Effects of Firm-Specific and Macroeconomic Environmental Variables on Cost and Profit Efficiencies: A Study of Commercial Banks in Taiwan

Sunil K. Mohanty*
Opus College of Business
University of St. Thomas
Minneapolis, MN 55403
Phone: (962) 651-4416
E-mail: skmohanty@stthomas.edu

Winston T. Lin
School of Management
State University of New York at Buffalo
Buffalo, New York 14260
Phone: (716) 645-3257
E-mail: mgtfewtl@buffalo.edu

and

Hong-Jen Lin
Brooklyn College
The City University of New York
Brooklyn, NY 11210
Phone: (718) 463-1918
E-mail: HJLin@brooklyn.cuny.edu

October 2013

JEL Classifications: G21, G28, G34, F23, F33

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*Corresponding author.

We thank Robert DeYoung, Douglas Evanoff, Barry Williams, Ike Mathur, and Jeff Oxman for providing useful comments on the earlier version of this paper. First author gratefully acknowledges support from the Opus College of Business at the University of St. Thomas. Second author is grateful to the Pacific Cultural Foundation and the School of Management, SUNY at Buffalo for providing research support for this project. Third author gratefully acknowledges research support from the Brooklyn College, the City University of New York.

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Abstract

Taiwan is one of the few economies going through the Asian financial crisis without major loss. Hence it is worth investigating cost and profit efficiency of commercial banks in Taiwan before and after the crisis (from 1995 to1999). To analyze the effects of firm-specific and macroeconomic environmental variables on banking efficiency, we develop a generalized dynamic model that accounts for heteroskedasticity in the inefficiency component of the error term. We find that asset size has a significant negative impact on cost efficiency, while the number of branches of a bank has a positive impact on both cost and profit efficiency. Privately owned banks seem to be more cost and profit efficient compared to government-owned banks. Our results suggest that early stages of bank reforms are associated with a reduction in profit efficiency. The results also show that the profit efficiency of the banking industry consistently fell over the study period.

JEL Classification: G21, G28, G34, F23, F33
Key Words: Stochastic Frontier, Cost Efficiency, Profit Efficiency

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1. Introduction

Taiwan is one of the nations that had undergone a series of bank reforms since early 1990s which dramatically changed the competitive structure and operating environment of the banking industry. For instance, the law that prohibited the establishments of new banks was repealed in 1991, and several new domestic banks were set up by the mid-1990s that altered the ownership structure and operating environment. Various interest rates including deposit rate, bank loan rate, and interbank call loan rate were also deregulated in the early 1990s. Moreover, the evolution of Taiwan's banking sector liberalization and its competitive environment during the early 1990s provide a unique opportunity to measure cost and profit efficiency of individual banks in Taiwan.[1] Fourth, Taiwan is one of the Asian countries that safely and successfully navigated through the 1998 Asian Financial Crisis. This time period for Taiwan is an unique window to observe how a banking system of a transitional economy has been re-shaped.

The past thirty years have witnessed the studies on banking efficiency covering geographic regions such as the United States (e.g., Berger and Humphrey, 1997; Berger and Strahan, 1998), Europe (e.g., Allen and Rai, 1996; Pastor, Perez, and Quesada, 1997; Altunbas, Gardener, Molyneux, and Moore, 2001), Asia-Pacific region (e.g.,Bhattacharya, Lovell, and Sahay, 1997; Rezvanian and Mehdian, 2002; Berger, Hasan, and Zhou, 2008; and Lin and Zhang, 2009), and in transitional economies in Eastern Europe (e.g., Bonin, Hasan and Wachtel, 2005;

[1] Hughes and Mester (2008) provide an excellent literature review on theory, practice and evidence of efficiency in banking.

Havrylchyk, 2006; and Yildirim and Philippatis, 2007). The empirical literature in general provides mixed evidence on cost efficiency of banks[2].

In terms of methodological issues, though several methods are available to measure cost efficiency in banking, the Stochastic Frontier (SF) approach introduced by Aigner, Lovell, and Schmidt (1977) and Meeusen and van dan Broeck (1977) has received increased attention among researchers over the last two decades (e.g., Cebenoyan, 1990; Ferrier and Lovell, 1990; Greene, 1993; LeCompte and Smith, 1990; Bauer, 1990; Berger and Humphrey, 1991; Weiss, 1991; Berger, 1993; Mester, 1993; Allen and Rai, 1996; Mester, 1996; Rai, 1996; Resti, 1997). [3]Numerou studies on measuring bank efficiency have used the basic SF model described above (e.g., Murray and White, 1983; Mester, 1987 and 1993; Cebenoyan, 1990; LeCompte and Smith, 1990; Berger and Humphrey, 1991; Weiss, 1991; and Resti, 1997; among others). Most studies followed Pitt and Lee (1981) and have used a two-step estimation procedure (e.g., Allen and Rai, 1996; Rai, 1996; Berger and DeYoung, 1997; Berger and Mester, 1997; Resti, 1997; DeYoung and Hasan, 1998; Bos and Kolari, 2005; Lieu et al., 2005; Bonin, Hasan, and Watchel, 2005; Yildirim and Philippatos, 2007; Berger, Hasan, and Zhou, 2008; and Lin and Zhang, 2009

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[2] For example, Bonin, Hasan and Wachtel (2005) find that domestically owned private banks are not significantly more efficient than government owned banks in Central and Eastern European countries. In contrast, Yildirim and Philippataos (2007) report that domestically owned private banks and state-owned banks are less cost efficient but more profit efficient relative to foreign banks in transition countries. Havrylchyk (2006) finds that foreign banks that acquired domestic banks do not enhance efficiency. Berger, Hasan and Zhou (2008) and Lin and Zhang (2009) find that the Big Four state-owned banks are less profit efficient relative to domestically owned private banks.

[3] The econometric approach for the estimating stochastic cost frontier model requires the separation of random errors from the systematic error component of a specified cost function. This entails the specification of a particular distribution form. The basic SF model assumes that a firm's observed cost deviates from the optimal cost due to a random noise (v_i) and an inefficiency component (u_i). It is usually assumed that u_i and v_i are independently and identically distributed. Further, the model assumes that v_i is normally distributed with a mean zero and constant variance, $v_{it} \sim N\left(0, \sigma_v^2\right)$, and the u_i is half-normally distributed, meaning the u_i is the absolute value of a variable that is normally distributed with a mean zero and constant variance, $u_i \sim | N\left(0, \sigma_u^2\right) |$. With these distributional assumptions, the basic stochastic econometric cost frontier model can be estimated using maximum likelihood techniques. Once the model is estimated, inefficiency measures can be estimated using the conditional mean of the inefficiency term, u_i, as proposed by Jondrow et al. (1982) or Greene (1993).

among others) to explore the impacts of bank-specific factors such as size, ownership, and branch banking on cost or profit inefficiency of banks. In the first step, the optimal stochastic frontier cost model (basic SF model) is estimated. In the second step, the firm-specific variables are regressed on bank inefficiency to identify the factors affecting it.

However, the literature on productivity analysis has raised two major issues associated with estimates of bank inefficiency based on the use of the basic SF model as well as the use of "two-step estimation procedure" described above.[4] First, the standard stochastic econometric frontier model (basic SF model) used in prior studies can lead to incorrect inferences because it doesn't account for heteroskedasticity in the inefficiency component of the error term, u_i (e,g., Caudill and Ford, 1993; Caudill, Ford, and Gropper, 1995; Mester, 1997). Second, Wang and Schmidt (2002) show that the SF model estimated in the first step is misspecified if input prices (e.g., cost of labor and cost of capital) and firm characteristics (e.g., size, ownership, and environmental variables) are correlated.[5] These firm-level factors such as size and ownership describe the patterns of different types of banks over the transition of bank reforms and the macro environmental variables control the factors during the periods of deregulation and financial crisis.

Our study differs from prior studies in several ways. First, we develop a generalized heteroskedastic stochastic frontier (HSF) model that accounts for heteroskedasticity in the

[4] The literature on productivity analysis provides strong evidence against use of the two-step estimation procedure because it provides biased estimates (Huang and Liu, 1994; Battese and Coelli, 1995; Wang and Schmidt, 2002).

[5] Wang and Schmidt (2002) show that the two-step estimation procedure can lead to biased results if the dependence of inefficiency on firm characteristics is ignored. They provide Monte Carlo evidence showing that the bias related to the two-step estimation procedure can be very severe. They find that the estimated firm-level efficiencies are "spuriously under-dispersed", causing the estimates from the second-step to be biased downward. See for example, Wang and Schmidt (2002) for a detailed discussion on "Why is the Two-Step Estimator Biased?"

inefficiency component of the error terms. Second, we circumvent the problems associated with the two-step estimation procedure, by employing a single-step estimation approach. Third, prior studies on bank efficiency suggest the importance of measurement of both cost and profit efficiency (e.g., Berger et al., 2008). In this study, we estimate both cost and profit efficiency of individual banks in our sample based on HSF models and a single-step estimation procedure. Finally, while the literature on banking efficiency recognizes several potential benefits of a comparative analysis of methodologies, only a few efficiency studies have utilized more than one econometric estimation technique for the same set of data (e.g., Bauer, Berger, and Humphrey, 1993; Allen and Rai, 1996). In this paper, we report the results based on the single-step estimation approach with HSF models and compare them with the results that are obtained from the basic SF models based on the traditional two-step estimation method using the same set of data. We find that our results based on the improved methodology are significantly different from the ones that are derived from the two-step estimation method based on standard SF models.

In order to estimate cost and profit efficiency of banks using HSF models with single-step estimation method, we select quarterly level data at firm level for a random sample of 24 commercial banks in Taiwan over the 1995-1999 period. Prior studies that analyze banking efficiency in Taiwan during 1990s mostly evaluate operational efficiency (technical efficiency) of banks using the Data Envelopment Analysis (e.g., Yeh, 1996; Chen, 2005 and Chen and Yeh, 2000).[6] Consistent with Berger et al. (2000), our study focuses on estimation of cost and profit

[6] Yeh (1996) examines operational efficiency (technical efficiency) of commercial banks of Taiwan in conjunction with financial ratios using the Data Envelopment Analysis (DEA, here after) over 1981-1989 period. Using the DEA, Chen and Yeh (2000) estimate operating efficiency (technical efficiency) of commercial banks in Taiwan over the 1995-1996 period. Lieu and et al. (2005) examine the effects of off-balance sheet activities on inefficiency in Taiwan's banks. Huang (2005) applies a single-step method to study the effects of information technology, capital and labor on technical efficiency

efficiency of banks. We examine the impact of size, ownership, and number of bank branches on cost and profit efficiency using HSF models with single-step estimation approach.

Our results show that asset size has a significant negative impact on cost efficiency, but has no significant effect on profit efficiency. We also find that private banks in Taiwan are more cost and profit efficient compared to government-owned banks. Further, banks with more branches are likely to be more cost and profit efficient. Our results also show that early stages of bank reform are associated with a reduction in profit efficiency. The cost and profit efficiencies of individual banks also differ significantly across banks. We find that results based on HSF models obtained from the single-step estimation approach are significantly better than that estimated from the traditional two-step procedure using basic SF models. We conclude that all future analysis on cost and profit efficiency in banking should adopt the single-step procedure that accounts for heteroskedasticity in the inefficiency component of the error terms.

The remainder of the paper is organized as follows: Section 2 develops a theoretical foundation for estimations of cost and profit efficiency of banks using a single-step heteroskedastic stochastic frontier model. Section 3 reports data and variables used in the study. Section 4 discusses empirical results, and Section 5 concludes with a summary.

2. Methodology

In the following section, we develop a generalized stochastic dynamic frontier model to account for heteroskedasticity in the inefficiency component of the error term, and propose a single-step estimation strategy to circumvent the above-mentioned problems associated with traditional SF models.

2.1 Heteroskedastic Stochastic Frontier (HSF) Model for Estimating Cost Efficiency

To circumvent the problem associated with the two-step estimation approach, Huang and Liu (1994) and Battese and Coelli (1995) use a one-step procedure using panel data. They specify a distribution function for the inefficiency component of the error term, u_i, and allow the parameters of that distribution to depend on the firm characteristics, but with a constant variance of u_i (i.e., σ_u^2 does not change with firm characteristics). Caudill and Ford (1993) suggest that not accounting for heteroskedasticity in the inefficiency component of the error term (u_i) can lead to biased parameter estimates.

In this study, we propose a two-equation generalized stochastic frontier model that accounts for heteroskedasticity and permits the single-step estimation of the parameters of the cost function as follows:

$$C_{it} = f(\mathbf{y}_{\mathbf{it}}, \mathbf{p}_{\mathbf{it}}; \beta) + u_{it} + v_{it}, \quad \text{and} \tag{1}$$

$$u_{it} = g(\mathbf{z}_{\mathbf{it}}; \alpha) + \varepsilon_{it}, \tag{2}$$

Where $\mathbf{y}_{\mathbf{it}}$ = vector of output variables, $\mathbf{p}_{\mathbf{it}}$ = vector of input prices, β is vector of parameters estimated, $\mathbf{z}_{\mathbf{it}}$ = a broad set of bank-specific factors (observable or unobservable), and macro-economic variables common to all banks.

α = vector of unknown coefficients to account for cost inefficiency, u_{it}.

$g(\cdot)$ = the optimized function of the cost inefficiency u_{it} of a given $\mathbf{z}_{\mathbf{it}}$ vector.

ε_{it} = ε_{it} ~| $N(0, \sigma_\varepsilon^2)$| with a one-sided distributed random error term.

Our generalized stochastic dynamic model is based on Huang and Liu (1994) and Battese and Coelli (1995) with two further extensions, which aim at minimizing model mis-specifications. The first extension is to incorporate the firm-specific, macroeconomic in the model using a cross-sectional time series or panel data. The $\mathbf{z}_{\mathbf{it}}$ vector in the g-function represents a wide range of factors including firm-specific factors (Mester, 1993; Allen and Rai, 1996; Rai, 1996; Miller and Noulas, 1997; Shao and Lin, 2000) and macroeconomic variables (e.g., Frankel and Rose, 1996; Kaminsky and Reinhart, 1999) that cause or explain the differences in cost inefficiencies over time and across banks. Kumbhakar and Hjalmarsson (1995) emphasize that the failure to include firm-specific and macroeconomic variables in the SF model is likely to bias the estimate of the one-sided error, u_{it}, which is one of the important elements of the estimation process. The reason for the bias is that the measure of inefficiency is based on the composite error term, which in turn is influenced by the parameter estimates of the frontier model. The second extension is to use a flexible distribution (see equation 2) for the inefficiency component of the error term (u_{it}) to account for heteroskedasticity in u_{it} . While heteroskedasticity may only affect estimation efficiency in a linear regression model, it leads to biased estimates in the SF model because a part of the error term (u_{it}) is asymmetrically distributed (e.g., Caudill and Ford, 1993; Caudill, Ford, and Gropper, 1995). In our model (1), u_{it} has a truncated normal distribution with a non-constant variance. The variance of u_{it} is a function of firm-specific and macroeconomic variables and it varies with time. Thus, our model allows the variance of u_{it} to be observation-specific. The specification of our model based on equations (1) and (2) represents an important and significant departure from the previous research based on the basic or deterministic model. In particular, our approach makes the inefficiency measure a dynamic and stochastic variable. Thus, the model allows us to use panel data at the firm-level to study if and how the cost inefficiency responds to the elements of $\mathbf{z}_{it}$. To our knowledge, this is the first application of the single-step estimation of parameters using HSF models in the banking efficiency literature.

We pool cross-sectional and time-series data across sample banks to measure both cost and profit efficiencies of commercial banks in Taiwan. The generalized stochastic cost frontier model (equations 1 and 2) that is based on a single-step estimation procedure is estimated using the LIMDEP program developed by Greene (1993) and is then compared with the results based on the basic SF model.

2.2 Heteroskedastic Stochastic Frontier (HSF) Model for Estimating Profit Efficiency

In the case of the profit function, the selection of output price variables depends on whether we assume the existence of market power of a bank in setting of output price (e.g., Berger and Mester, 1997; and Akhavein, Berger, and Humphrey, 1997). The standard profit frontier model assumes the existence of perfect competition in the markets for outputs and inputs; and in principle, the model requires information on the prices of the output vector, which in most cases is not available. Hence, most studies estimate an alternative profit frontier similar to the one developed by Berger et al. (2000). The alternative profit frontier model assumes that an imperfect competition exists with a given quantity of outputs and price of inputs. The goal of the bank is to maximize profits by adjusting the quantity of outputs and the price of inputs. The return on equity R_{it} (net profit to equity capital) serves as the dependent variable, a measure of profitability. Consequently, profit function and profit inefficiency are similar to cost function and cost inefficiency. However, the sign of the inefficiency term now becomes negative. The profit frontier model is specified as follows:

$$ln\,R_{it} = h(\mathbf{y}_{\mathbf{it}}, \mathbf{p}_{\mathbf{it}}; \beta^*) + e_{it} - \mathrm{m}_{\mathrm{it}}\text{, and} \quad (3)$$

$$m_{it} = k(\mathbf{z}_{\mathbf{it}}; \alpha) + \varepsilon_{it}, \quad (4)$$

where $\mathbf{y}_{\mathbf{it}}$ = vector of output variables, $\mathbf{p}_{\mathbf{it}}$ = vector of input prices, β* is vector of parameters estimated, $\mathbf{z}_{\mathbf{it}}$ = a broad set of bank-specific factors (observable and/or unobservable) and macroeconomic variables common to all banks.

α = vector of unknown coefficients to account for profit inefficiency, m_{it}.

$k(\cdot)$ = the optimized function of profit inefficiency m_{it} of a given $\mathbf{z}_{\mathbf{it}}$ vector.

$\varepsilon_{\mathrm{it}}$ = $\varepsilon_{it} \sim |N(0, \sigma_{\varepsilon}^2)|$ with a one-sided distributed random error term.

2.3 Specification of Bank Costs, Outputs and Inputs

There is considerable disagreement in prior literature on the definition of cost, outputs, and inputs for a bank. Two approaches have been suggested: an "intermediation approach" and a "production approach".[7] This study uses the intermediation approach for two reasons. First, commercial banks are considered financial intermediaries. Second, the intermediation approach is relevant to the measurement of cost or profit efficiency because an efficient bank would minimize the total operating and interest costs for any given output. Thus, consistent with the intermediation approach, total costs are defined as the sum of interest and non-interest expenses.

In equation (1), the output vector $\mathbf{y}_{\mathbf{it}}$ consists of three outputs, namely, LN_{it}, TD_{it}, and FI_{it}. LN_{it} includes the sum of personal loans, commercial loans, property and real estate loans, and industrial loans. TD_{it} constitutes the demand and term deposits. FI_{it} includes the total amount of

[7] See Berger, Hanweck and Humphrey (1987) for a detailed discussion on the issue.

investments in both short-term and long-term government securities. These three outputs are major banking activities that produce a flow of banking services.

The elements of $\mathbf{p_{it}}$ in equation (1) include the price of labor (w_{it}) and price of capital (c_{it}). Following Allen and Rai (1996), w_{it} is obtained by dividing the total staff expenses by the total number of reported employees of a bank, and c_{it} is measured by the average interest rate of deposits and other borrowed funds.

To allow for variation in the banking sector reform and related institutional developments across banks, several control variables (macroeconomic as well as firm-specific factors) are included in our model. In equation (2), the factors of $\mathbf{z_{it}}$ that account for the cost inefficiency involve macroeconomic factors (factors common to all banks) and firm-specific variables. The macroeconomic variables included in our model are M2 multiplier and CAP, the stock market capitalization to GDP. The M2 multiplier serves as a proxy for the overall liquidity in the economy, while the CAP variable serves as a proxy for the overall level of development of domestic stock markets. The firm-specific variables selected for our study are bank ownership (e.g., Altunbas, Evans, and Molyneux, 2001; Berger, Hasan, and Zhou, 2008); PUB, a dummy variable (1= government-owned banks and 0= privately owned banks); total assets (SIZE) as a proxy for the impact of size; total equity-to-asset ratio (EA) as a proxy for risk (e.g., Allen and Rai, 1996, Lieu et al., 2005) and the number of branches of bank i at time t, BRCH (see Berger, Leusner, and Mingo, 1997). In addition, several year dummy variables (D96, D97, D98, and D99) are included to control for economic impact attributed to different periods. One channel through which banking reform may have also had some impact on bank cost or profit efficiency is through adequacy of equity capital and some measures of constraints on risk taking. When combined with private ownership of banks and an objective of profitability, the reform in bank ownership structure and capital adequacy may strengthen the incentive for both cost and profit efficiencies of private banks in Taiwan.

The cost function of equation (1) takes a translog form, a widely used form of the cost frontier in the banking literature, while the g-function in equation (2) is assumed to be linear. The combination of the translog functional equation (1) with the linear equation (2) leads to equation (5) for our empirical analysis:

$$\ln C_{it} = \beta_0 + \sum_{k=1}^{2}\beta_{1k} \ln p_{kit} + \sum_{s=1}^{3}\beta_{2s} \ln y_{sit} + \frac{1}{2}\sum_{k=1}^{2}\sum_{k'=1}^{2}\beta_{3kk'} \ln p_{kit} \ln p_{k'it}$$

$$+ \frac{1}{2}\sum_{s=1}^{3}\sum_{s'=1}^{3}\beta_{4ss'} \ln y_{sit} \ln y_{s'it} + \sum_{k=1}^{2}\sum_{s=1}^{3}\beta_{5ks} \ln p_{kit} \ln y_{sit} + \alpha_1 B_{it} + ... + v_{it} + \varepsilon_{it}. \quad (5)$$

Finally, cost inefficiency, u_{it} , is not a good measure. Consistent with Berger et al. (1993), this study calculates the cost efficiency (CE_{it}) via u_{it} as follows:

$$CE_{it} = cost\ efficiency_{it} = \exp\left(u_{it}^{\min} - u_{it}\right), \quad (6)$$

Where $u_{it}^{\min}$ is the minimal u_{it} and is used as the benchmark to calculate the comparative efficiency for t=1, …, T (periods) and i= 1, …, N (banks). All estimates of the cost efficiency calculated from equation (6) fall between zero and one.

Similarly, the profit function can be specified as:

$$ln\, R_{it} = \beta_0 + \sum_{k=1}^{2}\beta_{1k} \ln p_{kit} + \sum_{s=1}^{3}\beta_{2s} \ln y_{sit} + \frac{1}{2}\sum_{k=1}^{2}\sum_{k'=1}^{2}\beta_{3kk'} \ln p_{kit} \ln p_{k'it}$$

$$+ \frac{1}{2}\sum_{s=1}^{3}\sum_{s'=1}^{3}\beta_{4ss'} \ln y_{sit} \ln y_{s'it} + \sum_{k=1}^{2}\sum_{s=1}^{3}\beta_{5ks} \ln p_{kit} \ln y_{sit} + ...$$

$$+ e_{it} - \mathrm{m}_{it}. \quad (7)$$

The specification (7) has been defined in Berger et al. (2000). Profit efficiency (PE_{it}) is defined as:

$PE_{it} = \exp(-m_{it}).$ (8)

These estimates are compared with the results that are based on the basic SF model for cost and profit efficiencies. Huang (2000) also indicates that the translog function could yield robust estimates. Definitions of variables, including specification of bank costs, outputs, and inputs are presented in Table 1.

[Table 1 about here]

3. Data

We select all publicly traded commercial banks that operate in Taiwan available between December 1995 and June 1999 for each bank. We compare all banks with shares circulated in the Taiwan Stock Exchange across sectional and longitudinal. Therefore, several government owned banks such as Taiwan Bank, Cooperative Bank and Land Bank without publicly traded stocks are not included. those banks without shares in the stock market do not operate under the market monitoring so they may tightly follow the policies and commands of the government while those with publicly traded shares are guided by both government and market power. Our sample includes quarterly data for 24 commercial banks over the 1995-1999 period. The code numbers (defined by the Taiwan Stock Exchange Corporation) and bank names are shown in Table 2. Except for the China Trust Commercial Bank, banks with code numbers ranging from 2801 to 2824 are the government-owned banks that were established before 1992. The oldest and biggest banks are Chang Hwa Bank, First Bank, and Hua Nan Bank. These three banks are government-owned banks that were taken over by the Taiwanese government from the Japanese in 1945. While banks with code numbers ranging from 2801 to 2824 (except #2815) are primarily government-owned and their stocks are publicly traded, four of them are partially owned by municipality or county governments. After the deregulation of the banking sector in

Taiwan, many new banks were established beginning in 1993; typically, these banks are privately owned. The quarterly accounting data for our sample banks are obtained from the Company Profile Database compiled by the Taiwan Economic Journal Co., Ltd., in Taipei, Taiwan. The financial data of Listed Companies are provided by the Taiwan Stock Exchange Corporation. The data on the macroeconomic variables (money supply and the ratio of market capitalization to GDP) are obtained from the Taiwan Economic Data Center operated by the Department of Education in Taiwan.

[Table 2 about here]

4. Empirical results and discussion

This section is organized as follows: Table 3 summarizes the statistics of the variables used, while Tables 4 and 5 show the empirical results of cost frontiers and profit frontiers, respectively. In Table 4, the original cost frontier [equation (1)] is presented for the purpose of comparison. Similarly, the original profit frontier is computed and presented in Table 5. Tables 6 and 7 display the measures of cost and profit efficiencies [i.e., equations (6) and (8)] and their rankings for each bank. Among all banks, a ranking of one is the most efficient and a ranking 28 is the least efficient.

4.1 Summary Statistics

Table 3 displays the summary statistics for outputs, inputs, input prices, and the average value of the M2 multiplier and the stock market capitalization to GDP ratio for sample banks for the 1995-1999 period. The sample is further divided into two groups: government-owned banks and privately owned banks. Descriptive statistics for outputs, inputs, and input prices for each group are reported in Table 3. Although all banks are publicly traded in the Taiwan Stock

Exchange, there are more government-owned shares in the old banks. All privately owned banks are new banks with short histories, and about 58% of all observations belong to this group.

[Table 3 about here]

The mean of total cost (interest and non-interest expenses) for all banks, measured in NT dollars, is 9,154 million. The average total cost of government-owned banks (NT$14,862 million) is significantly more than the average total cost of privately owned banks (NT$5.076 million). The summary data in Table 3 indicate that the average level of outputs (loans, deposits, and financial investments) of government-owned banks is larger than the average level of outputs of privately owned banks. This is not surprising because the average size of a government-owned bank is about three times the average size of a privately owned bank. A typical government-owned bank tends to have more branches than a privately owned bank. The average number of branches for a government-owned bank is about 82, while the average number of branches for a privately owned bank is about 25.

The most striking observation regarding Table 3 is that the average wage (in NT$1000) for a government-owned bank (291,430 vs. 212,960 NT dollars) is higher than the average wage for a privately owned bank. Another important observation is the mean rate of return on equity for government-owned banks is higher than that of privately owned banks (9.89% vs. 4.66%). This observation may not be surprising because the banking literature suggests that banking reform and deregulations encourage increased competition, which leads to smaller profit margins and lower returns for the banking industry. The average cost of funding (interest cost) for government-owned banks is less than the average cost of funding for privately owned banks (5.79% vs. 6.45%). The mean equity-to-asset ratio reported in Table 3 suggests that the average leverage ratio of a privately owned bank is lower than the average leverage ratio of a government-owned bank. Thus, it is possible that a typical government-owned bank in Taiwan tends to earn a higher rate of return on equity due to its lower cost of funding associated with government ownership, larger asset size, lower leverage ratio, and less competition. Overall, the government-owned banks produce more outputs at a lower cost of funding. On the other hand, privately owned banks tend be smaller compared to government-owned banks, and therefore, they raise more equity capital at higher cost to minimize the risk of insolvency.

While standard deviations of output variables for government-owned banks appear to be higher than that of privately owned banks, further analysis using the measure of coefficient variation (i.e., the ratio of the standard deviation to the mean, denoted as CV hereinafter) suggests that CVs of cost, ROE, FI, TD, and LN for new banks (privately owned) are higher than that of government-owned banks. Thus, measures of CV that are related to cost and output variables indicate that financial services offered by privately owned banks are generally more volatile than financial services offered by government-owned banks.

4.2 Cost Frontiers and Cost Inefficiency

To estimate the stochastic cost efficiency frontier for banks, we use the heteroskedastic SF methodology that permits the single-step estimation of parameters for the cost function and cost efficiency based on models (1) and (2). We also estimate parameters and cost efficiency using the basic SF model. Table 4 shows two sets of estimation results. Results reported in Table 4, Panel B are based on the heteroskedastic SF model that allows

[Table 4 about here]

firm-specific and macroeconomic factors to influence the position of the cost efficiency frontier. The estimation results based on the basic SF model are also reported in Table 4, Panel A for comparison only. As expected, the findings suggest that parameter estimates based on the basic SF model are not the same as those estimates based on the heteroskedastic SF model. For example, the coefficient associated with the financial investment variable (lny3) is negative but not significant in the heteroskedastic SF model (see Panel B), while the same is negative and significant in the basic SF model (see Panel A). Similarly, the coefficient of one of the interactive terms (lny2*lnp2) is positive and significant in the basic SF model, but it is not significant for the other. Consistent with Wang and Schmidt (2002), parameter estimates associated with the basic SF model (Panel A in Table 4) are likely to be biased because of misspecification of the model.

Our focus is on the results reported in Table 4 (Panel B) which show that, among input prices, only the cost of capital (lnp2) is negative and significant at the 5% level. Among the three output variables, only the total deposits variable (lny2) has a positive and significant impact on total costs. Thus, the more total deposits a bank has, the higher the total costs a bank incurs. In addition, interactive terms in the translog functional form such as lnp2*lnp2, lny1*lny3, lny2*lny2, lny1*lnp1, and lny2*lnp1 are statistically significant in determining total costs. The coefficients on dummy variables for each of the individual years are positive but statistically insignificant, indicating no secular trend in total costs of banks. The value of λ , obtained from the estimation based on the heteroskedastic SF model, differs from the estimation based on basic SF model ($\lambda = \sigma_u / \sigma_v$ = 3.6233 vs. 3.8503). The results suggest that the measure of cost inefficiency of banks based on the basic SF model is likely to be higher than the measure of cost inefficiency based on the heteroskedastic SF model that allows for firm-specific and macroeconomic variables using a single-step estimation procedure. Similarly, the 0.0649 value reported in Table 4 suggests that the total risk exposure (inefficiency component plus random error terms), $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$, is likely to be higher when we estimate the cost frontier model using the basic SF model (0.0701 vs. 0.0649). These results are consistent with the findings of Battese and Coelli (1995, 1997) and Wang and Schmidt (2002) that parameter estimates derived from the basic SF model are likely to be biased.

Parameter estimates reported in Table 4 (Panel B) indicate that firm-specific variables such as asset size (SIZE), type of ownership (PUB), and number of branches (BRCH) significantly correlate with the cost inefficiency, u. In contrast, environmental variables such as the M2 multiplier and the stock market capitalization to GDP ratio do not significantly correlate with cost inefficiency. The coefficient on size variable (SIZE) is positive and statistically significant at the 1% level, indicating that, on average, larger banks do not attain higher levels of cost efficiency in their operations. Allen and Rai (1996) also report that large banks are significantly less cost efficient than small banks in Australia, Italy, Japan, and the U.S. Similarly, the coefficient on the ownership variable (PUB) is positive and statistically significant at the 5% level, indicating that government-owned banks (old banks) are less cost efficient than privately owned banks (new banks). These results show that Taiwan banking sector appears to have become more competitive after the deregulation and the formation of newly-established banks. The higher level of cost and profit efficiency associated with privately-owned banks compared to publicly-owned banks are likely to be attributed to the substantial gains from privatization and bank reform and liberalization of economic policy in Taiwan during 1990s (e.g., Chen and Yeh, 2000). In contrast, the coefficient on the branch variable (BRCH) is negative and significant at 1% level, indicating that an increase in the number of branches of a bank helps improve cost efficiency. We interpret this finding as being consistent with a positive demand side effect of efficient operation, including effective service or better combination of prices and quality of service.

4.3 Profit Frontiers and Profit Inefficiency

Similar to the estimation of the stochastic cost frontier, we estimate the stochastic profit efficiency frontier for banks in Taiwan using the heteroskedastic SF methodology that permits the single-step estimation of parameters of the alternative profit function and profit efficiency based on models (4) and (5). Table 5 shows two sets of estimation results.

[Table 5 about here]

Comparable to the results reported in Table 4, Table 5 (Panel B) shows parameter estimates based on the heteroskedastic SF model that allows firm-specific and macroeconomic factors to influence the position of the profit efficiency frontier. We also report the parameter estimates of the alternative profit function using the basic SF approach based on model (1) in Table 5 (Panel A) for comparison only. The results reported in Table 5 (Panel B) reveal that parameter estimates based on the heteroskedastic SF model that allows firm-specific and environmental variables to influence the position of the profit efficiency frontier differ significantly from the estimates based on the standard SF model reported in Table 5 (Panel A). Our focus is on the results reported in Table 5 (Panel B) because, as pointed out earlier, the estimates based on the basic SF approach (Table 5, Panel A) are likely to be biased. The results presented in Table 5 (Panel B) suggest that all input prices and output variables are insignificant except for some second-order product terms such as lny1*lny3 and lny2*lny3 that are significant at the 1% level. As can be seen, the coefficients of the dummy variables for each of the individual years are negative and statistically significant, indicating a secular decline in return on equity since the year 1995. This may be attributed to increased competition and efficiency in the marketplace following the reform and deregulation in the Taiwan banking industry. While the estimates of error λ and σ are statistically significant in both models, the measures of profit inefficiency ($\lambda = \sigma_m / \sigma_e$) and total risk ($\sigma = \sqrt{\sigma_e^2 + \sigma_m^2}$) based on the basic SF profit model are understated when compared to their measures based on the heteroskedastic SF model. Hence, it makes a big difference in estimating profit frontiers when we use single-step estimation based on the heteroskedastic SF model. Again, consistent with Wang and Schmidt (2002), we argue strongly in favor of the one-step estimation model because we are interested in the effects of firm characteristics and environmental variables on the profit efficiency of banks.

Parameter estimates reported in Table 5, Panel B indicate that firm-specific variables such as use of equity capital (LEV), type of ownership (PUB), and number of branches (BRCH) significantly correlate with profit inefficiency (m). In contrast, macroeconomic variables such as the M2 multiplier and the ratio of stock market capitalization to GDP do not significantly correlate with profit inefficiency. The coefficient on size variable (SIZE) is negative but statistically insignificant, indicating that, on average, larger banks tend to be more profit efficient than smaller banks. As seen in Table 5 (Panel B), profit inefficiency is significantly negatively correlated with the level of equity capital (EA), indicating that better capitalized banks are more profit efficient. Consistent with Mester (1993) and Allen and Rai (1996), this finding accords with the moral hazard problem and agency costs. The coefficient on number of branches (BRCH) is negative and statistically significant at the 5% level, indicating banks with more branches are more profit efficient. This implies that a bank may provide better customer service or a better combination of prices and quality of service lead to higher cost and profit efficiency. In contrast, the coefficient on the ownership variable (PUB) is positive and statistically significant at the 5% level, indicating that government ownership of banks significantly correlates with profit inefficiency. This result is similar to the finding of Berger et al. (2008), which suggests that government ownership contributes negatively to the profit efficiency of commercial banks in China.

4.4 Measures and rankings of cost and profit efficiencies

Most bank efficiency studies have paid attention to cost efficiency, ignoring possible inefficiency on the revenue side. Prior studies related to the U.S. banking industry suggest that inefficiencies on the output side may be as large as or larger than those on the input side (e.g., Berger et. al., 1993; Berger and Humprey, 1997). Unlike the measure of cost efficiency, the measure of profit efficiency accounts for errors on the output side as well as on the input side. Thus, profit efficiency is concerned with both cost and revenue efficiency.

[Table 6 about here]

We measure both the cost and profit efficiency of our sample banks using the basic SF model as well as the correctly specified heteroskedastic SF models. Table 6 displays the estimates of cost as well as profit efficiency and the average rankings for each of the 24 commercial banks over the 1995-1999 period based on the basic SF model. We measure efficiency by comparing the inefficiency index of each bank with the index of the most efficient bank. The measure of efficiency takes a maximum value of one (the most efficient bank in the sample) and a minimum value of nine (the least efficient bank in the sample). As can be seen in Table 6 (Panel A), the most cost-efficient bank (rank #1) is the Chinese Commercial Bank, a privately owned bank with an average efficiency score of 0.9625; and the least cost-efficient bank (rank #24) is the Taishin International Bank, another privately owned bank with an average efficiency score of 0.8860. In contrast (see Table 6, Panel B), using the basic SF model we find that the least cost-efficient bank (Taishin International Bank) happens to be the most profit-efficient bank (rank #1).

[Table 7 about here]

As expected, results presented in Table 7 reveal that rankings on cost efficiency as well as on profit efficiency estimated from the heteroskedastic SF models using a single-step estimation procedure are different from the rankings on cost and profit efficiency estimated from the basic SF models. For example, consistent with the results reported in Table 6, Table 7 shows that the Chinese Commercial Bank is the most cost efficient and the Taishin International Bank is the most profit efficient. However, when we compare the results reported in Table 7 with that of Table 6, we notice that the order of rankings of cost and profit efficiency for the remaining banks differ dramatically. For example, the least cost-efficient bank reported in Table 7 is the Chiao Tung Bank, an old government-owned bank, while the least cost- efficient bank reported in Table 6 is the Taishin International Bank, a new privately owned bank. Similarly, the least profit-efficient bank reported in Table 7 is the Farmers Bank of China, an old government-owned bank, while the least profit-efficient bank reported in Table 6 is the Chiao Tung Bank, again an old government-owned bank.

It is worth noting that based on the efficiency ranking, the traditional big three banks (Chang Hwa Bank, First Bank, and Hua Nan Bank) appear to be more cost efficient but less profit efficient in comparison to privately owned banks. Since the big three banks are only partially government-owned and partially publicly traded in the stock market, it is possible that these three big banks may be able to lower their cost of funding due to ease of access to deposits or equity capital at a lower cost. The government-owned banks are likely to be less profit efficient because the goal of a government-controlled bank is not necessarily consistent with the objective of profit maximization. Our results also show that rankings of cost efficiency and profit efficiency vary among the privately owned banks, indicating that all privately owned banks are not necessarily cost-efficient or profit efficient.

Prior studies on bank efficiency suggest that it is important to consider rankings of both cost and profit efficiencies (see Berger et al., 2008). For example, some banks can be more profitable by providing financial services that are costly but generate higher net revenue. The last columns in Tables 6 and 7 show the rankings of bank efficiency based on the sum of cost efficiency and profit efficiency scores. As seen in Table 7, considering both profit and cost efficiency, the most efficient bank is the First Bank, a government-owned bank with a score of eight, followed by the Asia Pacific Commercial Bank, a privately owned bank with a score of nine. Overall rankings suggest that efficiency scores (last columns of Tables 6 and 7) that are based on the correctly specified SF models differ significantly from those that are based on the basic SF models.

4.5 Tobit Regression

We compare the results based on the single-step estimation procedure with the results from the traditional two-step estimation method. We estimate the cost and profit inefficiency in the first-step based on the basic SF model. In order to investigate the determinants of cost and profit efficiency, we use a Tobit regression in the second-step because of the limited nature of our cost or profit inefficiency measure (which ranges from 0 to 1). Table 8 displays the empirical results based on the second-stage Tobit regression. The left panel of Table 8 shows that the regression results associated with cost inefficiency (u). We compare Tobit regression results with the results that are reported in the right panel of Table 4 based on the single-step estimation method. While the effects of size (SIZE) and branching (BRCH) on cost inefficiency are the same regardless the estimation method used, the relation between ownership and cost inefficiency provides conflicting results. For example, Tobit regression results reported in Table 8 indicate that coefficient on ownership is insignificant, while the same results based on the one-step estimation method (see Table 4) is positive and significant at 5 percent level. Similarly, we also find conflicting results associated with leverage ratio (LEV), a measure of bank insolvency risk. While equity-to-asset ratio is positive and significant at 5 percent level for the Tobit regression results (see left panel of Table 8), the same is insignificant based on the results obtained from the single-step estimation method.

[Table 8 about here]

Now let us turn to the results of Tobit regression on the profit efficiency reported in right panel of Table 8 and compare them with results that are estimated from the single-step approach reported in the right panel of Table 5. While the effects of branching and ownership are significant in the single-step estimation method, none of the estimates are significant in the second-stage Tobit regression results. The comparison of results based on two different estimation methods demonstrates that the cost or profit frontier function and measures of efficiency are better specified when we account for heteroskedasticity in the inefficiency component of the error terms (e.g. Caudill, Ford, and Gropper, 1995; and Mester, 1997) and employ the single-step estimation procedure. Our results also suggest that two-step procedure used in prior studies to measure the determinants of bank efficiency can lead to biased results because the standard (SF) model estimated at the first step is misspecified. Thus, the results based on the correctly specified one-step estimation method are significantly different from those that are obtained from the traditional two-step estimation method. Thus, we encourage all future analysis of efficiency in banking should be based on one-step procedure.

5. Summary and Conclusions

To analyze the effects of firm characteristics and macroeconomic environmental variables on bank efficiency, we develop a generalized dynamic model that accounts for heteroskedasticity in the inefficiency component of the error term and adopt a "single-step" approach to circumvent the problems associated with the two-step estimation procedure used by earlier studies. We find that the results based on single-step HSF analysis are significantly different from those that are estimated based on the traditional "two-step" procedure with basic stochastic frontier (SF) models. It has been recognized in the prior literature (e.g., Battese and Coelli, 1995; Wang and Schmidt, 2002) that the two-step estimation procedure leads to biased results because the basic SF model estimated at the first step is misspecified.

We estimate the cost and profit efficiencies of 24 commercial banks in Taiwan using a single-step approach with HSF models and panel data for the 1995-1999 period. We find that asset size has a significant negative impact on cost efficiency, while the number of branches of a bank has a positive impact on both cost and profit efficiency. Privately owned banks seem to be more cost and profit efficient compared to government-owned banks. Our results suggest that early stages of bank reforms are associated with a reduction in profit efficiency. The results also show that the profit efficiency of the banking industry consistently fell over the study period. We find that cost efficiency as well as profit efficiency varies significantly across banks. The cost efficiency varies from 74% to 96%, while the profit efficiency varies from 25% to 78%. Based on the rankings of cost efficiency or profit efficiency, we conclude that government-owned banks can be more or less cost efficient than privately owned banks. Similarly, the government-owned banks can also be more or less profit efficient. Nevertheless, when both cost and profit efficiency scores are added together, overall rankings on efficiency also change.

We compare our results with those that are obtained from the traditional two-step estimation with basic SF models. We observe that the results based on the two-step estimation method with basic SF models are significantly different than those that are estimated based on the single-step approach with HSF models. Similar to the findings of Battese and Coelli (1995) and Wang and Schmidt (2002), we conclude that estimates based on the traditional two-step procedure are likely to be biased because the model estimated in the first-step is misspecified. We recommend that all future studies analyzing efficiency in banking account for heteroskedasticity in the inefficiency component of the error term and then use the single-step approach to estimate the parameters of the stochastic frontier and the inefficiency model simultaneously. The results of our study are likely to have significant implications for bank managers, financial analysts, and bank regulators.

REFERENCES

Aigner, D. J., Lovell,C. A. K., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6(1), 21-37.

Akhavein, J. D., Berger, A. N., Humphrey,D.B., 1997. A general method of driving the efficiencies of banks from a profit function. *Journal of Productivity Analysis* 8, 71-93.

Allen, L., Rai, A., 1996. Operating efficiency in banking: An international comparison. *Journal of Banking and Finance* 20, 655-672.

Altunbas, Y., Evans, L. and Molyneux, P., 2001. Ownership and efficiency in banking. *Journal of Money, Credit and Banking* 33 (4), 926-954.

Altunbas, Y., Gardener, E., Molyneux, P., Moore B., 2001. Efficiency in European banking. *European Economic Review* 45, 1931-1955.

Battese, G. E., Coelli,T. J., 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* 20, 325-332.

Battese, G.E., Coelli, T. J., 1997. Estimation of frontier production functions and the efficiency of Indian farms using panel data. *Journal of Quantitative Economics* 5, 327-348.

Bauer, P. W., 1990. Recent developments in the econometric estimation of frontiers. *Journal of Econometrics* 46, 39-56.

Bauer, P. W., Berger, A. N., Humphrey,D. B., 1993. Efficiency and productivity growth in U.S. banking. Harold O. Fried, C. A. Knox Lovell, and Shelton S. Schmidt (eds.), *The measurement of productive efficiency: techniques and applications*, 386-413. Oxford University Press.

Berger, A. N., Humphrey, D.B., 1991. The dominance of inefficiencies over scale and product mix economies in banking. *Journal of Monetary Economics* 28, 117-148.

Berger, A. N., Strahan, P.E., 1998. The consolidation of the financial services industry: causes, consequences, and the implications for the future. Working paper, Federal Reserve Bank of New York.

Berger, A. N., Hasan, I., Zhou, M., 2008. Bank ownership and efficiency in China: what will happen in the world's largest nation? *Journal of Banking and Finance*. forthcoming.

Berger, A. N., DeYoung, R., Genay, H., Udell, G.F., 2000. Globalization of financial institutions: evidence from cross-border banking performance. R. E. Litan and A. Santomero (eds.), *Brookings-Wharton Papers on Financial Services* 3. Philadelphia, PA: The Wharton School, 23-158.

Berger, A. N., Hunter, W.C., Timme, S.G., 1993. The efficiency of financial institutions: a review and preview of research: Past, present, and future. *Journal of Banking and Finance* 17, 221-249.

Berger, A.N., 1993. Distribution-free estimates of efficiency in the U.S. banking industry and tests of the standard distributional assumptions. *Journal of Productivity Analysis* 4(3), 261-292.

Berger, A.N. Humphrey, D.B., 1997. Efficiency of financial institutions: international survey and directions for future research. *European Journal of Operational Research* 98, 175-212.

Berger, A.N., Mester, L.J., 1997. Inside the black box: What explains differences in the efficiencies of financial institutions? *Journal of Banking and Finance* 21, 895-947.

Berger, A. N., Leusner, J. H., Mingo, J. J., 1997. The efficiency of bank branches. *Journal of Monetary Economics, Elsevier* 40(1), 141-162.

Berger, A. N., DeYoung, R., 1997. Problem loans and cost efficiency in commercial banks. *Journal of Banking and Finance* 21, 849-70.

Bhattacharya, A, Lovell, C.A.K., Sahay, P., 1997.The impact of liberalization on the productive efficiency of Indian commercial banks. *European Journal of Operational Research* 98 (2), 332-345.

Bonin, J. P., Hasan I., Wachtel, P., 2005. Bank performance, efficiency, and ownership in transition countries. *Journal of Banking and Finance* 29 (1), 31-53.

Bos J. W., Kolari J. W., 2005. Large bank efficiency in Europe and the United States: are there economic motivations for geographic expansion in financial services?' *Journal of Business* 78(4),1555-1592.

Caudill, S. B., Ford, J. M., 1993. Biases in frontier estimation due to heteroscedasticity. *Economics Letters*, 41(1),17-20.

Caudill, S. B., Ford, J. M., Gropper, D. M., 1995. Frontier estimation and firm-specific inefficiency measures in the presence of heteroscedasticity. *Journal of Business & Economic Statistics* 13(1), 105-11.

Cebenoyan, A. S., 1990. 'Scope economies in banking: the hybrid box-cox function', *The Financial Review* 25, 115-125.

Chen, T., and Yeh, T., 2000. A measurement of bank efficiency, ownership and productivity changes in Taiwan. *The Service Industries Journal* 20(1), 95 - 109.

Chen, T. 2005. A measurement of Taiwan's bank efficiency and productivity change during the Asian financial crisis. *International Journal of Services Technology and Management* 6(6), 525 - 543

Ferrier, G. D. and Lovell, C.A.K., 1990. Measuring cost efficiency in banking: econometric and linear programming evidence. *Journal of Econometrics* 46, 229-245.

Frankel, J. A., Rose, A.K., 1996. Currency crashes in emerging markets: an empirical treatment. *Journal of International Economics* 41, 351-366.

Greene, W. H., 1993. *Econometric Analysis*, 2nd Edition. New York, N. Y.: Macmillan Publishing Company.

Havrylchyk, O. , 2006. Efficiency of the Polish banking industry: foreign versus domestic banks. *Journal of Banking and Finance* 30 (7), 975-1996.

Huang, C. J., Liu, J.T., 1994. Estimation of a non-neutral stochastic production function. *Journal of Productivity Analysis* 5, 171-180.

Huang, T., 2000. Estimating X-Efficiency in Taiwanese banking using a translog shadow profit function. *Journal of Productivity Analysis* 14(3), 225-245.

Jondrow, J., Lovell, C.A.K., Materov, I.S., Schmidt, P., 1982. On the estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics* 19, 233-238.

Kaminsky, G. L. and Reinhart, C. M., 1999. The twin crises: the causes of banking and balance-of-payments problems. *American Economics Review* 89, 473-500.

Kumbhakar, S. C., Hjalmarsson, L., 1995. Labour-use efficiency in Swedish social insurance offices. *Journal of Applied Econometrics* 10(1), 33-47.

LeCompte, R. L. B., Smith, S.D., 1990. Changes in the cost of intermediation: The case of savings and loans. *Journal of Finance*, 45, 1337-1346.

Lieu, P.T., Yeh, T.-L., Chiu, Y.-H.. 2005. Off-balance sheet activities and cost inefficiency in Taiwan's Banks. *Service Industries Journal* 25 (7), 925-944.

Lin, X., Zhang, Y., 2009. Bank ownership reform and bank performance in China. *Journal of Banking and Finance*, 33(1), 20-29.

Meeusen, W., Van Den Broeck, J., 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review* 18(2), 435-444

Mester, L. J., 1987. A multiproduct cost study of savings and loans. *Journal of Finance* 42, 423-445.

Mester, L. J., 1993. Efficiency in the savings and loan industry. *Journal of Banking and Finance* 17, 267-286.

Mester L.J., 1996. Measuring efficiency at U.S. banks: accounting for heterogeneity is important. Working Papers 96-11/R, Federal Reserve Bank of Philadelphia.

Mester, L. J., 1997. Measuring efficiency at U.S. banks: accounting for heterogeneity is important. *European Journal of Operational Research* 230-242.

Miller, S. M., Noulas, A. G., 1997. Portfolio mix and large-bank profitability in the USA. *Applied Economics* 29, 505-512.

Murray, J. D., White, R.W., 1983. Economies of scale and economies of scope in multiproduct financial institutions: a study of British Columbia credit unions. *Journal of Finance* 38, 887-902.

Pastor J. M., Perez, F. and Quesada, J.,1997. Efficiency analysis in banking firms: an international comparison. *European Journal of Operational Research* 98, 395-407.

Pitt, M. M., Lee, L.F., 1981. The measurement and sources of technical inefficiency in the Indonesian weaving industry. *Journal of Development Economics* 9(1), 43-64.

Rai, A., 1996. Cost efficiency of international insurance firms. *Journal of Financial Service Research* 10, 213-233.

Resti, A., 1997. Evaluating the cost-efficiency of the Italian banking system: what can be learned from the joint application of parametric and non-Parametric techniques. *Journal of Banking and Finance* 21, 221-250.

Rezvanian R., Mehdian, S., 2002. An examination of cost structure and production performance of commercial banks in Singapore. *Journal of Banking and Finance* 26, 79-98.

Shao, B. B. M., Lin, W.T., 2000. Examining the determinants of production efficiency with IT as a production factor. *Journal of Computer Information Systems* 41, 25-30.

Wang, H., and Schmidt, P., 2002. One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *Journal of Productivity Analysis* 18, 129-144.

Weiss, M. A., 1991. Efficiency in the property-liability insurance industry. *Journal of Risk and Insurance* 58, 452-479.

Yeh, Quey-Jen., 1996. The application of data envelopment analysis in conjunction with financial ratios for bank performance evaluation. *The Journal of the Operational Research Society* 47(8), 980-988.

Yildirim, H.S., Philippatos, G.C., 2007. Efficiency of banks: recent evidence from the transition economies of Europe, 1993-2000. *The European Journal of Finance,* 13(2), 123-143.

Table 1. Definitions of Variables and Cross-Product Terms

C_{it} : the logarithm of the total cost (operating and interest) of production of bank i at time t. $\mathbf{y}_{\mathbf{it}}$: a vector of outputs (loans, deposits, financial investments, etc.). $LN_{it} = y_{1it}$: total loans (including personal, commercial, property and real estate, and industrial loans). $TD_{it} = y_{2it}$: total deposits (including demand and term deposits). $FI_{it} = y_{3it}$: financial investments (including long- and short-term investments). $\mathbf{p}_{\mathbf{it}}$: a vector of input prices (e.g., the wage of labor and price of capital). $w_{it} = p_{1it}$: the wage of labor. $c_{it} = p_{2it}$: the price of capital. $\mathbf{z}_{\mathbf{it}}$: a broad set of bank-specific factors (observable or unobservable) and macroeconomic variables common to all banks (cf. Lin, 1992). R_{it} : the logarithm of the return on equities to account for the profit of bank i at time t. SIZE= the amount of total assets in million NT dollars. LEV=the ratio of equity to assets of bank i at time t in percentage. BRCH: the number of branches of bank i at time t. M2M: the M2 multiplier =M2/base money (cf. Kaminsky and Reinhart, 1999). CAP: Stock market capitalization to GDP.	$f(\cdot)$: the optimized cost function of a given output vector and input prices. $g(\cdot)$: the optimized function of the cost inefficiency u_{it} of a given $\mathbf{z}_{\mathbf{it}}$ vector. $h(\cdot)$: the optimized profit function of a given output vector and input prices. β : a vector of unknown coefficients in the cost function. α : a vector of unknown coefficients to account for the cost inefficiency u_{it}. $\beta*$: a vector of unknown coefficients in the profit function. $v_{it} \sim N(0,\sigma_v^2)$: an unexplained random error of the cost function. $e_{it} \sim N(0,\sigma_e^2)$: an unexplained random error of the profit function. $u_{it} \sim \lvert N(0,\sigma_u^2)\rvert$: a one-sided distributed random error to account for the cost inefficiency. $\mathrm{m}_{\mathrm{it}} \sim \lvert N(0,\sigma_{\mathrm{m}}^2)\rvert$: a one-sided distributed random error to account for the profit inefficiency. $\varepsilon_{it} \sim \lvert N(0,\sigma_\varepsilon^2)\rvert$: a one-sided distributed random error of u_{it}.

Table 2. Bank Codes and Names of Sample Banks

Taiwan			
Code	Name	Code	Name
2801	Chang Hwa Bank	2829	Dah An Bank
2802	First Bank	2831	Chinese Commercial Bank
2803	Hua Nan Bank	2837	Cosmos Bank
2806	International Bank of China	2838	Union Bank of Taiwan
2808	International Bank of Taipei	2839	Bank Sinopac Co. Ltd.
2809	Medium Business Bank of Tainan	2840	E. Sun Commercial Bank Ltd.
2812	Taichung Commercial Bank	2842	Fubon Commercial Bank Ltd.
2815	China Trust Commercial Bank	2843	Asia Pacific Commercial Bank Ltd.
2822	Farmers Bank of China	2844	Taishin International Bank Co. Ltd.
2824	Chiao Tung Bank	2845	Far Eastern International Bank
2826	United World Chinese Commercial Bank	2847	Ta Chong Bank Ltd.
2828	Grand Commercial Bank	2849	Chung Shing Bank

Note: Banks coded from 2801 to 2824 (except 2815) are owned by government (local or central government) though all banks above are publicly traded in the Taiwan Stock Exchange Market.

Table 3. Summary Statistics

		All Banks			Government-Owned			Privately Owned		
Variable		Mean	Std.Dev.	Cases	Mean	Std.Dev.	Cases	Mean	Std.Dev.	Cases
COST		9,154	7,522	360	14,862	7,877	150	5,076	3,585	210
ROE		6.84	17.28	360	9.89	26.35	150	4.66	2.54	210
LOAN	=y1	213,771	175,344	360	351,372	190,737	150	115,484	59,828	210
TD	=y2	239,488	208,856	360	395,012	237,682	150	128,400	69,955	210
FI	=y3	41,064	38,903	360	69,685	42,294	150	20,619	17,788	210
W	=p1	245.65	70.66	360	291.43	72.35	150	212.96	47.60	210
C	=p2	6.18	0.57	360	5.79	0.47	150	6.45	0.46	210
SIZE		496,971	421,226	360	801,599	461,151	150	279,379	197,461	210
LEV		5.73	1.92	360	4.72	1.49	150	6.44	1.87	210
BRCH		48.62	37.36	360	81.94	37.33	150	24.82	6.16	210
M2M		9.00	1.07	360	9.00	1.07	150	9.00	1.07	210
CAP		1.02	0.17	360	1.02	0.17	150	1.02	0.17	210

Legend:
COST = total costs including operating costs and interest costs;
ROE = Return on Equities;
LN = y1, total loans (including personal, commercial, property and real estate, and industrial loans);
TD = y2, total deposits (including demand and term deposits);
FI = y3, financial investments (including long- and short-term investments);
W = p1, the wage of labor in thousand NY dollars;
C = p2, the price of capital in %;
SIZE = the amount of total assets in million NT dollars;
LEV = the ratio of equity to asset of a bank in %;
BRCH = the number of branches of bank i at time t;
M2M = the M2 multiplier = M2 / base money (cf. Kaminsky and Reinhart, 1999);
CAP = Stock market capitalization to GDP.

Table 4. Model Parameters of the Stochastic Cost Frontier and Cost Inefficiencies

Variable	Coefficient		*t*-value	Coefficient		*t*-value
	Basic SF Model (1)			Heteroskedastic SF Model: Single-Step Estimation		
Panel A:				Panel B:		
Constant	-1.9240		-1.33	-0.4546		-0.31
lnp1	-0.3449		-0.93	-0.1013		-0.26
lnp2	-4.3745	***	-3.85	-4.2655	***	-3.63
lny1	-1.1696		-1.61	-1.2532		-1.51
lny2	3.3449	***	4.44	2.5726	***	2.90
lny3	-0.7545	***	-3.37	-0.3187		-1.59
lnp1*lnp2	0.3505		1.15	0.4730		1.48
lnp1*lnp1	0.0077		0.17	-0.0786		-1.65
lnp2*lnp2	2.8864	***	5.53	2.4890	***	4.81
lny1*lny2	0.0486		0.36	0.0299		0.18
lny1*lny3	0.3826	***	9.21	0.3203	***	6.09
lny2*lny3	-0.3018	***	-7.57	-0.2613	***	-5.30
lny1*lny1	0.0279		0.21	-0.0446		-0.29
lny3*lny3	0.0103		0.91	0.0016		0.16
lny2*lny2	-0.3163	*	-1.79	-0.0991	*	-0.46
lny1*lnp1	0.2560		2.87	0.3725	***	3.33
lny1*lnp2	-0.6411	***	-2.70	-0.3185		-1.10
lny2*lnp1	-0.2665	***	-2.83	-0.3989	***	-3.38
lny2*lnp2	0.4678	**	1.99	0.3152		1.06
lny3*lnp1	0.0323		0.89	0.0075		0.23
lny3*lnp2	0.1292		1.57	-0.0041		0.42
D96	0.0144		1.26	0.0125		1.20
D97	0.0082		0.61	0.0198		1.03
D98	0.0015		0.11	0.0065		0.15
D99	0.0121		0.81	0.0161		0.50
Constant	--		--	-0.0327		-0.37
SIZE	--		--	0.1345	***	2.84
LEV	--		--	0.0094		1.36
BRCH	--		--	-0.0038	***	-2.67
PUB	--		--	0.1141	**	2.37
M2M	--		--	-0.0063		-0.62
CAP	--		--	-0.0776		-1.47
λ	3.8503	***	5.20	3.6233	***	4.16
σ	0.0701	***	18.18	0.0649	***	9.31
	Number of iterations = 71			Number of iterations = 65		

Legend:
*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.
About the definitions of variables in the cost frontiers, please see Table I.
SIZE = the amount of total assets in million NT dollars;
LEV = the ratio of equity to asset of a bank in %;
BRCH = the number of branches of bank i at time t;

M2M = the M2 multiplier = M2 / base money (cf. Kaminsky and Reinhart, 1999);
CAP = Stock market capitalization to GDP;
D96, D97, D98, and D99 = Dummy variables for 1996, 1997, 1998, 1999 with 1995 as base year
$\lambda = \sigma_u / \sigma_v$ and $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$.

Table 5. Model Parameters of the Stochastic Profit Frontiers and Profit Inefficiencies

Variable	Coefficient		*t*-value	Coefficient		*t*-value
	Basic SF Model			Heteroskedastic SF Model: Single-Step Estimation		
Panel A:				Panel B:		
Constant	7.4724		0.35	-7.2832		-0.37
lnp1	3.4195		0.74	-4.2048		-1.23
lnp2	-8.5813		-0.63	-4.3110		-0.29
lny1	3.6513		0.44	-1.0162		-0.10
lny2	-5.4412		-0.62	6.0025		0.52
lny3	2.5641		0.96	1.0923		0.47
lnp1*lnp2	-4.3032		-1.04	0.4194		0.14
lnp1*lnp1	0.9364		0.96	0.7607		1.50
lnp2*lnp2	-1.8025		-0.30	-1.6590		-0.25
lny1*lny2	-2.9094	*	-1.81	-3.3096	*	-1.76
lny1*lny3	2.6159	***	3.56	2.2430	***	3.05
lny2*lny3	-2.6303	***	-3.82	-1.9747	***	-2.94
lny1*lny1	-1.6091		-0.98	1.2523		0.77
lny3*lny3	-0.0271		-0.20	0.0998		0.74
lny2*lny2	6.8783	***	3.04	3.8095		1.45
lny1*lnp1	2.7394	***	3.71	0.7810		0.72
lny1*lnp2	4.1504		1.60	1.7475		0.47
lny2*lnp1	-3.4495	***	-3.62	-0.5171		-0.39
lny2*lnp2	-0.4977		-0.21	0.1984		0.05
lny3*lnp1	0.6870		1.57	0.0376		0.09
lny3*lnp2	-1.7779	*	-1.66	-1.5687	*	-1.68
D96	-0.5310	***	-2.75	-0.5672	***	-4.21
D97	-0.3028		-1.55	-0.4602	***	-3.10
D98	-0.7862	***	-4.01	-0.9214	***	-6.15
D99	-1.3824	***	-6.56	-1.5367	***	-8.61
Constant				10.3674	***	2.71
SIZE	--		--	-0.3640		-0.81
LEV				-0.4336	*	-1.91
BRCH				-0.0245	**	-2.34
PUB	--		--	2.6268	**	2.41
M2M	--		--	0.2466		1.46
CAP				-1.5283		-1.46
λ	11.4166	**	2.13	13.8106	***	3.19
σ	0.9901	***	26.90	1.2159	***	5.81
	Number of iterations = 58			Number of iterations = 85		

Legend:
*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.
About the definitions of variables in the profit frontiers, please see Table I.
SIZE = the amount of total assets in million NT dollars;
LEV = the ratio of equity to asset of a bank in %;
BRCH = the number of branches of bank i at time t;
M2M = the M2 multiplier = M2 / base money (cf. Kaminsky and Reinhart, 1999);
CAP = Stock market capitalization to GDP.

D96, D97, D98, and D99 = Dummy variables for 1996, 1997, 1998, 1999 with 1995 as base year

$\lambda = \sigma_m / \sigma_e$ and $\sigma = \sqrt{\sigma_e^2 + \sigma_m^2}$.

Table 6. Rankings of Cost and Profit Efficiency Based on the Basic SF Model

Code	Bank Name	Cost Efficiency	Rank	Profit Efficiency	Rank	Sum of Rank
2801	Chang Hwa Bank	0.9020	18	0.5223	16	34
2802	First Bank	0.9328	5	0.6281	6	11
2803	Hua Nan Bank	0.9359	4	0.5245	14	18
2806	International Bank of China	0.8913	23	0.5132	17	40
2808	International Bank of Taipei	0.9128	13	0.6424	5	18
2809	Medium Business Bank of Tainan	0.9112	15	0.4435	21	36
2812	Taichung Commercial Bank	0.9319	6	0.5004	20	26
2815	China Trust Commercial Bank	0.8917	22	0.5817	8	30
2822	Farmers Bank of China	0.9298	10	0.3429	23	33
2824	Chiao Tung Bank	0.8947	20	0.3275	24	44
2826	UnitedWorld Chinese Commercial	0.9308	8	0.5538	11	19
2828	Grand Commercial Bank	0.9299	9	0.6588	4	13
2829	Dah An Bank	0.9099	16	0.6915	2	18
2831	Chinese Commercial Bank	0.9625	1	0.5242	15	16
2837	Cosmos Bank	0.9122	14	0.5424	12	26
2838	Union Bank of Taiwan	0.8942	21	0.5374	13	34
2839	Bank Sinopac Co. Ltd.	0.9411	3	0.5795	9	12
2840	E. Sun Commercial Bank Ltd.	0.9458	2	0.5604	10	12
2842	Fubon Commercial Bank Ltd.	0.9222	12	0.5079	18	30
2843	Asia Pacific Commercial Bank Ltd.	0.9314	7	0.6876	3	10
2844	Taishin International Bank	0.8860	24	0.7103	1	25
2845	Far Eastern International Bank	0.9004	19	0.5035	19	38
2847	Ta Chong Bank Ltd.	0.9275	11	0.3940	22	33
2849	Chung Shing Bank	0.9095	17	0.6099	7	24

Notes:
The calculation of cost efficiency follows equation (7): $CE_{it} = \cos t \;\; efficiency_{it} = \exp\left(u_{it}^{\min} - u_{it}\right)$.
The calculation of profit efficiency follows equation (9): PE_{it} = exp(-m $_{it}$).
Measures of both cost and profit efficiencies are between zero and one.

Table 7. Rankings of Cost and Profit Efficiencies Based on the Heteroskedastic SF Model: The Single-Step Estimation

Code		Cost Efficiency	Rank	Profit Efficiency	Rank	Sum of Ranks
2801	Chang Hwa Bank	0.9273	11	0.5621	15	26
2802	First Bank	0.9473	2	0.6507	6	8
2803	Hua Nan Bank	0.9446	3	0.5176	18	21
2806	International Bank of China	0.8084	23	0.4580	20	43
2808	International Bank of Taipei	0.9132	14	0.6403	8	22
2809	Medium Business Bank	0.9293	9	0.4549	21	30
2812	Taichung Commercial Bank	0.9377	6	0.4908	19	25
2815	China Trust Commercial Bank	0.8446	22	0.5854	11	33
2822	Farmers Bank of China	0.8779	20	0.2478	24	44
2824	Chiao Tung Bank	0.7398	24	0.2497	23	47
2826	United World Chinese Bank	0.8830	19	0.5535	16	35
2828	Grand Commercial Bank	0.9289	10	0.7237	4	14
2829	Dah An Bank	0.9118	15	0.7341	3	18
2831	Chinese Commercial Bank	0.9624	1	0.5633	14	15
2837	Cosmos Bank	0.9091	16	0.5848	12	28
2838	Union Bank of Taiwan	0.8921	18	0.5756	13	31
2839	Bank Sinopac Co. Ltd.	0.9399	5	0.6298	9	14
2840	E. Sun Commercial Bank Ltd.	0.9444	4	0.6121	10	14
2842	Fubon Commercial Bank Ltd.	0.9255	12	0.5326	17	29
2843	Asia Pacific Commercial Bank	0.9355	7	0.7489	2	9
2844	Taishin International Bank Co.	0.8766	21	0.7758	1	22
2845	Far Eastern International Bank	0.9029	17	0.6453	7	24
2847	Ta Chong Bank Ltd.	0.9303	8	0.4186	22	30
2849	Chung Shing Bank	0.9212	13	0.7064	5	18

Notes: Please refer to Table 2 for Bank Code.
The calculation of cost efficiency follows equation (7): $CE_{it} = \cos t \ \ efficiency_{it} = \exp\left(u_{it}^{\min} - u_{it}\right)$.
The calculation of profit efficiency follows equation (9): PE_{it} = exp(-m $_{it}$).
The measures of both cost and profit efficiencies are between zero and one.

Table 8. Empirical results of Tobit Regressions

	Dependent variable: Cost inefficiency u			Dependent variable: Profit inefficiency m			
Variable	Coefficient	t-ratio		Coefficient	Coefficient	t-ratio	
Constant	-0.2256	-2.33	**	-0.8843	-0.77	0.4437	
SIZE	0.0212	3.01	***	0.0267	0.32	0.7519	
LEV	0.0049	2.12	**	0.0199	0.91	0.3633	
BRCH	-0.0003	-2.87	***	0.0036	1.11	0.2665	
PUB	0.0087	1.12		-0.4011	-1.24	0.2144	
M2M	0.0007	0.28		0.0016	0.07	0.9429	
CAP	-0.0143	-0.90		0.0668	0.46	0.6474	
Sigma	0.0460	25.19	***	0.1487	3.95	0.0001	***

*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.
SIZE = the amount of total assets in million NT dollars;
LEV = the ratio of equity to asset of a bank in %;
BRCH = the number of branches of bank i at time t;
M2M = the M2 multiplier = M2 / base money (cf. Kaminsky and Reinhart, 1999);
CAP = Stock market capitalization to GDP.
Sigma is the parameter in the Tobit regression.