Qual Quant (2012) 46:1865–1881
DOI 10.1007/s11135-011-9562-6

Does intellectual capital matter? Assessing the profitability and marketability of IC design companies

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Published online: 16 October 2011

Abstract Under a highly competitive market and a dynamic industrial environment, how to evaluate and enhance an integrated circuit (IC) design company's good performance is important. This paper develops a two-stage data envelopment analysis (DEA) combined intellectual capital theory through financial and non-financial data to evaluate a performance process on the IC design company. It adopts a new slacks-based measure (SBM) to obtain a more accurate performance estimation and rank between companies. This paper further uses the Simar and Wilson procedure with a truncated regression to explore the impact of intellectual capital variables on performance and competitive advantage. From the study we suggest to the company in how to enhance precisely its performance to create company value and success.

Keywords Data envelopment analysis · Slacks-based measure · Performance measurement · Intellectual capital

1 Introduction

Taiwan's integrated circuit (IC) design industry started in 1975 with government sponsorship and achieved growth in 1990. Its industry revenue is now the second largest in the world, and the numbers and scale of companies are only behind the United States. Taiwan now has a complete industrial chain and advanced manufacturing capacity, becoming an important global IC industry supply center. Because an IC design company has high profit with less investment and because consumption of electronics products have increased, more and more IC design companies have been set up worldwide. Accompanying this increase in the numbers and scale of IC design companies globally especially in China and India, competition has become more and more fierce. Under a highly competitive market and

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dynamic industrial environment, how to maintain an IC design company's good efficiency is very important (Chang and Tsai 2002). The performance estimation of IC design companies has been taken seriously quite recently (Chang et al. 2003; Hu and Li 2004; Chou and Liu 2005; Kuo and Shen 2005; Wu and Ho 2007), because they help lift Taiwan's overall economic efficiency. Many previously good performing management companies have had difficulty to maintain their past superior performance, and therefore an IC design company's accurate performance management is a subject worth discussing.

Market values of firms are estimated by the market, depending on several factors, such as book value, profit, economic outlook, speculation, and creating value ability. There exists gap between the book and market values such as the market value of Google was about U$50 billion in 2005, while its P/B ratio was about seventeen, which meant that the market value was seventeen times bigger than the book values of other firms. Such differences show that the existence of intellectual capital in firms.

Wernerfelt (1984) found that firms gain superior performance through acquiring, holding, and using strategic assets (namely, tangible and intangible assets) from a resource-based view. Intellectual capital represents knowledge-related intangible assets embedded in an organization. Its importance is highlighted in the era of a knowledge-based economy, where intellectual capital, instead of traditional tangible assets, is the dominant property driver for an enterprise (Edvinsson and Malone 1997). Van Buren (1999) proposed a model to illustrate the impact of intellectual capital on firm performance. Therefore, the literature shows that intellectual capital affects largely the value creation and performance of a company to bring competitive advantage (Amir and Lev 1996; Edvinsson and Malone 1997; Stewart 1997; Bontis 1999, 2001; Sullivan 2000; Juma and Payne 2004).

The IC design industry is a fabless sector with less fixed asset investment, and there are 270 IC design companies in Taiwan in 2007. The core value of an IC design company is its workers' high education and research innovation capability. Being a knowledge-intensive industry, intellectual capital is precisely the core essential factor for an IC design industry to maintain its competitive position and future living (Hung et al. 2004). Therefore, we investigate the relationship between intellectual capital and IC design firms' performance in order to advise managers to pay more attention to intellectual capital and to promote competitive ability.

The current study uses data envelopment analysis (DEA) as the tool for assessing the company performance. DEA can measure regarding multiple-inputs and multiple-outputs among various firm performance. It has been proven effective in multiple performance measures and also estimates the empirical efficient frontier from the observations while it does not require a priori information about the relationship among multiple performance measures. But traditional DEA models is the neglect of linking activities (intermediate products) or non-zero slack in inputs and outputs. To overcome the DEA methodological shortfalls referred to above when evaluating the performance of IC design firms in Taiwan, we adopt advanced DEA techniques, slacks-based measures (SBM) and slacks-based measures of super efficiency (super-efficiency-SBM), as respectively proposed by Tone (2001, 2002) to integrate the profitability as well as the efficiency of marketability to evaluate the IC design firms' performance based on Seiford and Zhu's model (1999).

The Tobit model was used to find intellectual capital factors which affect firms' performance, until Simar and Wilson (2007) demonstrated that it was inappropriate. Instead, they proved a truncated-regression approach with a bootstrap has satisfactory performance in Monte Carlo experiments. The adequacy of the functional form to the data is a prevalent problem and a common critique on the stochastic frontier models (Khumbakar and Lovell

2000). Here, we employ the Simar and Wilson (2007) approach to account for intellectual capital factors that might affect a firm's performance.

The remainder of this paper is organized as follows. The next section provides analysis on the IC design industry. In Sect. 3 we develop the two-stage value-creating process of an IC design firm. Section 4 offers the data selection and description. In Sect. 5 we present our methodology model. Section 6 includes our empirical research results and analysis, and Sect. 7 concludes with remarks.

2 IC design industry analysis

Taiwan's IC design industry is a very knowledge-intensive industry with less investment, shorter productive time, well-educated manpower, and shorter new product release time, with market demand satisfaction that is its competitive advantage. In 2007 Taiwan's IC design companies saw NT$ 3,997 billion in total revenue, for a growth of 23.6%. Taiwan's IC design industry has a 26.5% market share globally, second largest behind the U.S. Taiwan has a complete industrial chain and advanced manufacturing capacity, becoming an important global IC industry supply center. In 2007, IC design companies in Taiwan numbered 270, with competition becoming become more and more fierce. Thus, operation performance is something worth paying significant attention to.

The IC industry's technology advancement is rather quick, with the product frequency cycle decided by the market demand, new products being published, and meeting consumers' inexhaustible needs. For Taiwan's IC industry in 2007, the best performance was in LCD monitors and consumer products-related domain, as other products saw low gross profits. In 2007, the highest proportion went into product application, information application, and communication application. Under countries' national policy, strong capital support, and the global IC industry migrating to the Asia-Pacific area, China's own IC design industry has grown rapidly. Due to a highly competitive market and dynamic industrial environment, how to maintain good efficiency for an IC design company is very important. An IC design company in Taiwan needs to improve its performance with advanced design capability in order to face China's low capital and huge human resource advantage.

3 Two-stage value-creating process of an IC design firm

Since a company's performance is a complex phenomenon that cannot be characterized by just a single criterion, some studies have argued that a multi-factor performance measurement model may be used (Bagozzi and Phillips 1982; Chakravarthy 1986; Seiford and Zhu 1999; Zhu 2000; Luo 2003; Lu and Hung 2009). This study adopts Seiford and Zhu's two-stage profitability and marketability model of the top 55 U.S. banks (1999) to design two performance models (Fig. 1)—namely, a profitability performance model and a marketability performance model.

Figure 1 shows that the profitability performance model measures an IC design company's efficiency by three inputs (equity, liability and employees) and two outputs (revenues and intangible assets). The marketability performance model that measures an IC design company's market value by using two inputs (revenues and intangible assets) and two outputs (outstanding shares and market value). Previous studies use asset as the input parameter, where the question is from the accounting aspect: asset = equity + liability. Therefore, both material data have overlaps. This paper uses the liability representing the external resources

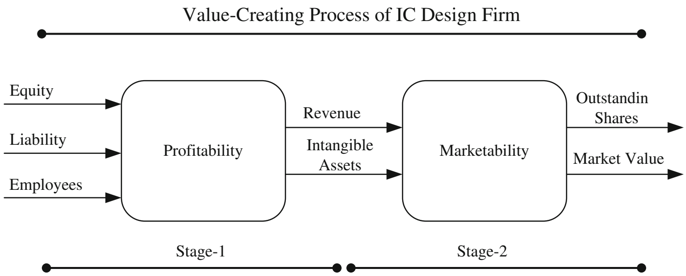

Fig. 1 Profitability and marketability efficiency models for IC design firms

and the equity representing the internal resources as input parameters replacing asset and equity.

The output and input factors (seven financial measures) used in this study are defined as follows.

- Equity, the ownership interest of shareholders in a corporation, is the residual interest in the assets of an entity after its liabilities have been deducted at the company's year-end.
- Liability is probable future sacrifices of economic benefits arising from present obligations.
- Employees are all staff members in an IC design company.
- Revenues, the entire amount of income before any deductions are made, include those of consolidated subsidiaries and exclude excise taxes.
- Intangible assets are assets that are saleable though not material or physical.
- Market value, a price which is likely to be paid for something, is obtained by multiplying the number of common shares outstanding by the price per common share at the last exchange date end of the year.
- Outstanding shares are stock currently held by investors, including restricted shares owned by the company's officers and insiders, as well as those held by the public.

4 Data selection and description

Equity, liability, number of employees, revenue, intangible assets, market value, and outstanding shares data of the companies in 2007 are collected from the database of Taiwan Economic Journal. The companies included in the sample are all publicly listed and the information is complete and easy to collect. This paper uses 38 IC design companies in Taiwan as sample data. Each of these IC design companies is treated as a decision making unit (DMU) in the DEA analysis. Table 1 presents the descriptive statistics for our dataset in 2007. From this table, we observe that the deviations in the variables used are quite large, because of the various sizes of the IC design companies.

The DEA technique presumes the correlation coefficient relationship among the input and output data as performed in Table 2. It can be observed that most input factors are highly correlated with output factors under a score larger than 0.7, implying that the IC design companies that employ more input resources will increase their revenue and market value. In the DEA model, the number of IC design companies should be at least twice the total number of input and output factors considered Golany and Roll (1989). In this study's profitability model the number of IC design companies is 38, which is at least twice the five factors

Table 1 Descriptive statistics for IC design firms in 2007

Variables	Mean	Minimum	Maximum	Std. dev.
Equity (NT$ thousand)	5,910,113	165,638	85,937,057	13,734,434
Liabilities (NT$ thousand)	1,593,343	48,970	11,353,281	2,491,581
Employees (persons)	358	55	1,817	392
Revenue (NT$ thousand)	6,879,256	223,536	74,778,579	13,001,787
Intangible assets (NT$ thousand)	16,312,737	13,711	352,261,943	55,492,651
Market value (NT$ million)	22,223	1,084	438,199	68,930
Outstanding shares (million)	245	27	1,409	324

Table 2 Correlation coefficients among inputs and outputs in 2007

	Equity	Liability	Employees	Revenues	Intangible assets	Market value	Outstanding shares
Equity	1.000						
Liability	0.802	1.000					
Employees	0.782	0.847	1.000				
Revenues	0.933	0.917	0.773	1.000			
Intangible assets	0.973	0.729	0.696	0.910	1.000		
Market value	0.983	0.747	0.717	0.919	0.999	1.000	
Outstanding shares	0.605	0.686	0.753	0.554	0.445	0.479	1.000

selected. Hence, the DEA model developed based on the profitability performance model has met construct validity requirement. By following the same rules, the marketability model in this study is also found on a required validity issue.

5 Methodology

The methodology procedures adopted are as follows. First, we use Tone's SBM model (Tone 2001) to evaluate the performance of the IC design companies in the current period. Then use the super-efficiency-SBM model (Tone 2002) to rank the best performers from those exhibiting an efficiency score of one. Finally, the truncated regression model (Simar and Wilson 2007) is employed to account for intellectual capital factors that might affect a firm's performance.

5.1 Slacks-based measure model

There are various DEA models that can be categorized into two forms (Cooper et al. 2000). The first form is the radial models including the CCR model by Charnes et al. (1978) and the BCC model by Banker et al. (1984). The second form is the non-radial models that are the additive model (Charnes et al. 1985), the Russell measure (Russell 1985), the range-adjusted measure (Aida et al. 1998), and the SBM model (Tone 2001).

We choose the SBM model as the appropriate version of DEA for investigating the efficiency of the process of converting multiple inputs into multiple outputs. The SBM model possesses more suitable features include: (1) processes directly with the input excesses and the output shortfalls of the firms concerned; (2) unit invariant and monotone decreasing with respect to input excesses and output shortfalls and affected by consulting the reference set of the DMUs not the whole dataset; (3) it is crucial to deal with negative outputs in the evaluation of efficiency and is closely connected to the other measures proposed, e.g., the CCR, BCC and the Russell measures.

The non-oriented SBM model gets the efficiency of the target DMU_o $(o = 1, \ldots, n)$ by solving the following fractional programs:

$$\begin{aligned}
&\text{Min } \eta_o = \left(1 - \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{io}\right) \Big/ \left(1 + \frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{ro}\right) \\
&s.t. \\
&x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^-, i = 1, \ldots, m, \\
&y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+, r = 1, \ldots, s, \\
&\sum_{j=1}^{n} \lambda_j = 1, \\
&\lambda_j \geq 0, \quad s_i^- \geq 0, \quad s_r^+ \geq 0.
\end{aligned} \tag{1}$$

Here, n is the number of firms each firm produces s different outputs, using m different inputs; $x_{ij} > 0$ and $y_{rj} > 0$ are the level of the ith input and $r$thoutput, respectively, at the jth firm; and λ_j is the weight of the firm j, the firm being evaluated is set as the target firm. The sum of the weights must be equal to one in Program (1), suggesting that the constructed best practice frontier exhibits variable returns to scale technology, so that, the frontier permits increasing, constant, and decreasing returns to scale. The efficiency score calculated by Program (1) reflects the target firm's current scale of operations. It is referred to as "pure" technical efficiency, for representing the ability of management to transform inputs in order to produce outputs, when $\eta_o^* = 1$. The value of λ_j indicates that the firm j is an exemplar for the target firm can learn.

Program 1 can be transformed into the program with a positive scalar variable t (Charnes and Cooper 1962).

$$\begin{aligned}
&\text{Min } \tau_o = t - \frac{1}{m}\sum_{i=1}^{m} ts_i^- \big/ x_{io} \\
&s.t. \\
&1 = t + \frac{1}{s}\sum_{r=1}^{s} ts_r^+ \big/ y_{ro} \\
&x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^-, i = 1, \ldots, m,
\end{aligned} \tag{2}$$

$$y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+, r = 1, \ldots, s,$$
$$\sum_{j=1}^{n} \lambda_j = 1,$$
$$\lambda_j \geq 0, \quad s_i^- \geq 0, \quad s_r^+ \geq 0, \quad t > 0.$$

Now let us define:

$$S_i^- = ts_i^-, \quad S^+ = ts_r^+, \quad \Gamma = t\lambda_j.$$

Program 2 then is transformed into the following linear program in t, S_i^-, S_r^+, and Γ:

$$\begin{aligned}
&\text{Min } \tau_o = t - \frac{1}{m}\sum_{i=1}^{m} S_i^-/x_{io} \\
&s.t. \\
&1 = t + \frac{1}{s}\sum_{r=1}^{s} S_r^+/y_{ro} \\
&tx_{io} = \sum_{j=1}^{n} x_{ij}\Gamma_j + S_i^-, i = 1, \ldots, m, \\
&ty_{ro} = \sum_{j=1}^{n} y_{rj}\Gamma_j - S_r^+, r = 1, \ldots, s, \\
&\sum_{j=1}^{n} \Gamma_j = t, \\
&\Gamma_j \geq 0, \quad S_i^- \geq 0, \quad S_r^+ \geq 0, \quad t > 0.
\end{aligned} \tag{3}$$

Note that $t > 0$ by virtue of the first constraint, the transformation is reversible. Thus, let an optimal solution of Program 3 be:

$$\left(\tau_o^*, t^*, \Gamma^*, S_i^{-*}, S_r^{+*}\right).$$

We then have an optimal solution of Program 1 defined by

$$\eta_o^* = \tau_o^*, \quad \lambda_{\text{j}}^* = \Gamma_j^*/t^*, \quad s_i^{-*} = S_i^{-*}/t^*, \quad s_r^{+*} = S_r^{+*}/t^*.$$

5.2 Super-efficiency-SBM model

The best performers share the fully efficient status denoted by a score of one such as multiple firms usually exhibit 'efficient' status. The super-efficiency model can rank these efficient firms to distinguish real benchmarks. The efficient observed firm is taken out from the production possibility set (PPS) by measuring the distance from the observed firm to the point located on the remaining PPS. If the distance is small, the super-efficiency of the firm is lower than the other firms. By contrast, if the distance is large, then the super-efficiency of the firm is higher than the remaining firms. Hence, we rank the efficient firms based on the super-SMB scores obtained.

Tone (2002) proposed the non-oriented super-SBM model for getting the super-efficiency of the observed DMU_o (x_{io}, y_{ro}) by solving the following fractional programs:

$$
\begin{aligned}
& Min\,\pi_o = \left(\frac{1}{m}\sum_{i=1}^{m}\overline{x}_i/x_{io}\right)\Big/\left(\frac{1}{s}\sum_{r=1}^{s}\overline{y}_r/y_{ro}\right) \\
& s.t. \\
& \overline{x}_i \geq \sum_{j=1, j\neq o}^{n} x_{ij}\lambda_j, i = 1, \ldots, m, \\
& \overline{y}_r \leq \sum_{j=1, j\neq o}^{n} y_{rj}\lambda_j, r = 1, \ldots, s, \\
& \sum_{j=1}^{n}\lambda_j = 1, \\
& \overline{x} \geq x_{io}, \quad \overline{y} \leq y_{ro}, \quad \overline{y} \geq 0, \quad \lambda_j \geq 0.
\end{aligned}
\tag{4}
$$

$\left(\overline{x}_i, \overline{y}_r\right)$ is located on the remaining PPS. A weighted l_1 distance from x_{io} to $\overline{x}_i$ $(\geq x_{io})$, is an average expansion rate of x_{io} to $\overline{x}_i$ of the point $\left(\overline{x}_i, \overline{y}_r\right)$. A weighted l_1 distance from y_{ro} to $\overline{y}_r (\leq y_{ro})$, is an average reduction rate for y_{ro} to $\overline{y}_r$ of the point $\left(\overline{x}_i, \overline{y}_r\right)$. Inversely an index of the distance from y_{ro} to $\overline{y}_r$. Hence, π_o is a product of two indices: one is the distance in the input space, and the other is the distance in the output space.

We define $\phi \in R^m$ and $\theta \in R^s$ such that $\overline{x}_i = x_{io}\,(1 + \phi_i)$ and $\overline{y}_r = y_{ro}\,(1 - \theta_r)$. It can be equivalently stated in terms of ϕ_i, θ_r, and λ_j as follows:

$$
\begin{aligned}
& Min\,\pi_o = \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\phi_i}{1 - \frac{1}{s}\sum_{r=1}^{s}\theta_r} \\
& s.t. \\
& \sum_{j=1, j\neq o}^{n} x_{ij}\lambda_j - x_{io}\phi_i \leq x_{io}, i = 1, \ldots, m, \\
& \sum_{j=1, j\neq o}^{n} y_{rj}\lambda_j + y_{ro}\theta_r \geq y_{ro}, r = 1, \ldots, s, \\
& \sum_{j=1}^{n}\lambda_j = 1, \\
& \phi_i \geq 0, \quad \theta_r \geq 0, \quad \lambda_j \geq 0.
\end{aligned}
\tag{5}
$$

We use a positive scalar variable t (Charnes and Cooper 1962).

$$
\begin{aligned}
& Min\,\pi_o = t + \frac{1}{m}\sum_{i=1}^{m} t\phi_i \\
& s.t. \\
& t - \frac{1}{s}\sum_{r=1}^{s} t\theta_r = 1 \\
& \sum_{j=1, j\neq o}^{n} x_{ij}\lambda_j - x_{io}\phi_i \leq x_{io}, i = 1, \ldots, m,
\end{aligned}
\tag{6}
$$

$$\sum_{j=1, j\neq o}^{n} y_{rj}\lambda_j + y_{ro}\theta_r \geq y_{ro}, r = 1, \ldots, s,$$
$$\sum_{j=1}^{n} \lambda_j = 1,$$
$$\phi_i \geq 0, \quad \theta_r \geq 0, \quad \lambda_j \geq 0, \quad t > 0.$$

By defining the following:

$$t\phi_i = \Phi_i, \quad t\lambda_j = \Lambda_j, \quad t\theta_r = \Theta_r$$

Program 6 transforms into the following linear program in Φ_i, Λ_j, and Θ_r.

$$\begin{aligned}
& Min\, \delta_o = t + \frac{1}{m}\sum_{i=1}^{m} \Phi_i \\
& s.t. \\
& t - \frac{1}{s}\sum_{r=1}^{s} \Theta_r = 1 \\
& \sum_{j=1, j\neq o}^{n} x_{ij}\Lambda_j - x_{io}\Phi_i \leq tx_{io}, i = 1, \ldots, m, \\
& \sum_{j=1, j\neq o}^{n} y_{rj}\Lambda_j + y_{ro}\Theta_r \geq ty_{ro}, r = 1, \ldots, s, \\
& \sum_{j=1}^{n} \Lambda_j = t, \\
& \Phi_i \geq 0, \quad \Theta_r \geq 0, \quad \Lambda_j \geq 0, \quad t > 0.
\end{aligned} \tag{7}$$

We have an optimal solution of Program 7 be $\left(\delta_o^*, \Phi_i^*, \Theta_r^*, \Lambda_j^*, t^*\right)$. We express an optimal solution of Program 5

$$\pi_o^* = \delta_0^*, \quad \lambda_j^* = \Lambda_j^*/t^*, \quad \phi_i^* = \Phi_i^*/t^*, \quad \theta_r^* = \Theta_r^*/t^*$$

the optimal solution of Program 4 is expressed by:

$$\overline{x}_{io}^* = x_{io}\left(1 + \phi_i^*\right) \quad \text{and} \quad \overline{y}_{ro}^* = y_{ro}\left(1 - \theta_r^*\right).$$

5.3 Truncated Regression Model

The paper assumes and tests Simar and Wilson (2007) truncated regression model as the following

$$TE = \mathbf{Z}\boldsymbol{\beta} + \boldsymbol{\varepsilon}, \tag{8}$$

here TE is a vector $(n \times 1)$ of technical efficiency; the $(d \times 1)$ vector $\boldsymbol{\beta}$ is unknown parameters to be calculated; $\mathbf{Z}$ is an matrix $(n \times d)$ of environmental variables; and $\boldsymbol{\varepsilon}$ is an $(n \times 1)$ vector of statistical noise.

Previous DEA literature use Tobit model to show that intellectual capital factors on firms' performance, until it was demonstrated inappropriate by Simar and Wilson (2007). They proved a truncated-regression approach with a bootstrap has satisfactory performance in

Monte Carlo experiments. Khumbakar and Lovell (2000) said that it is a prevalent problem and a common critique for the adequacy of the functional form to the data. We use the Simar and Wilson (2007) approach to prove intellectual capital factors on a firm's performance.

The distribution of $\boldsymbol{\varepsilon}$ is restricted by the condition $\boldsymbol{\varepsilon} \geq 1 - \alpha - \mathbf{Z}\boldsymbol{\beta}$, we follow Simar and Wilson (2007) and assume that this distribution is truncated normal with zero mean, unknown variance, and left truncation point. Formally, our model is expressed by:

$$TE = \mathbf{Z}\boldsymbol{\beta} + \boldsymbol{\varepsilon}, \quad \boldsymbol{\varepsilon} \sim N(0, \sigma_\varepsilon^2), \quad \text{such that } \boldsymbol{\varepsilon} \geq 1 - \mathbf{Z}\boldsymbol{\beta}, \tag{9}$$

here we maximize the corresponding likelihood function to estimate, with respect to $(\boldsymbol{\beta}, \sigma_\varepsilon^2)$, on our data. With asymptotic theory, normal tables are used to construct confidence when our regressands are not true variables, and their estimates are likely to be dependent on observed variables the construction can be more precise with a bootstrap. The bootstrap confidence intervals for the estimates of parameters $(\boldsymbol{\beta}, \sigma_\varepsilon^2)$ are constructed by using the parametric bootstrap for regression with incorporate information on the parametric structure and distributional assumption.

6 Empirical results and analysis

6.1 Measuring profitability and marketability performances

The evaluation of the IC design companies' profitability and marketability efficiencies is conducted for the year 2007. The non-oriented SBM model is applied to assess the relative performances of the 38 Taiwanese IC design companies. To distinguish those efficient IC design companies that can be treated as real benchmarks, the super-SBM model is used as a ranking measure. All of the results are shown in Table 3. The order (No.) of the IC design company is coded based on the respective sizes of the total assets.

The average scores computed from the SBM models based on the profitability and marketability models are 0.533 and 0.499, respectively. The results show that eight of the IC design companies are efficient with scores all equal to one in Table 3 in the profitability performance field. Eight of the thirty-eight IC design companies with efficiency scores of one in the marketability performance field.

To make comparisons among the IC design companies, we calculate the mean values of their profitability and marketability efficiency scores based on the main focus as shown in Table 4. An examination of the IC design companies' profitability performance reveals that analog IC design companies (with a mean value of 0.653) operate better than digital IC design companies (with a mean value of 0.506). This result shows that analog IC design companies are more likely to generate relatively higher profit. Those IC design companies whose main focus is analog IC design on average outperform the other types. The reason for this is that the demand for analog IC design has recently grown rapidly in Taiwan's market. By examining the performance of marketability, it is found that digital IC design companies operate better on average than analog ones, which can be explained by the finding that digital IC design companies can more easily attract the attention of investors with the trend towards digital circuit development.

6.2 Identification of benchmarks

Distinguishing among these efficient IC design companies and identifying the benchmarks have become interesting research subjects. Several authors have proposed methods for

Table 3 SBM-efficiency and SBM-super-efficiency for IC design firms in 2007

IC design firms	Code	Cast	Profitability model		Marketability model	
			SBM-Eff.	Super-SBM Eff.	SBM-Eff.	Super-SBM Eff.
Mediatek Incorporation	F01	C1	**1.000**	**3.205**	**1.000**	**1.836**
Novatek Microelectronics Corp.	F02	C1	**1.000**	**1.115**	0.367	0.367
Realtek Semiconductor Corp.	F03	C1	0.386	0.386	0.409	0.409
Richtek Technology Corp.	F04	C2	**1.000**	**1.305**	0.458	0.458
Sunplus Technology Co., Ltd.	F05	C1	0.288	0.288	0.468	0.468
Faraday Technology Corp.	F06	C1	0.414	0.414	0.723	0.723
VIA Technologies, Inc.	F07	C1	0.246	0.246	0.531	0.531
Elan Microelectronics Corp.	F08	C1	0.638	0.638	0.708	0.708
Phison Electronics Corp.	F09	C1	**1.000**	**1.160**	0.050	0.050
Ali Corp.	F10	C1	0.506	0.506	0.656	0.656
Silicon Integrated Systems Corp.	F11	C1	0.039	0.039	**1.000**	**4.773**
Elite Semiconductor Memory Technology In	F12	C1	0.386	0.386	0.152	0.152
Sonix Technology Co., Ltd.	F13	C1	0.559	0.559	0.250	0.250
Sitronix Technology Corp.	F14	C1	0.472	0.472	0.091	0.091
ITE Tech. Inc.	F15	C1	0.734	0.734	0.290	0.290
Etron Technology, Inc.	F16	C1	0.147	0.147	0.162	0.162
Holtek Semiconductor Inc.	F17	C1	0.367	0.367	0.267	0.267
Weltrend Semiconductor, Inc.	F18	C1	0.426	0.426	0.384	0.384
Anpec Electronics Corp.	F19	C2	0.516	0.516	0.156	0.156
Springsoft Inc.	F20	C1	0.258	0.258	**1.000**	**1.058**
Alcor Micro Corp.	F21	C1	0.775	0.775	0.191	0.191
Advanced Power Electronics Corp.	F22	C2	0.702	0.702	0.161	0.161
Princeton Technology Corp.	F23	C1	0.170	0.170	0.310	0.310
Syntek Semiconductor Co., Ltd.	F24	C1	0.275	0.275	**1.000**	**1.862**
Genesys Logic, Inc.	F25	C1	0.246	0.246	0.248	0.248
Prolific Technology Inc.	F26	C1	0.355	0.355	0.548	0.548
Integrated Service Technology Inc.	F27	C1	0.159	0.159	0.372	0.372
Ame Inc.	F28	C2	0.566	0.566	0.328	0.328
CoAsia Microelectronics Corp.	F29	C1	**1.000**	**1.540**	**1.000**	**1.777**
Service & Quality Technology Co., Ltd.	F30	C1	**1.000**	**1.596**	0.523	0.523
Aimtron Technology Co., Ltd.	F31	C2	**1.000**	**1.270**	0.310	0.310
Higher Way Electronic Co., Ltd.	F32	C1	0.603	0.603	0.222	0.222
Amic Technology Corp.	F33	C1	0.283	0.283	0.396	0.396
E-Cmos Corp.	F34	C2	0.478	0.478	0.999	0.999
Chip Hope Co., Ltd.	F35	C1	0.433	0.433	0.245	0.245
Avid Electronics Corp.	F36	C1	0.520	0.520	**1.000**	**1.142**
Analog Integrations Corp.	F37	C2	0.311	0.311	**1.000**	**1.000**

Table 3 continued

IC design firms	Code	Cast	Profitability model		Marketability model	
			SBM-Eff.	Super-SBM Eff.	SBM-Eff.	Super-SBM Eff.
HiMark Technology Inc.	F38	C1	**1.000**	**1.789**	**1.000**	**1.532**
Mean			0.533		0.499	

C1 digital IC design company; *C2* analog IC design company

Table 4 Summary statistics: TE of cast for IC design firms in 2007

Category	Number	Profitability performance		Marketability performance	
		Mean	Test (p-value)	Mean	Test (p-value)
Cast					
Digital IC design company	31	0.506	0.1452	0.502	0.6912
Analog IC design company	7	0.653		0.487	

ranking the best performers, including Andersen and Petersen (1993), Doyle and Green (1994), Tofallis (1996), Seiford and Zhu (1999), Zhu (2001), and Tone (2002). We refer to this problem as the 'super-efficiency' problem. The super-SBM model first proposed by Tone (2002) is an appropriate version of DEA for ranking the efficient IC design companies in this study. Several characteristics of the super-SBM model have been discussed before, especially its ability to cope with a small number of DMUs compared to the number of evaluation criteria.

The IC design company with higher super-SBM efficiencies reveals itself to be different in the input/output space, and thus can be either referenced by very few DMUs, or just by itself. From managerial implication, the IC design company is a self-evaluator for niche player (Charnes and Cooper 1962). Table 3 reports the super-SBM efficiencies for both profitability and marketability models. There are eight technically efficient IC design companies under the SBM model for the profitability stage. The order of ranking in descending order is Mediatek Incorporation (F01), HiMark Technology Inc. (F38), Service & Quality Technology Co, Ltd. (F30), CoAsia Microelectronics Corp. (F29), Richtek Technology Corp. (F04), Aimtron Technology Co, Ltd (F31), Phison Electronics Corp. (F09), and Novatek Microelectronic Corp. (F02). In the profitability model, Mediatek Incorporation (F01) is a niche player in the digital group, and Richtek Technology Corp. (F04) is a niche player in the analog group. The super-SBM efficiency for the eight technically efficient IC design companies in the marketability performance model is also reported herein. The order of ranking is Silicon Integrated Systems Corp. (F11), Syntek Semiconductor Co, Ltd. (F24), Mediatek Incorporation (F01), CoAsia Microelectronics Corp. (F29), HiMark Technology Inc. (F38), Avid Electronic Corp. (F36), Springsoft Inc. (F20), and Analog Integrations Corp. (F37). In the marketability model, Silicon Integrated Systems Corp. (F11) is a niche player in the digital group, and Analog Integrations Corp. (F37) is a niche player in the analog group. We therefore rank the efficient IC design companies from the highest to the lowest in order to rank the best performers based on the resulting list to determine niche players.

6.3 The relationship between intellectual capital and performance

The concept of intellectual capital was first proposed by economist Galbraith (1969) and is used as intangible assets to explain the differences between a company's market value and book value that are not reflected on the balance sheet. It represents the intangible assets of a firm, including any that may increase the organization value, promote the organization competitive advantage, exceed the book value, and have important effects on achieving company profit and competitive advantage in the market. Stewart (1994) thought that intellectual capital will become the value driver and the most advantageous competition power of an American company. Edvinsson and Malone (1997) also believed that in the knowledge economy era, intellectual capital management may transform knowledge as property. Thus, the literature argues that intellectual capital largely affects the value creation and performance of a company to bring competitive advantage (Amir and Lev 1996; Edvinsson and Malone 1997; Stewart 1997; Bontis 1999, 2001; Sullivan 2000; Juma and Payne 2004).

The IC design industry is a knowledge-intensive industry, which has many intangible assets. These intangible assets are of great importance for such an industry contained in the knowledge industry scope. Therefore, the many valuable intangible assets in the IC design industry have been the key area for its survival superiority and growth achievement. Thus, intellectual capital appears as a value in an IC design company. IC design companies, as such, gain competitive advantage and superior performance through acquiring and holding intangible assets.

Intellectual capital of a company, as an intangible asset, is developed from knowledge management, including expertise of knowledge, experiences, organizational technologies, customer relationships, and specialized skills. The core value of an IC design company is the education quality of its workforce and research capability. In IC design companies, valuable assets reside in the intellectual capital their employees produce, not in the tangible assets the company possesses. Many companies are sold far in excess of their book value. Previous literature indicates that successful Taiwanese IC firms have better effective intellectual capital performance management, but there is little consensus on how intellectual capital can best be conceptualized and measured. Furthermore, little empirical research has specifically examined the relationship between intellectual capital and IC design companies' performance. This paper focuses on the impact that intellectual capital has on an IC design company's performance and also on the management strategy it may have on this relationship.

The literature has a convergent view that a general concept of intellectual capital is divided into three elements: human capital, customer capital, and structure capital (Edvinsson and Malone 1997; Stewart 1997; Bontis 1999; Sullivan 2000; Choo and Bontis 2002). This paper classify intellectual capital into human capital, structure capital, and customer capital as three essential factors, in order to discuss the relatedness of intellectual capital, each construction surface, and an IC design company's performance. Staff who receive a higher education from the best universities are assumed to have more specialized knowledge and to have high potential intellectual capabilities to learn and accumulate new or tacit knowledge (D'Aveni and Kesner 1993). In the human capital variable selection part, we propose one human capital variable as antecedent distribution (above master) based on Edvinsson and Malone (1997). Structure capital consists of intellectual assets such as number of patents, research expenses and management expenses. Customer capital includes earnings growth rate.

We use DEA to obtain the efficiency value and take the explanation variable by the intellectual capital's three target variables, making the regression analysis. We adopt Simar and Wilson's (2007) procedure to explore the impact of intellectual capital on performance

Table 5 Results of regression in profitability model

	Coefficient	Std. error	z-Statistic	*p*-Value
Intercept	0.379241	0.109369	3.46752	0.001444
Structure capital	−0.000583	0.000416	−1.40349	0.169538
Human capital	0.001197	0.000313	3.82491	0.000533*
Customer capital	0.006680	0.002524	2.64683	0.012222*
R^2	0.418			

* Statistically significant at the 0.05 level

and competitive advantage with a truncated regression. The estimated specification is the following:

$$\theta_i = \alpha_0 + \alpha_1 \cdot Structure_i + \alpha_2 \cdot Human_i + \alpha_3 \cdot Customer_{i,j} + \varepsilon_i, \tag{10}$$

here θ represents the efficient score.

The truncated regression with a bootstrap model appears to fit the data well, with positive t-statistics, which are statistically significant for all parameters. The estimations generally conform to a priori expectations. It is observed from Table 5 that efficiency increases in the human and customer capital factors. The empirical results imply that human capital has an obvious positive effect on performance. Through better management of intellectual capital, firms can improve competitive advantages. Human capital is the primary factor that affects the firm performance, and management should put the most effort on it.

6.4 Analysis of managerial decision-making matrix

In the previous section the IC design companies' benchmarks are identified either by their profitability or marketability performance. An overview analysis including these two performance models has not yet been discussed. This section presents a decision making matrix in Fig. 2 to further illustrate the difference between profitability and marketability. In Fig. 2 classify the IC design companies, which fall into four quadrants—star, cow, sleepers, and dogs—which are similar to the classification done by the Boston Consulting Group. The IC design companies have been split subjectively into four groups plotted respectively in the zones of stars, sleepers, dogs, and cows. The IC design companies in each group are summarized as follows.

The zone of stars: In this zone, these IC design companies have high efficiency in both profitability and marketability efficiency dimensions. Three IC design companies are included here: Mediatek Incorporation (01), Coasia Microelectronics (29), and HiMark Technology (38), These companies have good performance and can be reference companies for others. From the intellectual capital factors analysis based on our collected data, Mediatek Incorporation has paid much attention in the antecedent distribution (above master) of human capital. Coasia Microelectronics should regard human capital and customer capital as important factors for maintaining its good performance.

The zone of sleepers: In this zone, these IC design companies have efficient marketability performance, but inefficient profitability performance. Five IC design companies are included in this zone: Silicon (11), Springsoft (20), Syntek (24), Avid (36), and Analog integrations (37). IC design companies in this zone should improve their profitability performance by putting more efforts to increase their revenue and intangible asset. From the intellectual

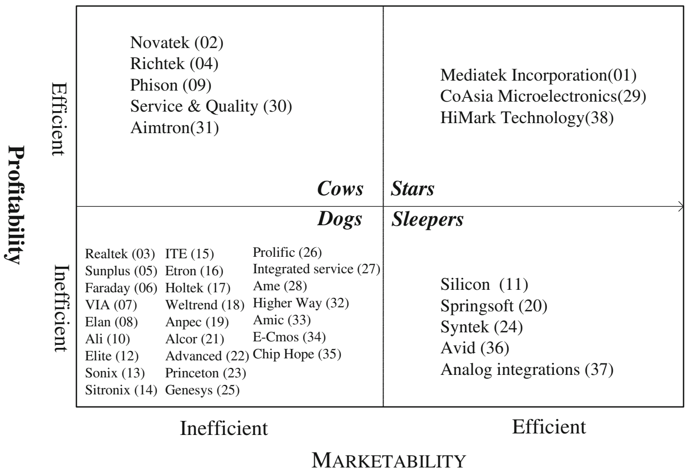

Fig. 2 Profitability/marketability efficiency cross-tabulation

capital factors analysis, these companies can achieve progress by paying more effort to raise their earnings growth rate of customer capital.

The zone of dogs: In this zone, these IC design companies are inefficient both in profitability efficiency and marketability efficiency. Twenty-five IC design companies are here: Realtek (03), Sunplus (05), Faraday (06), VIA (07), Elan (08), Ali (10), Elite (12), Sonix (13), Sitonix (14), ITE (15), Eton (16), Holtek (17), Weltrend (18), Anpec (19), Alcor (21), Advanced (22), Princeton (23), Genesys (25), Prolific (26), Integrated Services (27), Ame (28), Higher Way (32), Amic (33), E-Cmos (34), and Chip Hope (35). They should improve their performance in creating profit and market. For instance, Higher Way can pay more effort on human capital and customer capital to improve its performance.

The zone of cows: In this zone, these IC design companies have efficient profitability but inefficient marketability performance. There are five IC design companies: Novatek (02), Richtek (04), Phison (09), Service & Quality (30), and Aimtron (31). Phison could emphasize human capital investment in the antecedent distribution (above master) and average period of service.

The IC design companies classified into the zone of stars are almost all digital IC design companies. This shows that digital IC design companies have better competitive power than analog IC design firms.

7 Concluding remarks

This paper has adopted a two-stage efficiency estimation model for using SBM DEA method on an IC design company. While DEA has been widely adopted in the literature on IC design company efficiency studies, it has limitations on deeply evaluating the intellectual capital variables' effect on performance. The paper uses the Simar–Wilson procedure with a truncated regression to find out the obvious intellectual capital factors affecting an IC design company's performance. Thus, the contribution of this paper to the literature is: to adopt a new two-stage DEA evaluation process by the SBM model in order to evaluate and rank the performance; by combining DEA measurement with a recently developed Simar–Wilson method and a truncated regression, to verify that the intellectual capital effect on DEA efficiency performance. The findings are that human capital has a positive impact on IC design companies' performance. Furthermore, the paper suggests to an inefficient company on how to manage its intellectual capital, arguing that human capital and customer parameters can create and enhance a company's efficiency and success.

Acknowledgment The authors want to express their gratitude to Dr. Wen-min Lu for his discussion and assistance in DEA software usage.

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