>
<td>2498.10</td>
<td>18871.57</td>
<td>745.22</td>
<td>17035.01</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>36028.83</td>
<td>3845.63</td>
<td>58493.74</td>
<td>1573.84</td>
<td>27921.75</td>
</tr>
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<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Minimum</td>
<td>2726.34</td>
<td>58.49</td>
<td>3143.98</td>
<td>262.82</td>
<td>2342.43</td>
</tr>
<tr>
<td>Maximum</td>
<td>160961.33</td>
<td>11725.04</td>
<td>217192.26</td>
<td>5479.83</td>
<td>107270.72</td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>4239.52</td>
<td>87.99</td>
<td>4944.57</td>
<td>559.88</td>
<td>3323.25</td>
</tr>
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<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Minimum</td>
<td>120.79</td>
<td>6.18</td>
<td>270.97</td>
<td>19.29</td>
<td>49.21</td>
</tr>
<tr>
<td>Maximum</td>
<td>25631.78</td>
<td>577.95</td>
<td>23709.93</td>
<td>3268.08</td>
<td>18027.28</td>
</tr>
<tr>
<td>Total</td>
<td>6609.72</td>
<td>611.73</td>
<td>7917.43</td>
<td>349.22</td>
<td>4898.96</td>
</tr>
<tr>
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<td>92</td>
<td>92</td>
<td>92</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Minimum</td>
<td>18997.83</td>
<td>1667.80</td>
<td>28328.51</td>
<td>834.31</td>
<td>13159.70</td>
</tr>
<tr>
<td>Maximum</td>
<td>47.43</td>
<td>5.49</td>
<td>3.41</td>
<td>6.64</td>
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<td>11725.04</td>
<td>217192.26</td>
<td>5479.83</td>
<td>107270.72</td>
</tr>
</tbody>
</table>

Notes: 1. The values of output and inputs are expressed in millions of 2002 NT dollars.
2. The output variable (sales) has been deflated by the real effective exchange rate index.
3. The input variables have been deflated by the producer price index.
Table 2  Descriptive statistics of input and output variables in 2007

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>sales</th>
<th>R&amp;D expenditures</th>
<th>fixed assets</th>
<th>labor costs</th>
<th>operating costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>5068.98</td>
<td>454.39</td>
<td>417.61</td>
<td>133.07</td>
<td>3226.99</td>
</tr>
<tr>
<td>Design</td>
<td>Standard deviation</td>
<td>10926.54</td>
<td>1021.24</td>
<td>784.47</td>
<td>274.87</td>
<td>5953.53</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>94.67</td>
<td>1.27</td>
<td>5.70</td>
<td>12.59</td>
<td>56.84</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>74778.58</td>
<td>7187.03</td>
<td>5221.85</td>
<td>2082.30</td>
<td>32552.18</td>
</tr>
<tr>
<td></td>
<td>Number of firms</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>68034.27</td>
<td>4525.47</td>
<td>79002.34</td>
<td>2830.17</td>
<td>48590.92</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Standard deviation</td>
<td>92183.40</td>
<td>4958.05</td>
<td>77649.43</td>
<td>3657.59</td>
<td>52198.90</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>4550.04</td>
<td>80.76</td>
<td>1716.56</td>
<td>579.73</td>
<td>3012.40</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>313647.64</td>
<td>15913.83</td>
<td>234564.56</td>
<td>12604.84</td>
<td>173218.43</td>
</tr>
<tr>
<td></td>
<td>Number of firms</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>10473.39</td>
<td>208.39</td>
<td>8518.79</td>
<td>969.29</td>
<td>6868.40</td>
</tr>
<tr>
<td>Packaging and</td>
<td>Standard deviation</td>
<td>17003.39</td>
<td>407.05</td>
<td>10662.98</td>
<td>1336.42</td>
<td>10941.18</td>
</tr>
<tr>
<td>testing</td>
<td>Minimum</td>
<td>254.03</td>
<td>4.75</td>
<td>276.11</td>
<td>46.94</td>
<td>91.91</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>64022.41</td>
<td>1584.77</td>
<td>36286.80</td>
<td>4823.69</td>
<td>41364.96</td>
</tr>
<tr>
<td></td>
<td>Number of firms</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>13205.39</td>
<td>838.07</td>
<td>10896.67</td>
<td>626.20</td>
<td>9028.63</td>
</tr>
<tr>
<td>Total</td>
<td>Standard deviation</td>
<td>36883.20</td>
<td>2198.34</td>
<td>34733.80</td>
<td>1583.29</td>
<td>22702.47</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>94.67</td>
<td>1.27</td>
<td>5.70</td>
<td>12.59</td>
<td>56.84</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>313647.64</td>
<td>15913.83</td>
<td>234564.56</td>
<td>12604.84</td>
<td>173218.43</td>
</tr>
<tr>
<td></td>
<td>Number of firms</td>
<td>92.00</td>
<td>92.00</td>
<td>92.00</td>
<td>92.00</td>
<td>92.00</td>
</tr>
</tbody>
</table>

Note: units for values of variables in this table are the same as those in Table 1.
IV. Results

A. Three-stage DEA efficiencies and input adjustments

Empirically, we first apply the standard BCC-DEA model using the sample input and output firm data for the years 2002 and 2007. The BCC model provides efficiency scores for each sample firm and input slacks for each inefficient firm. We then apply the COLS model for each input slack and adjust the input level accordingly. Furthermore, since our sample covers the upstream (Design), mid-stream (Manufacturing) and downstream (Packaging and Testing) sub-sectors of the semiconductor industry, as indicated in preceding section the producing unit sizes of the input variables among these three sub-sectors exhibit significant differences. Such vast difference in unit would cause the result of input adjustment, adjusted by the difference between maximum predicted slack and predicted slack, to be unreasonable. To avoid such statistical bias in prediction due to the unit size problem, we express the dependent variables (input slacks) in the second stage as percentages, which also suggested by the Fried et al. (1999). Then, following the Fried et al. (1999, 2002), we apply the standard BCC model again using the adjusted inputs and outputs to obtain the pure efficiency scores after removing the uncontrollable environmental effects.

Table 3 shows the average efficiencies of the sub-sectors for the semiconductor industry in 2002 and 2007 before the input adjustment. By comparing the CRS technical efficiencies, VRS technical efficiencies and the scale efficiencies from 2002 to 2007, we find all efficiency figures to have increased over time for the semiconductor industry as a whole and for most of its sub-sectors except for the scale efficiency of the IC design sector. However, as mentioned previously that these efficiency values are compounded with some external environment effects. We therefore adjusted inputs based on the proposed model and ran the BCC model again to obtain pure efficiency scores.
Table 3  Average efficiencies of 3 sub-sectors of the semiconductor industry in 2002 and 2007 using the original input and output data

<table>
<thead>
<tr>
<th></th>
<th>Year 2002</th>
<th>CRSTE</th>
<th>VRSTE</th>
<th>SCALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0.717</td>
<td>0.765</td>
<td>0.939</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.539</td>
<td>0.687</td>
<td>0.810</td>
<td></td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>0.787</td>
<td>0.834</td>
<td>0.948</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.715</td>
<td>0.773</td>
<td>0.927</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Year 2007</th>
<th>CRSTE</th>
<th>VRSTE</th>
<th>SCALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0.801</td>
<td>0.866</td>
<td>0.924</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.734</td>
<td>0.793</td>
<td>0.932</td>
<td></td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>0.864</td>
<td>0.905</td>
<td>0.952</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.809</td>
<td>0.867</td>
<td>0.931</td>
<td></td>
</tr>
</tbody>
</table>

Note: Notations description of this table is as follows:

CRSTE: technical efficiency under CRS DEA; VRSTE: technical efficiency under VRS DEA; SCALE: scale efficiency.

Tables 4 and 5 show the results of the COLS estimation for four input slacks deterministic frontiers in 2002 and 2007, respectively. We use the ratios of the input slacks divided by the input quantities as the dependent variables for input slack regressions. The environmental variables including Listed company ($Z_1$), foreign investor ratio ($Z_2$), and total assets ($Z_3$) were used as independent variables in these COLS estimations. The results of input slack frontiers in 2002 are shown in Table 4. Among all four input slacks, Table 4 indicate that all three environmental variables affect significantly to the slack of “Fixed Assets”, whereas other input slacks are only affected by the environment variable $Z_3$, “Total Assets”. Similarly, the results of input slack frontiers in 2007 are shown in Table 5. Table 5 show that environmental variables such as Foreign Investor Ratio ($Z_2$) and Total Assets ($Z_3$) have significant influence on all input slacks in 2007. It can be seen from Table 5 that $Z_2$ ($Z_3$) has negative (positive) impact on slack across all inputs, which implies that the firm with more foreign investors may help decrease slack and the firm with larger size may increase input slack. In sum, we find
that environmental variables do have some effects on inefficiency of input use in our study. Therefore, input adjustments are necessary to obtain pure management efficiencies of sample firms.

Table 4  COLS regression estimate results for input slacks in 2002

<table>
<thead>
<tr>
<th>environment variable</th>
<th>slacks</th>
<th>R&amp;D expenditures</th>
<th>fixed assets</th>
<th>labor costs</th>
<th>operating costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.0808</td>
<td>-0.4951**</td>
<td>-0.1943</td>
<td>0.0113</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.1370)</td>
<td>(0.1464)</td>
<td>(0.1315)</td>
<td>(0.1052)</td>
<td></td>
</tr>
<tr>
<td>Z1</td>
<td>-0.0156</td>
<td>-0.8092**</td>
<td>-0.0698</td>
<td>-0.0966</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0722)</td>
<td>(0.2982)</td>
<td>(0.0693)</td>
<td>(0.0554)</td>
<td></td>
</tr>
<tr>
<td>Z2</td>
<td>-0.3476</td>
<td>0.1181**</td>
<td>-0.4772</td>
<td>-0.2816</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.2792)</td>
<td>(0.0210)</td>
<td>(0.2680)</td>
<td>(0.2143)</td>
<td></td>
</tr>
<tr>
<td>Z3</td>
<td>0.0297</td>
<td>-0.1181**</td>
<td>0.0693**</td>
<td>0.0339*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0196)</td>
<td>(0.0209)</td>
<td>(0.0188)</td>
<td>(0.0151)</td>
<td></td>
</tr>
<tr>
<td>min(e)</td>
<td>-0.3784</td>
<td>-0.6973</td>
<td>-0.5054</td>
<td>-0.3529</td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1. ** and * represent the statistical significance at 1% and 5%, respectively.
3. The estimate of intercept term by COLS is “Constant + min(e) ”.
Table 5  COLS regression estimate results for input slacks in 2007

<table>
<thead>
<tr>
<th>Environment variable</th>
<th>R&amp;D expenditures</th>
<th>fixed assets</th>
<th>labor costs</th>
<th>operating costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>−0.0724</td>
<td>−0.3653**</td>
<td>−0.2230</td>
<td>−0.1056</td>
</tr>
<tr>
<td></td>
<td>(0.1096)</td>
<td>(0.1375)</td>
<td>(0.1208)</td>
<td>(0.0987)</td>
</tr>
<tr>
<td>Z1</td>
<td>0.0636</td>
<td>−0.0200</td>
<td>0.0570</td>
<td>0.0391</td>
</tr>
<tr>
<td></td>
<td>(0.0423)</td>
<td>(0.0531)</td>
<td>(0.0467)</td>
<td>(0.0381)</td>
</tr>
<tr>
<td>Z2</td>
<td>−0.5641**</td>
<td>−0.7708**</td>
<td>−0.5514**</td>
<td>−0.5052**</td>
</tr>
<tr>
<td></td>
<td>(0.1397)</td>
<td>(0.1752)</td>
<td>(0.1540)</td>
<td>(0.1258)</td>
</tr>
<tr>
<td>Z3</td>
<td>0.0312*</td>
<td>0.0774**</td>
<td>0.0512**</td>
<td>0.0332*</td>
</tr>
<tr>
<td></td>
<td>(0.0148)</td>
<td>(0.0186)</td>
<td>(0.0163)</td>
<td>(0.0133)</td>
</tr>
<tr>
<td>min(e)</td>
<td>−0.2900</td>
<td>−0.4254</td>
<td>−0.3255</td>
<td>−0.2515</td>
</tr>
</tbody>
</table>

Notes: 1. ** and * represent the statistical significance at 1% and 5%, respectively.
2. notations($Z_1$, $Z_2$, $Z_3$) described in this table are the same as Table 4.
3. The estimate of intercept term by COLS is “Constant + min(e) ”.

According to the empirical COLS estimates of the slack frontiers as in Tables 4 and 5 and by using equation (12), we calculate the quantities adjusted for each input and make the corresponding input adjustments. We again measure the DEA efficiencies using the adjusted inputs and the BCC model as stated in the Stage Three of the proposed model. The firms’ technical efficiencies resulted from the input adjustments are shown in Table 6. By comparing the efficiency results between 2002 and 2007, we find that all average efficiency figures have increased over time except for the scale efficiency of the IC design sector. Among the three sectors, Table 6 also indicates that the Packaging & Testing sector has the best efficiency scores (CRSTE, VRSTE and SCALE), which are followed by the IC Design sector and then the Manufacturing sector for both 2002 and 2007. On overall, the average efficiency score (VRSTE) for Taiwanese sample semiconductor industry is 77.6% in 2002 and 88.9% in 2007, which indicating about 11% of inefficiency capacity to improve in the future. Such improvement of efficiency over time may be partially attributed to the effective promotion of the “Two-trillion and Two-star” project by Taiwanese government.
Table 6  Average efficiencies of 3 sub-sectors of the semiconductor industry in 2002 and 2007: after input adjustment

<table>
<thead>
<tr>
<th>Year 2002</th>
<th>CRSTE</th>
<th>VRSTE</th>
<th>SCALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0.710**</td>
<td>0.759**</td>
<td>0.935</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.568*</td>
<td>0.708**</td>
<td>0.824</td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>0.795</td>
<td>0.852*</td>
<td>0.940</td>
</tr>
<tr>
<td>Total</td>
<td>0.714</td>
<td>0.776</td>
<td>0.924</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 2007</th>
<th>CRSTE</th>
<th>VRSTE</th>
<th>SCALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0.811**</td>
<td>0.882**</td>
<td>0.917</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.765**</td>
<td>0.859</td>
<td>0.890</td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>0.870*</td>
<td>0.920*</td>
<td>0.942</td>
</tr>
<tr>
<td>Total</td>
<td>0.820**</td>
<td>0.889**</td>
<td>0.920</td>
</tr>
</tbody>
</table>

Notes: 1. ** and * represent the statistical significance at 1% and 5% for testing the null hypothesis: “a firm’s efficiency score before input adjustment is the same as that of after input adjustment”, respectively.

2. Notations (CRSTE, VRSTE, SCALE) described are the same as Table 3.

It is also interesting to see the magnitude of the impact of external environment on firm’s efficiency. The impacts of environmental variables on firms’ efficiency performance were examined by testing the null hypothesis: “a firm’s efficiency score before input adjustment is the same as that of after input adjustment”. We make such test by sectors and by time. Table 6 marked those test results which rejected the null hypothesis at statistical significance levels 1% and 5%. In 2002, significant impacts of environmental variables on firm’s efficiency performance have been found on IC design firms (CRSTE and VRSTE), IC manufacturing firms (CRSTE and VRSTE) and IC packaging and testing firms (VRSTE). Similar results have also been found on IC design firms (CRSTE and VRSTE), IC manufacturing (CRSTE) and IC packaging and testing firms (CRSTE and VRSTE) in 2007. By comparing Tables 3 and 6, we find that except IC design sector, the efficiencies (CRSTE and VRSTE) for other sectors are higher in scenario of after input adjustment than those in
scenario of before input adjustment. Thus, the semiconductor industry as a whole have increased their technical efficiency scores in both 2002 and 2007 after purging the external environmental effects.

**B. Three-stage MPI and productivity changes**

To measure the changes of semiconductor firms’ efficiency, technology and productivity between 2002 and 2007, we adopt the Malmquist productivity index (MPI) for empirical estimation. Since the inputs we used are adjusted for external environment, our estimated changes, which are free of external environmental effects, are mostly representing pure manager’s ability. On the contrary, without such input adjustment, those measures may be confounded with external environmental effects. Both MPI results for scenarios of before input adjustment and after input adjustment are shown in Table 7. Since we use a BCC version of input orientation MPI, we can decompose the total factor productivity change (TFPCH) into efficiency change (EFFCH) and technology change (TECHCH), and also decompose further into pure technical change (PECH) and scale efficiency change (SECH).

To compare the results of productivity changes over time both before and after the input adjustments, we proceed with the proposed Malmquist TFP estimation procedure using the data before and after the input adjustments. Table 7 shows the Malmquist DEA results before input data adjustments for the years 2002 and 2007. We find that, during that period, the Malmquist TFP of the semiconductor industry as a whole and all its sub-sectors have increased, which implies that the productivity of the semiconductor industry as a whole and all its sub-sectors has improved in the years 2002 and 2007. For the decomposition effects of the MPI, all of the sub-sectors and the semiconductor industry as a whole have shown efficiency improvements and the technical progress when the years 2002 and 2007 are compared, except that IC manufacturing firms seem to have experienced slight technological regress and IC design firms face the decrease in scale efficiency.
Table 7  Malmquist DEA results before the input adjustment

<table>
<thead>
<tr>
<th>Sector</th>
<th>EFFCH</th>
<th>TECHCH</th>
<th>PECH</th>
<th>SECH</th>
<th>TFPCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>1.161</td>
<td>1.035</td>
<td>1.185</td>
<td>0.999</td>
<td>1.199</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>1.419</td>
<td>0.981</td>
<td>1.242</td>
<td>1.185</td>
<td>1.415</td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>1.124</td>
<td>1.091</td>
<td>1.117</td>
<td>1.009</td>
<td>1.227</td>
</tr>
<tr>
<td>Total</td>
<td>1.180</td>
<td>1.043</td>
<td>1.175</td>
<td>1.022</td>
<td>1.229</td>
</tr>
</tbody>
</table>

Note: Notations description of this table are as follows:

  EFFCH (efficiency change), TECHCH (technology change), PECH (pure efficiency change), SECH (scale efficiency change), TFPCH (total factor productivity change).

After we control for the effects of environmental factors, the Malmquist DEA results after the input adjustment are shown in Table 8. We find that all efficiency and productivity indicators for semiconductor industry as a whole are greater than 1, which implies an improvement in efficiency as well as technology in 2007 as compared with 2002. Such dominance in the productivity and efficiency indicators, implying technical progress, efficiency improvement, technology progress, as well as productivity growth, are also mostly found for all sub-sectors. Technology regress on manufacturing sector and the decrease of scale efficiency on IC Design sector are only exceptions. Based on the results of the Malmquist DEA using the adjusted inputs, in general we conclude that the semiconductor industry in Taiwan has enjoyed efficiency improvement, technical progress and productivity growth in 2002-2007.
Table 8  Malmquist DEA results after the input adjustment

<table>
<thead>
<tr>
<th>Sector</th>
<th>EFFCH</th>
<th>TECHCH</th>
<th>PECH</th>
<th>SECH</th>
<th>TFPCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>1.191</td>
<td>1.003</td>
<td>1.214</td>
<td>0.999</td>
<td>1.192</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>1.419</td>
<td>0.938</td>
<td>1.317</td>
<td>1.104</td>
<td>1.352</td>
</tr>
<tr>
<td>Packaging and testing</td>
<td>1.121</td>
<td>1.051</td>
<td>1.113</td>
<td>1.012</td>
<td>1.181</td>
</tr>
<tr>
<td>Total</td>
<td>1.199</td>
<td>1.008</td>
<td>1.201</td>
<td>1.013</td>
<td>1.207</td>
</tr>
</tbody>
</table>

Note: Notations described in this table are the same as Table 7.

By comparing the results of after input adjustment scenario in Table 8 and the result of before input adjustment scenario in Table 7, we find that the magnitudes of productivity progress of the semiconductor industry in after input adjustment scenario are all lower than those in without input adjustment scenario. However, while the efficiency changes with input adjustments are mostly higher than those without input adjustment, the technical changes in before input adjust scenario are higher those in after input adjustment scenario. Therefore, without considering the effects of the environmental factors, the evaluation of firms’ changes in productivity and technology will be overestimated for the semiconductor industry, whereas the efficiency improvement will be mostly underestimated.

V. Concluding Remarks

In this paper, we attempt to evaluate the productivity performance of Taiwanese semiconductor companies and examine the external environmental factors that may affect the firms’ performance. We adopt the multi-stage input-oriented DEA model of Fried et al. (1999, 2002) and extend it to a three-stage Malmquist DEA model to account for those environmental factors that may affect the firms’ managerial performance over time. Using the firm data for the Taiwanese semiconductor industry, we examine the relative efficiency and technical progress and productivity growth of this industry for the years 2002 and 2007.
The empirical results show that the efficiency scores using the input-adjusted third-stage DEA model are in general higher than those obtained using the first-stage DEA approach. The factors that could affect the inefficiency of firms include those firm characteristics such as listed company in open financial market, ratio of investment by foreign owners and total assets. The Malmquist DEA model after adjusting the inputs shows that, for the semiconductor industry as a whole and for all its sub-sectors, the productivity indicators including efficiency and technical change and productivity growth are in general shown to be better in 2007 as compared to those in 2002. Therefore, it is plausible to conclude that the recent government’s launched project, the project of “Two-trillion and Two-star industries”, has resulted in efficiency improvement, technology progress and productivity growth for semiconductor firms in Taiwan during 2002-2007. It is also recognized the importance of considering the external environments in measuring the true efficiency and productivity performance for semiconductor industry in Taiwan. Failing to consider the environmental effects in the model, the evaluation of productivity changes and the technological changes in the semiconductor industry will be overestimated, while the extent of the improvement in efficiency will be underestimated. The empirical results generated in this paper seem to be the useful information to managers of Taiwanese semiconductor companies for their formulating effective strategies or plans to improve their technology and efficiency levels.

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台灣半導體公司生產力評估：三階段麥氏資料包絡分析法

黃美瑛*、黃舒瑜**

摘要

本文旨在利用一個考量外部環境對廠商管理績效影響的三階段麥氏資料包絡分析跨
期追蹤模型，評估台灣半導體公司之生產力表現。實證結果顯示，外部環境對於廠商效
率有顯著影響。根據本文採用之投入調整模型之實證結果，可得到如下結論：台灣半導
體產業在2002-2007年期間，已經享受到效率改善、技術進步，以及生產力成長的成果。
但是，本研究亦發現，若未考量環境因素影響，則半導體產業廠商之生產力及技術變動
將會高估，然其效率改善則大部分為低估。

關鍵詞：半導體產業、效率、生產力、資料包絡分析、麥氏指數

JEL分類：C33, D24, L63, L86

* 國立台北大學經濟學系教授，本文聯繫作者。電話：(02)26748189#67167，
  Email：mayin@mail.ntpu.edu.tw。

** 行政院公平交易委員會約聘助理研究員。