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Do market share and efficiency matter for each other? An application of the zero-sum gains data envelopment analysis

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Current studies that use traditional data envelopment analysis (DEA) neglect the 100% market share restriction. This study adopts zero-sum gains data envelopment analysis to measure the efficiency scores of securities firms (SFs) and indicates that the traditional DEA model underestimates the efficiency scores of inefficient SFs. This research analyses 266 integrated securities firms in Taiwan from 2001 to 2005 and employs three inputs (fixed assets, financial capital, and general expenses) and a single output (market share). The foreign-affiliated ownership of SFs positively affects the efficiency scores. The two-stage least squares procedure confirms that the market share and efficiency score simultaneously reinforce each other.

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1. Introduction

Many studies consider the strategic incentives of a product's market power when examining the effects of market share, and market share is a frequently identified goal of corporate management (Mueller, 1985). Firms focus on market share in order to increase shareholder value through improved efficiency, thereby benefiting consumers. Goldberg and Rai (1996), Peltzman (1977), Smirlock (1985) and Demsetz (1973) note the correlation between market share and profitability. Hannan (1991) considers the greater efficiency of firms with larger market shares to be a source of the positive relationship between profits and concentration. Goldberg and Rai (1996) develop the efficient-structure (EFS) hypothesis which suggests that efficient firms increase in terms of their size and market share due to their ability to generate higher profits, thus leading to a higher degree of market concentration. Smirlock (1985) includes market share as an independent variable that is positively and significantly related to profitability even after controlling for concentration. However, Goldberg and Rai (1996) and Shepherd (1986) indicate that the conclusion depends on whether market share can be regarded as a proxy for the efficiency of larger firms rather than as a measure of their market power. Martin (1988) shows how larger firms have lower costs due to the economies of scale in their industries or because of their inherent superiority within their respective industries. The larger firms have price-cost margin advantages over their smaller rivals. Based on the above literature, this study considers the restriction imposed by constant output in investigating the relationship between the market share and the efficiency score.

Blundell *et al* (1999) point out that total industry profits decrease when more firms share the market. The dominant firms tend to innovate more and industry evolution is characterized by their persistent dominance. In the securities industry, investors at large discount brokerages using personal computer-based trading tend to trade more actively. Barber and Odean (2001) have strongly suggested that there is a link between the Internet and increased trading. Guerrero *et al* (2007) examine how banks use Internet banking to lower costs and increase their income by attracting new customers and increasing sales to current customers.

The securities industry in Taiwan has become increasingly competitive, especially following the establishment of financial holding companies (FHCs) in 2003. In other words, the environment in Taiwan is close to one with zero-sum gains (Lins *et al*, 2003) in which securities firms (SFs) expand their market share within a 100% constraint. Tracy and Chen (2005) significantly improve existing data envelopment analysis (DEA) models by providing a methodology for weight restrictions. In addition, Lins *et al* (2003) introduce a zero-sum gains data envelopment analysis (ZSG-DEA) model, in which the sum of the outputs is constrained, in order to assess

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the ranking of participating countries in the Sydney 2000 Olympic Games based on single aggregated medals. With these developments in mind, this paper proposes a framework to apply this ZSG-DEA model to the study of the securities industry that is based upon the maximization of market share.

Since efficiency is an important topic in banking and finance, there have been numerous related studies (Drake and Hall, 2003; Camanho and Dyson, 2005; Chong *et al*, 2006; Drake *et al*, 2006). However, very few studies have paid attention to the securities industry's efficiency. Ashton (2001) mentions that many research studies in the US and Europe have investigated the efficiency characteristics of banking, yet very little is known about the measurement of efficiency in the securities sector. Goldberg *et al* (1991) indicate that the lack of firm-level data in the US has made research on SFs very difficult and rarely seen. Fukuyama and Weber (1999) construct the production technology and measure the cost efficiency for Japanese SFs during 1988–1993 using a DEA model. Wang *et al* (2003) use the two-stage DEA procedures to assess the technical efficiencies of integrated securities firms (ISFs) and conclude that the diversity of services decreases technical efficiency. Zhang *et al* (2006) adopt a DEA approach to investigate the technological progress, efficiency, and productivity of the US securities industry during 1980–2000 and report that smaller regional firms experience large decreases in both efficiency and productivity. However, there are still several important securities issues that need to be further explored.

First, while market share is a frequently identified goal among market players, the literature seldom considers the pursuit of market share, and also neglects the zero-sum gains restriction. The development of the performance evaluation under zero-sum gains deserves further careful study. This paper therefore applies this model of maximizing the market share to analyse the competition among SFs in Taiwan.

Second, many studies use the DEA model to compute technical efficiency. However, empirical studies rarely investigate the relationship between the market share and the efficiency score. The paper thus studies the simultaneity between the market share and the efficiency score using the two-stage least squares procedure (2SLS) proposed by Heckman (1978). Martin (1979) indicates that advertising intensity, seller concentration, and profitability are simultaneously determined. Brockett *et al* (2004) recommend the use of simultaneous-equation estimation methods to examine the endogeneity of joint advertising and other variables in future studies. O'Brien (2002) employs 2SLS simultaneous equations systems to test whether expenditures and votes are simultaneously determined. Daneshvary and Clauretie (2007) examine the effect of employer-provided health insurance on the annual earnings of married men and married women and account for the endogeneity of the health insurance decision using 2SLS.

Moreover, a comparison of the operating efficiency between foreign-affiliated and domestic SFs has seldom been empirically investigated. In order to accelerate the internationalization and liberalization of the domestic capital market, the Ministry of Finance in Taiwan launched ISFs in May 1988. Foreign SFs were subsequently permitted to set up branches in Taiwan in 1989. At the end of 2005, a total of 11 foreign SFs had set up branches in Taiwan. Advanced technology accompanies foreign direct investment entering the host country, thereby making foreign firms more efficient than their domestic competitors (Dimelis and Louri, 2002). Feinberg (2001) indicates that 94.1% of households use domestic financial institutions as their primary provider of financial services in the US. Deyoung and Nolle (1996) find that foreign banks are less profit-efficient than US banks. This research also investigates the impact of a foreign ownership structure on the efficiency score of SFs in a small open economy, namely, Taiwan. We define the foreign-affiliated SFs as those branches of multinational SFs in Taiwan since 1989, in contrast to the domestic SFs.

The remainder of this paper is organized as follows. Section 2 describes the traditional DEA model developed by Banker, Charnes and Cooper (1984) (BCC-DEA) as well as the ZSG-DEA model. Section 3 presents the data set and the variables utilized. Section 4 discusses the results of the BCC-DEA model, ZSG-DEA model and the simultaneous equations. Section 5 concludes with a summary of the empirical results.

2. Traditional BCC-DEA and zero-sum gains DEA methodology

DEA is a linear programming model that identifies an efficient frontier, which consists of efficient decision-making units (DMUs). Efficient DMUs are those units for which no other DMUs are able to generate at least the same amount of each output under given inputs (Charnes *et al*, 1978). The efficiency score reflects the ability of firms to generate the maximum outputs under a given level of inputs.

2.1. Traditional BCC-DEA model

DMU_i represents the object unit that is attempting to maximize its output. All DMUs in the same year constitute the reference set used to construct the efficiency frontier for each DMU_i. The aim of the traditional DEA model is to make the less efficient object unit at least as efficient as the others by increasing its output. For each DMU_i the efficiency score (θ_i) is obtained from a measure of the ratio of all outputs over all inputs. Charnes *et al* (1978) develop the constant-returns-to-scale (CRS) DEA model as below:

$$\theta_i = \text{Max} \frac{\sum_{m=1}^{M} u_m y_i^m}{\sum_{k=1}^{K} v_k x_i^k}$$

$$\text{s.t.} \quad \frac{\sum_{m=1}^{M} u_m y_j^m}{\sum_{k=1}^{K} v_k x_j^k} \leqslant 1, \qquad j = 1, \ldots, N$$

$$u_m, v_k \geqslant 0, \qquad m = 1, \ldots, M, \qquad k = 1, \ldots, K \quad (1)$$

where θ_i is the efficiency score of DMU_i; $x_j^k, y_j^m > 0$ represent input and output data for the jth DMU with the ranges for j, k, and m indicated in (1); N is the number of DMUs; x_j^k is the amount of the kth input consumed by the jth DMU; y_j^m is the amount of the mth output produced by the jth DMU; u_m and v_k are output and input weights assigned to the mth output and the kth input, respectively.

One problem with this above ratio form is that the number of solutions is infinite—for example, if (u_m^*, v_k^*) is a solution, then (cu_m^*, cv_k^*) is another solution, where c is a constant. In order to avoid this problem, an output-oriented DEA model, which is to achieve the efficient DMU by a radial expansion in outputs, can impose the constraint $\sum_{m=1}^{M} u_m y_j^m = 1$, which provides:

$$
\begin{aligned}
\text{Min} \quad & \sum_{k=1}^{K} v_k x_j^k \\
\text{s.t.} \quad & \sum_{m=1}^{M} u_m y_j^m = 1 \\
& \sum_{k=1}^{K} v_k x_j^k - \sum_{m=1}^{M} u_m y_j^m \geqslant 0, \qquad j = 1, \ldots, N \\
& u_m, v_k \geqslant 0, \qquad m=1, \ldots, M, \qquad k=1, \ldots, K
\end{aligned} \tag{2}
$$

Banker *et al* (1984) extend the CRS DEA model to a variable returns to scale (VRS) situation. The dual solution of the traditional output-oriented BCC-DEA model using duality expressed by Coelli (1996) to measure the efficiency score θ_i for DMU_i is shown as:

$$
\begin{aligned}
& 1/\theta_i = \text{Max}\phi_i \\
& \phi_i, \lambda_1, \ldots, \lambda_N \\
& \text{s.t.} \qquad \phi_i y_i^m \leqslant \sum_{j=1}^{N} \lambda_j y_j^m, \qquad m = 1, \ldots, M \\
& x_i^k \geqslant \sum_{j=1}^{N} \lambda_j x_j^k, \qquad k = 1, \ldots, K \\
& \sum_{j=1}^{N} \lambda_j = 1 \\
& \lambda_1, \ldots, \lambda_N \geqslant 0
\end{aligned} \tag{3}
$$

where ϕ_i depicts the inverse of the efficiency score of DMU_i; the efficiency score θ_i of DMU_i is $1/\phi_i$; N is the number of DMUs; K and M are, respectively, the numbers of inputs and outputs; x_j^k is the amount of the kth input consumed by the jth DMU; y_j^m is the amount of the mth output produced by the jth DMU; and λ_j is each efficient DMU's individual share in the definition of the target for DMU_i.

The BCC-DEA model here measures the firm-level efficiency score (θ_i) in the securities industry. An SF (as a DMU in the DEA model) that is pursuing more market share naturally means that other SFs lose some market share, because the total market share is 100%. Accordingly, this constant sum of output is unable to use the traditional BCC-DEA model,

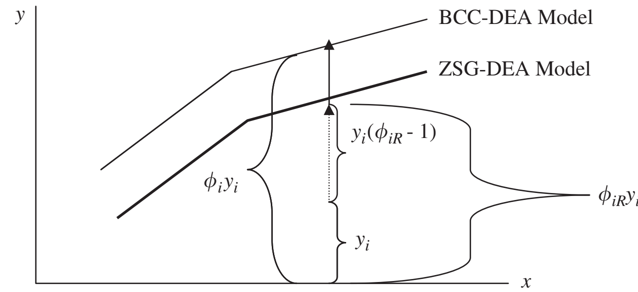

Figure 1 Graphical representation of the equal output reduction method.

in which the output of any given DMU is not influenced by the output of the others, to assess the efficiency score. This is our motivation for adopting the ZSG-DEA model to measure the efficiency scores of SFs.

2.2. *Zero-sum gains DEA model*

The ZSG-DEA model assesses the efficiency score provided that the sum of outputs is constant. Lins *et al* (2003) indicate that this is similar to a zero-sum game whereby how much is won by a player is lost by one or more of the other players. The equal output reduction strategy is generated to measure the efficiency score $(\theta_{iR} = 1/\phi_{iR})$ for DMU_i in Equation (4) using duality expressed shown below and is graphically represented using a simple case involving one input, x, and one output, y, in Figure 1:

$$
\begin{aligned}
& 1/\theta_{iR} = \text{Max}\phi_{iR} \\
& \phi_{iR}, \lambda_1, \ldots, \lambda_N \\
& \text{s.t.} \qquad \phi_{iR} y_i^m \leqslant \sum_{j=1}^{N} \lambda_j y_j^m \left[1 - \frac{y_i^m(\phi_{iR} - 1)}{N - 1}\right], \\
& \quad m = 1, \ldots, M \\
& x_i^k \geqslant \sum_{j=1}^{N} \lambda_j x_j^k, \qquad k = 1, \ldots, K \\
& \sum_{j=1}^{N} \lambda_j = 1 \\
& \lambda_1, \ldots, \lambda_N \geqslant 0
\end{aligned} \tag{4}
$$

where the term ϕ_{iR} is the inverse of the efficiency score of the ZSG-DEA model with $\phi_{iR} \geqslant 1$; and the efficiency score θ_{iR} of DMU_i is the inverse of ϕ_{iR} $(\theta_{iR} = 1/\phi_{iR})$ in the ZSG-DEA model. The term $y_i^m(\phi_{iR} - 1)$, representing losses of the other DMU j $(j \neq i)$, must have one DMU i to gain $y_i^m(\phi_{iR} - 1)$ output units.

This model here causes some DMUs to have a negative output after replacing the output as the reduction coefficient. A simple example in Appendix A illustrates an unreasonable case in which an equal output reduction under a zero-sum game generates a negative output. Hence, provided that $y_i^m(\phi_{iR} - 1) \leqslant \min(y_j^m)$, $m = 1, \ldots, M$, this equal output reduction strategy can apply. To avoid this major weakness,

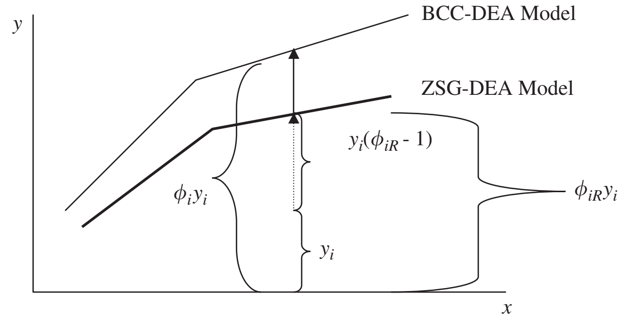

Figure 2 Graphical representation of the proportional output reduction method.

Lins *et al* (2003) further develop the proportional output reduction strategy for any given DMUi using the ratio $((y_i^m(\phi_{iR}-1))/(Y^m-y_i^m))$, where Y^m is the constant sum of the mth output. Thus, DMU i needs to win $y_i^m(\phi_{iR}-1)$ output units, and the losses of the other DMUs are proportional to their levels of output. The condition that the sum of the losses is equal to the gains of DMU i still holds.

Figure 2 represents the ZSG-DEA frontier created by this proportional reduction strategy and the BCC-DEA frontier using a simple case involving one input and one output. DMU i gains $y_i^m(\phi_{iR}-1)$ output units, and the losses of other DMUs are proportional to their respective levels of output, which is $y_j^m(y_i^m(\phi_{iR}-1))/(Y^m-y_i^m)$. If the output y_j of DMU j is larger than those of other DMUs, then the output reduction $y_j^m(y_i^m(\phi_{iR}-1))/(Y^m-y_i^m)$ is also larger than those of the others, and vice versa. Model (5) substitutes model (4) for the proportional output reduction strategy in measuring the efficiency score ($\theta_{iR}=1/\phi_{iR}$) of DMU$_i$ as:

$$
\begin{aligned}
& 1/\theta_{iR} = \mathrm{Max}\phi_{iR} \\
& \phi_{iR}, \lambda_1, \ldots, \lambda_N \\
& \text{s.t.} \quad \phi_{iR} y_i^m \leqslant \sum_{j=1}^{N} \lambda_j y_j^m \left[1 - \frac{y_i^m(\phi_{iR}-1)}{Y^m - y_i^m}\right], \\
& \quad m = 1, \ldots, M \\
& x_i^k \geqslant \sum_{j=1}^{N} \lambda_j x_j^k, \qquad k = 1, \ldots, K \\
& \sum_{j=1}^{N} \lambda_j = 1 \\
& \lambda_1, \ldots, \lambda_N \geqslant 0
\end{aligned} \tag{5}
$$

However, Lins *et al* (2003) report that obtaining results based on this non-linear programming problem is very labour-consuming in particular because of the large number of variables. The model is thus simplified by having only a single output ($m=1$). Appendix A provides an example to explain the computational steps of the proportional output reduction strategy.

The following theorem holds under a single output ZSG-DEA proportional reduction strategy:

LGSS Theorem (Lins *et al*, 2003) *The target for a DMU to reach the efficiency frontier in a ZSG-DEA proportional output reduction strategy model equals the same target in the traditional BCC-DEA model multiplied by the reduction coefficient* $(1-(y_i(\phi_{iR}-1))/(Y-y_i))$.

Owing to this theorem, Equation (6) below holds.

$$
\begin{aligned}
\phi_{iR} y_i &= \sum_{j=1}^{N} \lambda_j y_j \left[1 - \frac{y_i(\phi_{iR}-1)}{Y - y_i}\right] \\
&= \phi_i y_i \left[1 - \frac{y_i(\phi_{iR}-1)}{Y - y_i}\right]
\end{aligned} \tag{6}
$$

The efficiency score of the ZSG-DEA model is obtained from Equation (7):

$$
\theta_{iR} = \frac{\theta_i y_i (Y - y_i) + y_i^2}{y_i (Y - y_i + 1)} \tag{7}
$$

In this paper, due to the fact that the sum of the total market share in percentage terms is 100, Y is always 100 and Equation (7) above can be expressed as Equation (8):

$$
\theta_{iR} = \frac{\theta_i y_i (100 - y_i) + y_i^2}{y_i (100 - y_i + 1)} \tag{8}
$$

Lins *et al* (2003) also infer that the value of the weight of DMU i's peers (λ_i) equals its value in the traditional BCC-DEA model. This ZSG-DEA model is then applied to measure the efficiency score of SFs when the market share in percentage terms always sums up to 100.

3. Variables and data

3.1. Variables

This paper follows the model developed by Lins *et al* (2003) in that it chooses a single output and multiple inputs to measure the efficiency score. Drake *et al* (2006) introduce a profit-oriented model with revenue components as outputs and cost components as inputs in a banking efficiency study. Banks pursue their profit maximization goal by increasing revenue and reducing cost. In the securities industry, an individual SF pursues the goal of market share maximization by innovating itself as an e-broker or e-trader. Thus, this output-oriented ZSG-DEA model chooses market share as the single output. Drake and Hall (2003) adopt general and administrative expenses and fixed assets as the two inputs of the DEA model. Berger and Mester (1997) indicate that another important aspect of efficiency measurement is the treatment of financial capital. A bank's financial capital that is available to absorb possible losses helps reduce its insolvency risk. Accordingly, the study adopts fixed assets, in which the SFs increase their fixed assets by investing in computer hardware, financial capital as well as general and administrative expenses as the three inputs of the ZSG-DEA model.

Table 1 Variables

Variables	*Yr.*	*Obs.*	*Average*	*Min*	*Max*	*σ*
Inputs						
x^1: Fixed assets (NT$mn)	2001	61	932.13	5.74	4455.02	1074.12
	2002	54	1006.18	1.84	4306.02	1132.26
	2003	51	1067.66	0.00	4413.71	1259.69
	2004	50	1135.49	0.00	6203.25	1439.44
	2005	50	1141.64	0.00	6692.11	1482.82
x^2: Financial capital (NT$mn)	2001	61	1637.57	48.70	7815.06	1733.19
	2002	54	5112.88	151.29	24 689.52	5439.46
	2003	51	5594.04	154.58	25 382.95	5958.09
	2004	50	6163.88	156.84	31 988.93	6822.10
	2005	50	6284.13	157.81	33 559.95	7069.14
x^3: Expenses (NT$mn)	2001	61	4413.48	150.00	22 315.20	4730.23
	2002	54	1935.13	10.64	10 560.52	2323.28
	2003	51	2126.09	11.12	8587.78	2555.90
	2004	50	3010.77	21.18	14 008.10	3757.83
	2005	50	3213.83	26.80	12 772.28	3682.73
Output						
y: Market share (%)	2001	61	1.64	0.05	8.66	1.89
	2002	54	1.85	0.02	10.48	2.42
	2003	51	2.02	0.01	11.01	2.53
	2004	50	2.00	0.02	9.39	2.51
	2005	50	2.00	0.02	7.63	2.31
Exogenous variables						
Asset: Total assets (NT$bn)	2001	61	13.69	0.24	91.03	17.59
	2002	54	16.34	0.25	103.37	20.66
	2003	51	19.31	0.22	120.35	24.55
	2004	50	21.96	0.35	127.17	28.72
	2005	50	23.93	0.58	149.49	31.55
Profit: Profits (NT$bn)	2001	61	0.36	−0.80	2.96	0.65
	2002	54	0.25	−0.57	3.87	0.69
	2003	51	0.57	−0.58	6.11	1.05
	2004	50	0.43	−0.60	2.29	0.70
	2005	50	0.19	−1.18	1.44	0.50

Data sources: Taiwan Stock Exchange Corporation (http://www.tse.com.tw/ch/statistics/statistics_list.php?tm = 03&stm = 004).

3.2. *Data*

A panel data set covering the period 2001–2005 includes 266 ISFs in Taiwan. During 2002, eight SFs were merged and one foreign-affiliated SF established branches in Taiwan. In 2003, four SFs were merged and one foreign-affiliated institution joined the securities market in Taiwan. Appendix B lists the number of observations from 2001 to 2005. Since the data cover 5 years, several variables, including three inputs, which are exogenous variables in the 2SLS are deflated with the gross domestic product (GDP) deflator (2001 = 100) to avoid the distortion caused by inflation (Bierlen and Featherstone, 1998; Li *et al*, 2004). Market share is the trading amount in brokerage and proprietary trading of an individual firm divided by the total trading amount of all securities' brokers and dealers. The firm-level data for the exogenous variables in the 2SLS are the trading amounts, fixed assets, general expenses, financial capital, total assets, and profits. All variable data are obtained from the reports of the *Taiwan Stock Exchange Corporation* during the 2001–2005 period (http://www.tse .com.tw/ch/statistics/statistics_list.php?tm = 03&stm = 004, accessed 4 April, 2007). The descriptive statistics for all the variables are shown in Table 1.

4. Empirical results

4.1. *Examining the results of the ZSG-DEA and BCC-DEA models*

This research adopts the output-oriented VRS BCC-DEA model (Banker *et al*, 1984) and the ZSG-DEA model (Lins *et al*, 2003) to compute the efficiency scores of the SFs. Output orientation is a better choice here because the obvious aim of an individual SF is to obtain the maximum market share in order to dominate the market. The securities industry in Taiwan provides an opportunity to apply the ZSG-DEA model, because of its characteristics of high competition and low concentration (the top-three banks' concentration ratios, *CR*3, were all less than 0.3 during 2001–2005). Market share is the most important performance indicator among the SFs.

Table 2 Test results of the differences between the efficiency scores of BCC-DEA and ZSG-DEA

Year	*N*	*BCC-DEA Mean*	*ZSG-DEA Mean*	*BCC-ZSG Difference*	*t-Test (BCC-ZSG) t-value*
2001	61	80.10	80.68	−0.58	−3.54***
2002	54	74.89	75.64	−0.75	−3.50***
2003	51	74.82	75.81	−1.01	−3.83***
2004	50	80.87	81.44	−0.57	−2.73***
2005	50	76.73	77.21	−0.48	−2.71***

Notes: Eight SFs were merged and one Hong Kong-based SF established its Taiwan branch in 2002.
Four securities firms were merged and one American-based SF was established in 2003.
*** indicates significance at the 1% level.

Equations (3) and (8) calculate the efficiency scores θ_i and θ_{iR} from the BCC-DEA and ZSG-DEA models, respectively, which are presented in Appendix B. It is obvious that when faced with the reality of a constant sum of outputs, the traditional BCC-DEA model underestimates the average efficiency score compared with the ZSG-DEA model. This study calculates a paired-difference t test to determine whether the efficiency scores of these two models are significantly different. Table 2 presents the results of the paired t test. The efficiency scores (θ_{iR}) in the ZSG-DEA model are statistically significantly higher than those (θ_i) in the BCC-DEA model during 2001–2005. The gap in efficiency scores between the efficient and inefficient SFs under a zero-sum gains framework is significantly less than that under the traditional models. Hence, with the objective of maximizing their market share, the efficient SFs need to develop more marketing strategies and introduce more techniques to maintain their leading role in the market. We are also able to derive this trend in the descriptive statistics. The average fixed assets of (x^1) and financial capital (x^2) in 2005 respectively increased by 23% and by more than three times the value in 2001, showing that the SFs continuously enhance their capital and fixed assets to develop electronic trading hardware to maximize their market shares. The average expenses in 2005 were also nearly 30% lower than the corresponding values in 2001. However, the average market share of SFs in 2005 reflected an increase of only 22% compared with the value in 2001. Owing to the fact that the market share competition is like a zero-sum constraint, the severe competition resulted in each SF obtaining a higher efficiency score under the ZSG-DEA model than under the BCC-DEA model.

4.2. Simultaneous relationship between market share and efficiency score

The EFS hypothesis states that efficient firms increase in size and market share due to their ability to generate higher profits (Goldberg and Rai, 1996). Martin (1988) indicates that larger firms have lower costs, either because of the economies of scale in their industries or due to the inherent superiority of the larger firms in their industries. Lo and Lu (2006) report that large-sized financial institutions are more likely to generate profits with their large scales of assets. Three research hypotheses are thus constructed:

Hypothesis A: More efficient SFs have larger market shares.
Hypothesis B: Dominant SFs have higher efficiency scores.
Hypothesis C: The efficiency scores and market shares of SFs have positive impacts on each other.

Consequently, this study examines the simultaneous relationship between the efficiency scores, market shares, and firm-specific attributes using the 2SLS procedure in Equations (9) and (10):

$$ms_i = b_0 + b_1\theta_{iR} + b_2 asset_i + b_3 profit_i + \varepsilon_{i1} \quad (9)$$

$$\theta_{iR} = a_0 + a_1 ms_i + a_2 Foreign_i + \varepsilon_{i2} \quad (10)$$

where θ_{iR} is the efficiency score of SF_i in the ZSG-DEA model; ms_i is the firm-level market share of SF_i; Equation (9) includes firm-level asset values (*asset*) and profit (*profit*) as exogenous variables, while Equation (10) includes one exogenous variable: a dummy variable (*Foreign*) with 1 for a foreign-affiliated SF and 0 for a domestic SF in Taiwan; and ε_{i1} and ε_{i2} are stochastic error terms with mean $E(\varepsilon_{i1}) = 0$, $E(\varepsilon_{i2}) = 0$ and variance $\sigma^2(\varepsilon_{i1}) = \sigma_1^2$, $\sigma^2(\varepsilon_{i2}) = \sigma_2^2$. It is verified that these equations satisfy all of the assumptions of the classical linear regression model.

The 2SLS procedure involves obtaining unique estimates that are consistent and asymptotically efficient, and the equations may be exactly identified or over-identified (Ramanathan, 2002). This paper estimates these two simultaneous equations using the following procedure:

First, by estimating the reduced form for the endogenous variable (ms_i), we obtain the following reduced form equations through Equations (9) and (10):

$$\begin{aligned} ms_i &= b_0 + b_1\theta_{iR} + b_2 asset_i + b_3 profit_i + \varepsilon_{i1} \\ ms_i &= b_0 + b_1(a_0 + a_1 ms_i + a_2 Foreign_i + \varepsilon_{i2}) + b_2 asset_i \\ &\quad + b_3 profit_i + \varepsilon_{i1} \\ &= b_0 + b_1 a_0 + b_1 a_1 ms_i + b_1 a_2 Foreign_i + b_1 \varepsilon_{i2} \\ &\quad + b_2 asset_i + b_3 profit_i + \varepsilon_{i1} \end{aligned}$$

$$ms_i = \left(\frac{b_0 + a_0 b_1}{1 - a_1 b_1}\right) + \left(\frac{a_2 b_1}{1 - a_1 b_1}\right) Foreign_i + \left(\frac{b_2}{1 - a_1 b_1}\right) asset_i + \left(\frac{b_3}{1 - a_1 b_1}\right) profit_i + \frac{b_1 \varepsilon_{i2} + \varepsilon_{i1}}{1 - a_1 b_1}$$

$$ms_i = \pi_0 + \pi_1 Foreign_i + \pi_2 asset_i + \pi_3 profit_i + v_1 \quad (11)$$

where v_1 is a new error term that depends on ε_{i1} and ε_{i2}.

Consequently, tackling the endogeneity problem involves the following stages:

Stage 1: Regress ms_i on *Foreign*, *asset*, *profit*, and the constant based on Equation (11). Then save $\hat{ms}_i$, the predicted value of ms_i as obtained from the reduced form estimates, where $\hat{ms}_i = \hat{\pi}_0 + \hat{\pi}_1 Foreign_i + \hat{\pi}_2 asset_i + \hat{\pi}_3 profit_i$.

Stage 2: Estimate the structured equation and use as instruments the predicted endogenous variables obtained in the first stage. We regress θ_{iR} on the constant, $\hat{ms}$, *Foreign*, for Equation (10).

4.2.1. Test for randomness and multicollinearity The Durbin–Watson statistic (Durbin and Watson, 1950, 1951) is 1.717 when derived from Equation (11) and 1.923 when derived from Equation (10), indicating that the error terms are not auto-correlated with $P = 0.01$. Variance inflation factors (*VIF*) are used to detect the presence of multicollinearity (Belsley *et al*, 1980). $VIF_{foreign}$, VIF_{asset}, and VIF_{profit} are 1.137, 2.235, and 2.045 in Equation (11), respectively. $VIF_{Foreign}$ and VIF_{ms} are 1.127 in Equation (10). A *VIF* value in excess of 10 is taken as an indication of multicollinearity. Hence, multicollinearity among these explanatory variables is not a problem in our 2SLS equations. The estimated parameters obtained using 2SLS are as follows (standard errors are in the parentheses):

$$\hat{ms}_i = \underset{(0.104)}{0.326} - \underset{(0.110)}{0.144}\, Foreign_i + \underset{(0.009)}{0.071}\, asset_i + \underset{(0.230)}{0.706}\, profit_i \quad (12)$$

$$R^2 = 0.902, \qquad F = 244.8$$

$$\hat{\theta}_{iR} = \underset{(0.019)}{0.617} + \underset{(0.007)}{0.058}\, \hat{ms}_i + \underset{(0.027)}{0.279}\, Foreign_i \quad (13)$$

$$R^2 = 0.426, \qquad F = 63.1$$

The coefficients of market share and foreign-affiliated organizations are significantly positive, and the adjusted R^2 of Equation (13) is 0.426. These two factors, namely, the market share and the foreign-affiliated ownership structure, have a significantly beneficial impact on the efficiency scores, suggesting that foreign-affiliated SFs are more efficient than domestic ones in Taiwan. The foreign-affiliated SFs take advantage of their fine, international reputation as well as the investment knowledge of global research teams to attract more customers and maximize market share using less expenditure. This result further confirms the trend that there was a continuous stream of prestigious foreign-affiliated SFs that established branches in Taiwan during 2001–2005, including Deutsche Securities (Asia) Limited, Lehman Brothers Incorporated, HSBC Securities (Asia) Limited, and Macquarie Securities (this was originally ING Securities in Taiwan and was bought by Macquarie Securities).

Market share also has a significantly positive impact on the efficiency score. This result also supports the view that larger firms have lower costs, because of the economies of scale in their industries or due to the inherent superiority of the larger firms in these industries (Martin, 1988). The larger market share SFs are also able to more easily attract the attention of customers and account for higher efficiency scores. The empirical results support the conjectures of policy-makers in Taiwan that merging large-sized financial institutions can simultaneously increase their market shares and efficiency scores.

In Equation (12), the other two exogenous variables, namely, total assets and profits, have significantly beneficial effects on market share. This conclusion also proves that large-sized SFs do achieve benefits from their market share and is consistent with the finding that large-sized financial institutions are more likely to generate profits with their large-scale assets (Lo and Lu, 2006). During 2001–2005, at least 80% of the top 10 SFs in terms of assets also gained leading roles in terms of market share. This fact further confirms that the large-sized SFs are able to capture larger market shares.

5. Conclusion

Current studies that apply the traditional BCC-DEA model (Banker *et al*, 1984) assume that an increase in the output of any given DMU does not affect the output of the other units. However, given the fact that a SF's gain in market share is another's market share loss, the traditional BCC-DEA model is unable to take into account the zero-sum game competition reality. Since SFs in Taiwan have developed Internet trading techniques to expand their market shares, this provides a plausible reason to apply the ZSG-DEA model developed by Lins *et al* (2003).

This study analyses 266 integrated SFs in Taiwan covering the period from 2001 to 2005 and employs three inputs (including fixed assets, financial capital, and general expenses) and a single output (market share). In view of the fact that a SF's market share gain is another's market share loss, the traditional BCC-DEA model has a shortcoming in that it ignores the zero-sum game competition and underestimates the average efficiency score as compared with the

ZSG-DEA model. Meanwhile, the gap in efficiency scores between the efficient and inefficient SFs under a zero-sum gains framework is significantly less than that under the traditional model.

A foreign-affiliated ownership structure is found to have a significantly positive effect on the efficiency scores of SFs. This empirical result also explains the tendency for Deutsche Securities (Asia) Ltd., Lehman Brothers Incorporated, and HSBC Securities (Asia) Ltd. to set up new branches in Taiwan during the sample period.

The 2SLS estimation of the simultaneous equations model confirms the simultaneity between the efficiency score and the market share. The empirical results indicate that SFs with larger market shares achieve higher efficiency scores, because large-market-share SFs are able to more easily attract the attention of customers. The more efficient SFs are also able to generate larger market shares, because of the advantages associated with larger profits and more substantial assets. The empirical results support the current suggestions from policy-makers in Taiwan that mergers among large-sized financial institutions should be encouraged in order to increase market shares and efficiency scores. This paper has provided a general framework to test the simultaneity between the market share and ZSG-DEA efficiency score, which can be applied to studying other financial or non-financial markets in the future.

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Appendix A. A simple numerical example

To illustrate the equal reduction strategy and proportional strategy pointed out by Lins *et al* (2003), we derive our new measure of output reduction by providing a simple example involving observations for 10 DMUs with their market share y_i in Table A1.

Step 1: Assume that DMU 1 tries to achieve an efficiency score of 100 via market share maximization from 25 to 43%. DMU 1 gains an 18% market share, indicating that the other DMU j ($j \neq 1$) loses a market share of $y_i\ (\phi_{iR} - 1) = 18\%$.

Step 2: Replace the output (y_j) of each DMU j ($j \neq 1$) based on the original output minus the equal output reduction following the equation: $y_j - ((y_i(\phi_{iR} - 1))/(N-1))$. $((y_i(\phi_{iR}-1))/(N-1)) = 18\%/(10-1) = 2\%$. Then calculate $y_{je} = y_j - ((y_i(\phi_{iR} - 1))/(N-1))$ for each j in Table A1.

Step 3: The fourth column of Table A1 shows that the equal output reduction strategy is inappropriate because of the negative market share value ($y_{10e} = -0.5\%$) in DMU 10 after applying this measurement.

Step 4: The proportional output reduction calculations are shown in the last column of Table A1 via

$$y_{jp} = y_j - \frac{y_j y_i(\phi_{iR} - 1)}{Y - y_i} = y_j - \frac{y_j \times 18}{(100-25)}$$

for DMU $j\,(j \neq 1)$. When

$$j{=}2,\ y_{2p}{=}y_j{-}\frac{y_j y_i(\phi_{iR}{-}1)}{Y - y_i}{=}20 - \frac{20{\times}18}{(100-25)}$$
$$= 20 - 4.8 = 15.2(\%).$$

When

$$j{=}3,\ y_{3p}{=}y_j{-}\frac{y_j y_i(\phi_{iR}{-}1)}{Y - y_i} = 15{-}\frac{15 \times 18}{(100{-}25)}$$
$$= 15 - 3.6 = 11.4(\%),\ \text{etc.}$$

The proportional output reduction strategy avoids the drawback of the equal output reduction, and becomes the model that we apply.

Appendix B.

In Table B1 are the efficiency scores using the BCC-DEA and ZSG-DEA models for the SFs in Taiwan during the period 2001–2005.

Table A1 An illustrative example

DMU j	$y_i(\%)$	*Equal output reduction* $(e_j)(j \neq 1)$	$y_{ie}(\%) = y_i - e_j$ $(j \neq 1)$	*Proportional output reduction* $(p_j)(j \neq 1)$	$y_{ip}(\%) = y_i - p_j$ $(j \neq 1)$
DMU 1	25	18	43.0	18.0	43.0
DMU 2	20	−2	18.0	−4.8	15.2
DMU 3	15	−2	13.0	−3.6	11.4
DMU 4	10	−2	8.0	−2.4	7.6
DMU 5	8	−2	6.0	−1.9	6.1
DMU 6	6	−2	4.0	−1.4	4.6
DMU 7	5.5	−2	3.5	−1.3	4.2
DMU 8	5	−2	3.0	−1.2	3.8
DMU 9	4	−2	2.0	−1.0	3.0
DMU 10	1.5	−2	−0.5	−0.4	1.1
Total market share	100	0	100	0	100

Note: Assume that DMU 1 tries to achieve an efficiency score of 100 via market share maximization from 25 to 43%. The equal output reduction strategy prompts DMU 10 to become a negative output ($y_{10e} = -0.5\%$), using equation $((y_i^m(\phi_{iR} - 1))/(N-1))$; however, the proportional output reduction strategy avoids this drawback.

Table B1 Efficiency scores (θ_i) of BCC-DEA and ZSG-DEA models for the SFs in Taiwan during 2001–2005

Securities firms	2001		2002		2003		2004		2005	
	BCC	*ZSG*	*BCC*	*ZSG*	*BCC*	*ZSG*	*BCC*	*ZSG*	*BCC*	*ZSG*
JIH SUN	95.10	98.93	100.00	100.00	76.30	81.05	88.40	93.07	100.00	100.00
JEN HSIN	59.70	59.58								
FIRST	59.60	59.54	85.40	85.12	62.60	62.47	64.20	63.87	43.00	42.75
ASIA	74.80	75.24	58.40	58.72	56.40	56.64				
TINGKONG	65.30	65.55								
ENTRUST	55.20	55.06								
HORIZON	45.20	46.01	37.60	37.89	47.80	48.18	38.50	38.65	46.70	46.66
MACQUARIE*	50.10	49.86	62.30	61.98	100.00	100.00	100.00	100.00	89.80	89.36
ABN AMRO*	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
MERRILL LYNCH*	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
NOMURA (HK)*	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	67.10	66.57
SOCIETE GENERALE (HK)*	100.00	100.00	100.00	100.00	100.00	100.00	67.20	66.57	87.50	87.40
GOLDMAN SACHS (ASIA)*	100.00	100.00	100.00	100.00	49.90	49.44	100.00	100.00	100.00	100.00
ORIENTAL	98.00	98.65	49.00	49.24	100.00	100.00	100.00	100.00	100.00	100.00
FIRST TAIWAN	48.00	47.87	44.20	44.02						
TACHAN	73.50	73.37	78.10	77.81	53.40	53.33	99.30	98.81	76.50	76.37
HUA NAN	80.90	82.72	95.70	97.97	78.60	80.49	95.00	96.54	86.00	87.96
FULL LONG	62.50	62.35	64.80	64.63	31.40	31.30	54.70	54.33	18.60	18.55
PACIFIC	82.70	83.10	61.40	61.66	51.60	51.77	46.00	46.02	46.50	46.48
TA CHING	84.40	84.39	79.40	79.36	69.10	69.12	77.70	77.43	68.60	68.36
CAPITAL	88.70	92.73	81.20	85.88	72.80	77.07	100.00	100.00	92.00	96.66
CHUNG HSING	62.30	62.24	55.80	55.71						
FIRST TAISEC	90.80	90.88	79.80	79.94	81.30	81.76	75.10	75.89	92.50	94.28
FORWIN	44.60	44.51	35.30	35.18	38.40	38.26	49.20	48.84	17.30	17.16
SINOPAC	89.90	93.29	85.40	90.73	87.60	93.87	87.60	92.25	96.50	100.00
TAIWAN	100.00	100.00	89.90	94.53	84.60	90.00	100.00	100.00	100.00	100.00
TAIYU	65.90	66.17	66.90	67.39						
KGI	100.00	100.00	83.30	87.40	75.90	80.44	99.50	100.00	100.00	100.00
IBT	97.70	97.65	67.20	67.30	100.00	100.00	100.00	100.00	92.10	93.18
GRAND CATHAY	83.10	86.91	69.70	73.32	78.00	81.83	94.80	100.00	100.00	100.00
TAIWAN INTL.	88.10	90.40	85.00	87.77	68.70	71.13	71.40	73.60	78.50	81.17
PRESIDENT	92.80	96.67	95.80	100.00	89.20	93.58	94.50	98.14	94.60	98.11
MASTERLINK	85.80	89.02	75.60	79.10	80.90	85.20	91.30	95.06	89.80	92.96
PRIMASIA	48.20	48.16	65.10	64.82	60.70	60.50	79.90	79.70	48.70	48.45
CHINATRUST	100.00	100.00	51.10	51.59	77.70	78.59	90.90	91.88	100.00	100.00
BARITS	100.00	100.00	71.20	71.82						
GRAND FORTUNE	58.30	58.24	53.00	52.82	60.10	59.89	41.20	40.87	56.30	55.79
TA CHONG	93.70	93.53	63.20	63.12	53.20	53.14	77.60	77.29	64.60	64.45
RELIANCE	77.20	76.99	100.00	100.00	40.60	40.87	58.90	58.56	58.10	57.70
MEGA	62.10	62.77	56.90	57.43	86.30	90.44	75.70	78.64	88.40	91.21
CONCORD INTL.	65.30	65.32	90.50	90.24	57.80	57.67	100.00	100.00	47.70	47.60
JINHWA	60.50	60.13								
WATERLAND	62.30	62.77	60.70	61.60	52.90	53.87	69.60	70.26	55.60	56.20
HSINBAO	99.50	99.91								
J.P. MORGAN*	65.70	65.75	68.80	68.71	61.90	61.78	60.10	59.97	79.60	79.40
CONCORD	83.20	84.03	64.80	65.58	62.80	63.61	79.70	80.21	72.40	73.28
CONCOURSE	67.80	67.81								
SINOPAC(OLD)	78.70	79.28								
GRAND ORIENT	61.10	61.05								
SHINKONG	61.40	61.44	25.90	25.98	76.80	76.56	67.80	67.45	72.80	72.75
CITIBANK*	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
FU HWA	83.10	84.98	87.90	90.52	82.80	85.40	88.00	90.34	70.30	72.59
SUN-FUND	100.00	100.00	49.80	49.55	37.40	37.21	40.90	40.57	32.10	31.82
HO TUNG	100.00	100.00	50.30	49.90	82.30	81.65	63.30	62.79		
E. SUN	80.70	80.13	70.50	70.04	44.20	44.14	61.80	61.60	65.50	65.39
DAIWA	100.00	100.00	94.30	93.63	100.00	100.00	100.00	100.00	100.00	100.00
FUBON	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
POLARIS	95.30	99.44	97.50	100.00	99.50	100.00	100.00	100.00	100.00	100.00
YUANTA	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
FAR EASTERN	66.00	65.59	60.90	60.42	44.30	43.98	55.40	54.93	25.20	25.03

Table B1 Continued

Securities firms	2001		2002		2003		2004		2005	
	BCC	*ZSG*	*BCC*	*ZSG*	*BCC*	*ZSG*	*BCC*	*ZSG*	*BCC*	*ZSG*
YUAN LI	91.60	91.33	74.30	74.01	100.00	100.00				
DEUTSCHE (ASIA)*			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LEHMAN BROTHERS*					100.00	100.00	100.00	100.00	100.00	100.00
HSBC (HK)*									46.70	46.30
CATHAY							38.40	38.07	69.10	68.66
Average	80.10	80.68	74.89	75.64	74.82	75.81	80.87	81.44	76.73	77.21

Notes: The reason for the unbalanced panel data was mainly due to the mergers that took place in the securities industry during 2002–2003 and the new Taiwan branches that were set up by foreign-owned SFs in 2003, respectively. To establish the financial holding companies (FHCs), eight SFs were merged in 2002. Deutsche Securities (Asia) Limited, Lehman Brothers Incorporated, HSBC Securities (Asia) Limited and Macquarie Securities (ING Securities in Taiwan was acquired by Macquarie Securities) established new branches in Taiwan during 2002–2005.
* indicates the foreign-owned SFs.

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