Stock selection using data envelopment analysis

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Abstract

Purpose – The purpose of this study is to adopt data envelopment analysis (DEA) to construct portfolios, and compare their return rates with the market index to examine whether DEA portfolios created superior returns. In addition, this study investigated whether using the "size effect" as a stock selection strategy is appropriate in Taiwan.

Design/methodology/approach – This study applied two DEA models to evaluate the efficiency of the firms and construct portfolios by selecting stocks with high efficiency. Furthermore, the return rates of the portfolios constructed by small-size firms, DEA models and market indices were compared via empirical data analysis.

Findings – The results showed that size effect seems inappropriate as a stock selection strategy in the Taiwan stock market. However, the portfolios constructed by DEA models achieved noticeable superior returns.

Research limitations/implications – Future studies can apply DEA models to other stock markets in different countries to confirm the effectiveness of DEA methods in stock selection.

Originality/value – This study is the first attempt to select stocks using DEA models and compares the performances of the portfolios composed by DEA analysis, small-size firms and the stock market indices. The proposed approach provides useful managerial implications in stock selection and insight to improve financial efficiencies of corporations.

Keywords Data analysis, Financial services, Portfolio investment

Paper type Research paper

1. Introduction

The main objective of fund managers in financial service industry is to select stocks with high-expected returns to lift the performance of their funds. However, the number of stocks listed on stock markets is increasing. This trend has increased the challenge of selecting stocks to create a portfolio that will have superior returns. For example, the New York Stock Exchange (NYSE) already contains more than 2,800 company stocks, while the National Association of Securities Dealers Automated Quotations (NASDAQ) stock market lists approximately 3,600 electronics companies in 2007. Government funds and mutual fund managers in financial service industry thus face growing challenges in properly screening these stocks.

Academics have long stated that competition among traders eliminates asset mispricing. As a result, every stock is always correctly priced and efforts to outperform simple random selection of stocks are destined to fail. Jensen (1968) demonstrated that fund managers in financial service industry generally failed to outperform a random selection of stocks. Other researchers continue to suggest that investors can seldom achieve superior returns (Walker and Hatfield, 1996; Dellva and Olson, 1998;

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Weigand *et al.*, 2004). Therefore, selecting stocks with high-expected returns to beat the market seems difficult to achieve.

Previous studies have discussed several factors related to expected stock returns. For instance, Banz (1981) examined the empirical relationship between returns and the market values of NYSE common stocks. According to that study, smaller firms have higher average returns than larger firms do. Moreover, this "size effect" has existed for at least four decades. Fama and Fench (1992) investigated the same issue, indicating that two variables were consistently related to stock returns:

(1) firm size; and

(2) firm market/book ratio.

After adjusting for other factors, Fama and Fench (1992) found that smaller firms have yielded relatively high returns, and that returns are higher for stocks with low market/book ratios. Conversely, they found no relationship between a stock's beta and its return. Moreover, Kothari and Shanken (1997) found that both book-to-market and dividend yield tracked time-series variation in expected real stock returns. Among these factors, "size effect" is the most widely discussed variable relating to expected stock returns. Following Banz (1981) and Fama and Fench (1992), numerous studies have examined size effects of stock markets in different countries and periods (Jensen *et al.*, 1997; Brusa *et al.*, 2000; Leledakis *et al.*, 2003; Mills and Jordanov, 2003; Zepp, 2003; Gaunt, 2004; Guo, 2004; Kousenidis, 2005). Consequently, the "size effect" may be applied to select stocks for investment. The first purpose of this study is, therefore, to examine whether using the "size effect" as a stock selection strategy can beat the market.

On the other hand, the present study proposes that the fundamental operating situation and efficiency may impact firm stock price. This concept was based on the study of Brigham and Houston (2007), which indicated that the ratios in financial statements will influence stock prices. In fact, the numbers in financial statements reflect the performance and efficiency of the company. Investing in the stocks of firms with better efficiency should yield better returns. Although evaluating the efficiencies of firms with different inputs and outputs is difficult, the data envelopment analysis (DEA) models developed by Charnes *et al.* (1978) and Banker *et al.* (1984) can objectively combine multiple inputs and outputs of an entity into a single measure of overall organizational efficiency. Consequently, DEA should be a useful method for selecting and screening stocks for fund managers in financial service industry. Moreover, the study of applying DEA models to select stocks for investment has not been found in previous literature. Therefore, the second objective of this study is to adopt DEA to construct portfolios, and compare their return rates with the market index. Historical data of the Taiwan Stock Exchange Corporation (TSEC) are adopted as the empirical data in this work.

The rest of this paper is organized as follows. Section 2 illustrates the models of DEA. Section 3 then discusses the research methods employed in this work. Next, Section 4 uses real world data to compare the performances of the small firm, DEA model and market index portfolios. Section 5 discusses the managerial implications of the analytical results. Conclusions are finally drawn in Section 6.

2. Data envelopment analysis model

The concept of efficiency is derived from physical and engineering science and indicates the relationship between inputs and outputs (Hwang and Chang, 2003). Charnes *et al.* (1978) (CCR) introduced the ratio definition of efficiency, also known as the CCR ratio definition, which generalizes the single-output to single-input ratio definition used in classical science to multiple outputs and inputs without requiring pre-assigned weights. The main strength of the CCR ratio as it is applied in this study lies in its ability to combine multiple inputs and outputs into a single summary measure to select efficient firms for investment.

Charnes *et al.* (1978) proposed that the efficiency, h_O, of a decision-making unit (DMU_0) can be determined by solving the following CCR model:

$$\begin{aligned} \max\ h_0 &= \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \\ \text{subject to}\ & \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \\ & j = 1, \ldots, n, \ \text{where}\, u_r, v_i > 0, i = 1, \ldots, m, r = 1, \ldots, s. \end{aligned} \tag{1}$$

In this study, the $y_{rj}, x_{ij} > 0$ represent the outputs and inputs for DMUj with the ranges for i, r and j indicated in equation (1). Additionally, v_i denotes the weight given to input i, u_r represents the weight given to output r, s is the number of outputs, m is the number of inputs, n is the number of DMUs, and h_0 is the efficiency value of DMU_0. The outputs and inputs may take the form of theoretically prescribed values or they may take the form of observations. The constraints in equation (1) ensure that an optimal $h_0^* = \max h_0$ will always satisfy $0 \le h_0^* \le 1$with the optimal solution values $u_r^*, v_i^* > 0$.

The CCR model as equation (1) allows each DMU to specify its own weights to maximize its own efficiency value. The flexibility for this model to choose its input and output weights produces the efficient DMUs in general (Ertay and Ruan, 2005). Therefore, the efficiency value of any DMU can be estimated and rated via equation (1). This study defines a DMU as a listed firm. And the amounts of output and input will be determined based on the real values in the financial statements.

The CCR model was developed based on the assumption of constant returns to scale. Banker *et al.* (1984) (BCC) extended the CCR model by introducing a new separate variable u_0 and enabled the determination of the efficiency of any DMU, whether operations were conducted in regions with increasing, constant or decreasing returns to scale.

The model proposed by Banker *et al.* (1984) is equivalent to a fractional programming problem, and can be expressed as the following BCC model:

$$\max \frac{\sum_{r=1}^{s} u_r y_{r0} - u_0}{\sum_{i=1}^{m} v_i x_{i0}}$$

$$\text{subject to} \quad \frac{\sum_{r=1}^{s} u_r y_{rj} - u_0}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \tag{2}$$

$$j = 1, \ldots, n, \quad \text{where } u_r, v_i > 0, i = 1, \ldots, m, r = 1, \ldots, s.$$

with, u_0 unconstrained in sign.

Since being proposed by Charnes *et al.* (1978) and Banker *et al.* (1984), the DEA models have been widely applied in evaluating the efficiencies of manufacturing and service industries (Hwang and Chang, 2003; Casu and Molyneux, 2003; Fiordelisi and Molyneux, 2004; Ertay and Ruan, 2005; Sigala *et al.*, 2005; Staat, 2006; Hsu and Lin, 2007). A recent research by Mostafa (2007) employed DEA to evaluate the relative efficiency of the top 100 Arab banks. However, the DEA models are rarely used in portfolio management. Research on stock selection using DEA models has not been found in previous literature. Therefore, this study applies DEA models to assess the efficiency of the firms listed on the TSEC and constructs portfolios by selecting the stocks with high efficiency values.

3. Method

This study applies the "size effect" and DEA models to construct portfolios and compare their returns with industry average returns for Taiwan Stock Exchange listed stocks. The historical financial ratios and stock prices of the firms listed in eight major industries on the TSEC are used as the empirical data. The eight major industries represented on the Taiwan Stock Exchange market include cement, food, plastics, textiles, electronics and machinery, paper and pulp, construction, and banking and insurance. Stocks in these industries are selected by size or DEA methods for portfolio construction, and portfolios are selected for each industry using the small size and DEA methods, respectively.

The empirical data used in this study covers the period from the second quarter of 2004 to the second quarter of 2007. Based on the financial data of the second quarter of 2004, stocks are selected and portfolios are constructed using the size effect or DEA models. Furthermore, the performances of these portfolios in the next quarter (the third quarter of 2004) are compared with the average returns of all stocks in the eight major industries. From the second quarter of 2004 to the first quarter of 2007, the same procedure is repeated to construct portfolios and compare their performances with average industry stock returns in the next quarter. Based on this procedure, the results of the empirical analysis can examine whether efficiency values of DEA models are good predictors of future stock prices. The historical data used in this work was obtained from the data system of *Taiwan Economic Journal* (*TEJ*), a leading database company in Taiwan.

Banz (1981) and Fama and Fench (1992) defined the "size" of a firm as its market equity (ME). That is a stock's price times the number of shares outstanding. Therefore, the first step conducted in this study is to find the firms with low ME in eight major industries as small size companies. The corporations in the Taiwan Stock Exchange market were categorized according to industry, with each industry then being classified into two categories of small and large sized firms based on their ME. The average firm sizes in each industry were used as the benchmarks for classification.

DEA was applied as the other strategy to select stocks and construct portfolios. Both the CCR and BCC models were used to select firms with high efficiency. As mentioned above, multiple inputs and outputs of an entity can be combined objectively in the DEA model to yield an overall measure of efficiency. In this study, average equity, average asset, and sales cost were defined as input factors. In addition, revenues, operating profit and net income were defined as output factors. The input and output factors were selected by referring to the studies of Rosenberg *et al.* (1985), Johnsen and Melicher (1994), Suzuki (1998) and Foreman (2003). With the CCR and BCC models, the firms with high efficiency in eight major industries were selected and included in portfolios. The software *DEA-Frontier* was used to solve the DEA models.

The amounts of outputs and inputs in the DEA models are constrained to larger than or equal to 0. And, some firms with negative operating profit during these time periods were unable to process the DEA methods. However, the objective of the DEA models is to construct high efficiency portfolios. Therefore, firms with negative operating profits can be classified as "inefficient" and excluded from the portfolios.

4. Results and discussion

The results of the DEA models produce the efficiency value of every firm, with the highest value being 1. Therefore, firms with efficiency values of 1 can be classified as efficient firms and included in the DEA portfolios. For example, considering the data of the second quarter of 2004, 15 and 23 companies were selected among 45 companies in the banking and insurance industry using the CCR and BCC models, respectively. The results are shown in Table I.

These efficient firms were included in portfolios. Moreover, the returns of the portfolios in the quarter following the second quarter of 2004 were compared with the industry averages. Additionally, the average stock returns of small firms in the eight major industries were compared. The returns of 12 quarters (3 years) from the third quarter of 2004 to the second quarter of 2007 are listed in Tables II-IV. The last rows of the tables show the superior returns, namely those returns that exceed the average returns of the firms in the eight major industries.

Tables II-IV demonstrate that the portfolios constructed by BCC model beat the market 68 out of 96 times of comparison (and in 8 industries over 12 quarters). Additionally, the portfolios constructed by the CCR model beat the market 67 times. Moreover, the BCC portfolios achieved superior returns of 6.90 per cent, 3.48 per cent, 6.51 per cent and the CCR portfolios achieved superior returns of 5.86 per cent, 4.16 per cent, 5.72 per cent for year 1, year 2 and year 3, respectively. On the other hand, the portfolios of small firms did not perform well during these 12 quarters. The portfolios of small firms achieved superior returns of 0.94 per cent in the first quarter of 2005, 0.16 per cent in the first quarter of 2006 and 0.43 per cent in the third quarter of 2006. However, they obtained returns below the industry averages in the other nine quarters.

Stock number	Efficiency value CCR	BCC
2801	0.6034	1
2807	0.8137	1
2808	0.7817	1
2809	0.5623	0.6770
2811	1	1
2812	–	–
2816	1	1
2820	1	1
2822	0.7312	0.9104
2823	0.9613	0.9991
2825	–	–
2827	–	–
2831	0.6451	0.9432
2832	1	1
2833	1	1
2834	–	–
2836	0.9912	1
2837	–	–
2838	0.9123	0.9436
2841	–	–
2845	1	1
2847	0.9804	1
2849	0.7310	0.7912
2850	1	1
2851	0.9046	1
2852	–	–
2854	1	1
2855	1	1
2856	0.8916	0.8989
2880	–	–
2881	–	–
2882	1	1
2883	–	–
2884	1	1
2885	–	–
2886	–	–
2887	1	1
2888	–	–
2889	–	–
2890	0.6758	1
2891	0.9917	1
2892	1	1
5854	1	1
6004	1	1
6012	–	–

Notes: The "–"indicates the firm has negative operating profit

Table I.
Efficiency values of companies in the banking and insurance industry as estimated by DEA models

Furthermore, the portfolios of small firms had total returns of −10.32 per cent, 5.27 per cent and 39.11 per cent over the 3 years, respectively. This number is 4.66 per cent, 5.56 per cent and 3.58 per cent less than the industry average for the 3 years, respectively. Restated, the size effect seems inappropriate to be used as a stock selection

	Industry average (per cent)	Small (per cent)	BCC (per cent)	CCR (per cent)
2004/third quarter				
Cement	6.74	−0.43	15.74*	15.74*
Food	−4.33	−7.73	−1.27*	0.77*
Plastics	6.42	1.90	7.02*	7.36*
Textiles	−3.29	−1.93*	−4.15	−6.52
Electric & Machinery	−5.17	−4.90*	−1.77*	−2.15*
Paper & Pulp	−2.55	−2.97	−3.06	−4.44
Construction	2.05	−5.57	3.65*	1.01
Banking & Insurance	−0.58	−1.35	1.58*	2.39*
Average	−0.09	−2.87	2.22*	1.77*
Superior return	–	−2.78	2.31	1.86
2004/fourth quarter				
Cement	−1.79	−4.07	0.49*	0.49*
Food	−0.37	−1.93	0.08*	0.48*
Plastics	−1.14	−3.61	−0.51*	0.09*
Textiles	0.29	−4.12	3.32*	2.78*
Electric & Machinery	−5.38	−6.01	−5.08*	−3.77*
Paper & Pulp	0.37	−2.20	−0.20	−0.51
Construction	6.19	5.80	8.96*	12.99*
Banking & Insurance	4.31	5.72*	4.63*	3.42
Average	0.31	−1.30	1.46*	2.00*
Superior return	–	−1.61	1.15	1.69
2005/first quarter				
Cement	−1.01	−0.76*	0.20*	0.20*
Food	1.09	3.22*	2.50*	2.08*
Plastics	2.62	−2.33	6.51*	5.46*
Textiles	−2.12	0.01*	−0.83*	0.38*
Electric & Machinery	6.02	12.51*	7.48*	8.80*
Paper & Pulp	−0.66	−4.27	−4.69	−4.27
Construction	0.32	5.76*	5.67*	4.61*
Banking & Insurance	−1.59	−1.91	−0.49*	−0.44*
Average	0.59	1.53*	3.38*	2.10*
Superior return	–	0.94	2.79	1.51
2005/second quarter				
Cement	−5.01	−2.07*	−5.73	−5.73
Food	−2.05	−3.48	0.89*	3.16*
Plastics	−6.91	−9.40	−5.14*	−5.32*
Textiles	−5.10	−4.31*	−3.44*	−3.16*
Electric & Machinery	−5.94	−5.94	−5.01*	−6.63
Paper & Pulp	−13.25	−17.44	−17.22	−17.22
Construction	−9.06	−11.01	−5.52*	−5.72*
Banking & Insurance	−4.46	−7.77	−5.39	−4.71
Average	−6.47	−7.68	−5.82*	−5.67*
Superior return	–	−1.21	0.65	0.80

Notes: *Investment return is superior to that of the industry average

Table II.
Return rates of the portfolios constructed by small firms, the BCC model, CCR model and industry average from 2004/third to 2005/second quarter (year 1)

strategy in the Taiwan Stock Exchange market. However, DEA models created noticeable superior returns.

To confirm that the BCC portfolios and CCR portfolios outperformed the industry averages, the Wilcoxon signed-rank test and *t*-test were adopted to test the statistical

	Industry average (per cent)	Small (per cent)	BCC (per cent)	CCR (per cent)
2005/third quarter				
Cement	−2.00	−7.40	−3.95	−3.99
Food	−4.83	−4.34*	−5.30	−5.83
Plastics	−12.15	−19.53	−11.15*	−11.83*
Textiles	−10.24	−14.47	−8.75*	−7.18*
Electric & Machinery	−3.23	−2.08*	−2.61*	−0.25*
Paper & Pulp	−9.91	−16.11	−7.80*	−7.80*
Construction	−15.65	−12.75*	−18.10	−17.88
Banking & Insurance	−8.50	−7.93*	−9.29	−9.20
Average	−8.31	−10.58	−8.37	−8.00
Superior return	–	−2.27	−0.06	0.31
2005/fourth quarter				
Cement	−0.72	−3.20	1.99*	4.33*
Food	0.59	−4.10	0.30	1.60*
Plastics	1.56	6.91*	2.01*	−0.02
Textiles	−1.03	−5.79	−0.14*	−0.37*
Electric & Machinery	4.03	−1.19	5.06*	5.67*
Paper & Pulp	−1.29	−1.84	−0.70*	−0.64*
Construction	0.91	−3.05	0.28	−1.63
Banking & Insurance	−3.22	−1.66*	−4.49	−5.33
Average	0.10	−1.74	0.54	0.45
Superior return	–	−1.84	0.44	0.35
2006/first quarter				
Cement	4.02	3.78	5.13*	4.80*
Food	1.32	0.64	0.26	2.42*
Plastics	−2.82	−3.12	−0.14*	0.19*
Textiles	−1.89	−1.54*	−3.35	−3.05
Electric & Machinery	−1.64	0.52*	1.12*	1.61*
Paper & Pulp	−1.35	−2.63	6.42*	9.50*
Construction	12.57	10.57	4.29	9.07
Banking & Insurance	−5.55	−2.32*	−4.23*	−2.12*
Average	0.58	0.74	1.19	2.80
Superior return	–	0.16	0.60	2.22
2006/second quarter				
Cement	11.18	10.52	10.87	15.61*
Food	18.50	16.30	19.84*	15.99
Plastics	5.98	8.44*	13.64*	10.18*
Textiles	21.92	17.80	17.03	18.19
Electric & Machinery	11.27	13.52*	17.18*	12.27*
Paper & Pulp	27.37	20.64	34.63*	32.10*
Construction	45.39	40.18	44.09	43.58
Banking & Insurance	6.07	7.38*	10.41*	9.99*
Average	18.46	16.85	20.96	19.74
Superior return	–	−1.61	2.50	1.28

Notes: * Investment return is superior to that of the industry average

Table III.
Return rates of the portfolios constructed by small firms, the BCC model, CCR model and industry average from 2005/third to 2006/second quarter (year 2)

significance of the differences between the performances of the portfolios based on the DEA models and industry averages. The results of the Wilcoxon signed-rank test showed that the Z-value of comparing the returns of BCC portfolios with industry averages was 3.15 ($p = 0.002$), while the Z-value of comparing the returns of CCR

	Industry average (per cent)	Small (per cent)	BCC (per cent)	CCR (per cent)
2006/third quarter				
Cement	−1.37	−2.56	−1.44	−0.18*
Food	−1.12	−3.14	−0.65*	1.54*
Plastics	−1.43	−1.58	−2.04	−1.11*
Textiles	−4.97	−3.18*	−1.84*	−3.47*
Electric & Machinery	−5.90	−2.78*	0.01*	1.23*
Paper & Pulp	1.70	1.25	11.48*	11.49*
Construction	−2.14	−2.63	−2.33	−3.09
Banking & Insurance	−5.39	−2.56*	−2.56*	−2.36*
Average	−2.58	−2.15	0.08	0.51
Superior return	–	0.43	2.66	3.08
2006/fourth quarter				
Cement	34.41	29.61	36.71*	38.52*
Food	26.23	24.32	23.81	31.71*
Plastics	30.50	27.38	19.08	20.79
Textiles	47.50	46.69	54.62*	36.62
Electric & Machinery	31.99	35.18*	32.27*	30.88
Paper & Pulp	42.11	39.81	47.22*	43.30*
Construction	65.69	58.96	58.35	57.93
Banking & Insurance	17.50	13.40	20.31*	22.75*
Average	36.99	34.42	36.55	35.31
Superior return	–	−2.57	−0.45	−1.68
2007/first quarter				
Cement	−8.03	−5.62*	−6.72*	−5.81*
Food	2.80	5.78*	7.81*	10.94*
Plastics	11.36	8.68	4.95	7.98
Textiles	1.14	0.59	5.16*	5.58*
Electric & Machinery	4.73	8.79*	7.17*	8.25*
Paper & Pulp	−9.11	−7.32*	−8.84*	−8.28*
Construction	−4.70	−10.37	−4.23*	−2.51*
Banking & Insurance	−4.80	−2.15*	−2.28*	−3.15*
Average	−0.83	−1.65	0.38	1.62
Superior return	–	−0.82	1.20	2.45
2007/second quarter				
Cement	20.22	17.13	27.84*	27.85*
Food	13.56	16.18*	16.76*	18.43*
Plastics	7.94	10.36*	12.02*	10.43*
Textiles	8.50	7.78	5.55	−0.88
Electric & Machinery	14.23	12.20	20.10*	16.61*
Paper & Pulp	4.87	4.53	5.12*	4.99*
Construction	1.62	−3.81	3.34*	4.01*
Banking & Insurance	1.97	3.56*	6.95*	6.45*
Average	9.11	8.49	12.21	10.99
Superior return	–	−0.62	3.10	1.87

Notes: *Investment return is superior to that of the industry average

Table IV.
Return rates of the portfolios constructed by small firms, the BCC model, CCR model and industry average from 2006/third to 2007/second quarter (year 3)

portfolios with the industry averages was 2.75 ($p = 0.006$). The results of the t-test demonstrated that the t-value of the differences between the returns of BCC portfolios and the industry averages is 3.22 ($p = 0.003$), and the t-value of the differences between the returns of CCR portfolios and the industry averages is 2.95 ($p = 0.006$).

Both the Wilcoxon signed-rank test and the *t*-test revealed that the DEA portfolios significantly outperformed the industry averages in statistics.

In order to compare the risk-adjusted returns of the portfolios constructed using DEA and the industry averages, the Sharpe ratios were calculated and compared. The Sharpe ratios of the portfolios constructed using CCR and BCC were 0.36 and 0.34, respectively, in the period from the second quarter of 2004 to the second quarter of 2007. Both of them outperformed the portfolios of industry, which had the Sharpe ratio of 0.25. In addition, the Sharpe ratio of the portfolios constructed by the small companies was only 0.18. This result revealed that the portfolios constructed using DEA generated higher risk-adjusted returns than those of the industry, and portfolios of small firms.

5. Managerial implications

Applying advanced information and data systems to analyze the investment opportunities and risks is very important for investors and managers in financial service industry. For example, Ferruz and Vargas (2008) found that the incorporation of more information technologies and systems improved the explanatory power of macroeconomic variables in predicting expected investment fund returns. Lin and Chen (2008) proposed a new genetic-based hybrid approach to predict the possibility of corporations' financial distress and to avoid investment risks. However, the application of DEA model proposed by Charnes *et al.* (1978) to measure the efficiencies of corporations and select stocks has been considered as a complex process. Fortunately, the information system and software have been developed and enhanced in the recent years. Evaluating the efficiencies of enterprises has become easy in the era of electric finance. Therefore, investors and fund managers in financial service industry should find better investment opportunities using DEA models.

The empirical result of this study showed that the portfolios constructed by DEA models demonstrated the ability to create noticeably superior returns. This result is not consistent with the efficient market hypothesis (EMH) proposed by Fama (1970). Fama (1970) held that stock prices are always in equilibrium and it is impossible for an investor to consistently "beat the market". However, the result of this study is consistent with some of the recent articles. For example, Eakins and Stansell (2003) found that the portfolios created by neural network and based on a set of financial ratios provided investment returns superior to the Dow-Jones industrial average and S&P 500. Chen *et al.* (2006) applied support-vector machines and back propagation (BP) neural networks to forecast the indices of the six major Asian stock markets. The results showed the superiority of both models and confirmed the fitness of using these two models in predicting the indices of the six major Asian stock markets. Tsang *et al.* (2007) built a stock buying/selling alert system using a BP neural network. The system was tested with data from one of the Hong Kong stocks, The Hong Kong and Shanghai Banking Corporation (HSBC) holdings. The result showed that the system was capable of achieving an overall hit rate of 78 per cent. Therefore, the EMH has confronted with more and more arguments in the recent years. The result of this study also demonstrated that stock selection using DEA to obtain superior returns is possible. Investors and fund managers in financial service industry can use the approach applied in this research to select stocks for investment and create superior returns.

The portfolios composed by small firms only created superior returns in three quarters including the first quarter of 2005, the first quarter of 2006 and the third

quarter of 2006. However, they obtained returns below the industry averages in the other nine quarters. Furthermore, the returns of portfolios based on small firms were 4.66 per cent, 5.56 per cent and 3.58 per cent less than the industry average for the 3 years, respectively. This result is not consistent with that of Fama and Fench (1992). The possible reason is that Fama and Fench (1992) used the stocks in the USA as the data of empirical analysis, whereas the stocks in Taiwan were used in this study. Fama and Fench (1992) defined the "size" of a firm as its ME. The average firm size in the market was used as the benchmarks for classifying corporations into "large" or "small" categories. However, there is large difference between the market equities of American firms and Taiwanese firms. The small size corporations in Taiwan may confront with the shortage of capital invested in research and development (R&D). They also have more difficulties in obtaining capitals from financial institutions due to higher risk. This phenomenon may affect the growth and stock prices of small firms in Taiwan. However, the small-sized firms in the USA are still large enough to invest in R&D or information technology and to achieve economic scale. Therefore, investment in the stocks of small-sized firms may have different results in the USA and Taiwan.

Moreover, the results of this study made an important managerial contribution and insight to managers of general enterprises. According to the study of Brigham and Houston (2007), the primary goal of managers in enterprises is stock price maximization. The results of this study showed that the relative efficiency of corporations significantly affects their stock prices. Managers should evaluate the relative efficiency of their corporations to improve their corporations' performances and stock prices. For example, 15 banks or insurance corporations such as stock numbers of 2812 and 2825 in Table I have negative operating profit. These banks or insurance corporations should notice their financial status and analyze the reasons for the poor performance. The negative operating profit is generally caused by low operating revenue. The managers of these firms should keep an eye on this situation and establish the strategies to resolve this problem.

Other 15 banks or insurance corporations such as stock numbers of 2801 and 2807 in Table I have relative efficiency values of less than 1. The managerial efficiencies of these corporations are lower than those with value of 1. Although these banks or insurance corporations do not face the serious financial problems as those with negative operating profit, they should also investigate the problems of managerial efficiency. In this study, average equities, average assets and sales costs were selected as input factors in DEA models. Managers of these inefficient corporations are suggested to reduce sales costs to improve managerial efficiency because average equities and assets are long term investment and may be difficult to be reduced in short term for banking and insurance industries.

On the other hand, revenues, operating profit and net income were defined as output factors in this study. Managers of these corporations should analyze these three factors together because they are correlated to each other. Trend analysis is also suggested for these corporations to evaluate their financial status in recent years or quarters. It is important to analyze trends of these factors as well as their relative efficiency values, because trend analysis gives clues as to whether a firm's financial condition is likely to enhance or to deteriorate. In addition, comparing these financial numbers with those of other firms is also important. The analysis involving comparisons with other firms in the same industry helps managers to evaluate which factor should be noticed and improved.

Managers are suggested to estimate their relative efficiency values every quarter because financial statements are published quarterly in Taiwan. Managers can apply DEA to evaluate their performances every quarter and decide their strategies to improve their managerial efficiency. The mangers of financial departments also can predict the stock prices of their corporations and other companies by using DEA models to make their investment decisions and strategies.

6. Conclusions

Previous studies have suggested that investors can seldom earn superior returns (Walker and Hatfield, 1996; Dellva and Olson, 1998; Weigand *et al.*, 2004). Accordingly, selecting stocks with high-expected returns to beat the market is not easy for fund managers and investors in financial service industry to achieve. Additionally, previous studies have not applied DEA models to select stocks for investment although DEA models have been widely used in efficiency evaluation by manufacturing and service corporations. This study compared the return rates of portfolios constructed by small firms, BCC model, CCR model and industry averages for eight major industries represented on the Taiwan Stock Exchange market. As mentioned, the reason why size effect portfolios were compared with DEA portfolios was that size effect was discussed more than other anomalies in previous studies. The results showed that the size effect appears inappropriate as a stock selection strategy in the Taiwan stock market. Portfolios of small firms achieved total returns of 4.66 per cent, 5.56 per cent and 3.58 per cent less than the industry average for the 3 years, respectively. However, the portfolios constructed by DEA models demonstrated good ability to create noticeably superior returns. The BCC portfolios achieved superior returns of 6.90 per cent, 3.48 per cent, 6.51 per cent and the CCR portfolios achieved superior returns of 5.86 per cent, 4.16 per cent, 5.72 per cent for year 1, year 2 and year 3, respectively. Furthermore, the Wilcoxon signed-rank test and *t*-test confirmed that the DEA portfolios significantly outperformed the industry averages in statistics. The Sharpe ratio was also applied to evaluate the risk-adjusted return, and the result confirmed that the DEA portfolios generated greater risk-adjusted returns than those of the industry, and portfolios of small firms. Managerial implications were then discussed. The proposed approach and the results of this study should be helpful for investors and fund managers in financial service industry to select stocks for investment and obtain superior return.

This study is the first attempt to select stocks using DEA models and compares the performances of the portfolios composed by DEA models, small-size firms and the stock market indices. This study used historical data of the firms listed on the Taiwan Stock Exchange as the empirical data. Future studies can apply DEA models to other stock markets in different countries to confirm the effectiveness of DEA methods in stock selection.

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