1-1-2010

Measuring technical inefficiency factors for Thai listed manufacturing enterprises: A stochastic frontier (SFA) and data envelopment analysis (DEA)

Yot Amornkitvikai
University of Wollongong, ya979@uow.edu.au

Charles Harvie
University of Wollongong, charvie@uow.edu.au

Measuring technical inefficiency factors for Thai listed manufacturing enterprises: A stochastic frontier (SFA) and data envelopment analysis (DEA)

Abstract

This study employs stochastic frontier analysis (SFA) and two-stage DEA approaches to predict firm technical efficiency and analyse an inefficiency effects model for overall Thai listed manufacturing sector enterprises including sub-listed manufacturing sector enterprises using an unbalanced panel data for 178 Thai listed manufacturing enterprises over the period 2000 to 2008. Both estimation approaches are found to produce consistent results for overall Thai listed manufacturing sector enterprises. For sub-listed manufacturing sector enterprises both approaches empirically find quite consistent results in coefficient signs, but significance results from both estimation approaches may be different. Focusing on overall Thai listed enterprises both approaches suggest that leverage (financial constraints), executive remuneration, managerial ownership, exports, some types of listed firms (i.e., family-owned firm, foreign-owned firm, and hybrid-owned firm), and firm size have a negative (positive) and significant effect on technical inefficiency (technical efficiency).The empirical results obtained from both approaches also suggest that liquidity, external financing, and research & development (R&D) have a significantly positive (negative) effect on technical inefficiency (technical efficiency)

Keywords

Measuring, technical, inefficiency, factors, for, Thai, listed, manufacturing, enterprises, stochastic, frontier, SFA, data, envelopment, analysis, DEA

Disciplines

Business | Social and Behavioral Sciences

Publication Details

Amornkitvikai, Y. & Harvie, C. (2010). Measuring technical inefficiency factors for Thai listed manufacturing enterprises: A stochastic frontier (SFA) and data envelopment analysis (DEA). Australian Conference of Economists (pp. 1-29). Sydney: Economic Society of Australia.

Measuring Technical Inefficiency Factors for Thai Listed Manufacturing Enterprises:

A Stochastic Frontier (SFA) and Data Envelopment Analysis (DEA)

Yot Amornkitvikai* Charles Harvie**

Abstract

"This study employs stochastic frontier analysis (SFA) and two-stage DEA approaches to predict firm technical efficiency and analyse an inefficiency effects model for overall Thai listed manufacturing sector enterprises including sub-listed manufacturing sector enterprises using an unbalanced panel data for 178 Thai listed manufacturing enterprises over the period 2000 to 2008. Both estimation approaches are found to produce consistent results for overall Thai listed manufacturing sector enterprises. For sub-listed manufacturing sector enterprises both approaches empirically find quite consistent results in coefficient signs, but significance results from both estimation approaches may be different. Focusing on overall Thai listed enterprises both approaches suggest that leverage (financial constraints), executive remuneration, managerial ownership, exports, some types of listed firms (i.e., family-owned firm, foreign-owned firm, and hybrid-owned firm), and firm size have a negative (positive) and significant effect on technical inefficiency (technical efficiency).The empirical results obtained from both approaches also suggest that liquidity, external financing, and research & development (R&D) have a significantly positive (negative) effect on technical inefficiency (technical efficiency)"

Keywords: Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA), Technical Efficiency, Thailand

***** PhD Candidate, School of Economics, University of Wollongong, Australia

Email: ya979@uow.edu.au

** Associate Professor

Director, Centre for Small Business and Regional Research

School of Economics, University of Wollongong, Australia

Email: Charvie@uow.edu.au

I. Introduction

In recent years, Thailand has faced a real challenge of sustaining its growth and escaping from its middle income trap (World Bank Office -Thailand, 2008). For Thailand to transition to higher income and quality growth in the long term, measures to improve productivity and competitiveness over the long term in all sectors (agriculture, industry, and services) are urgently needed. The manufacturing sector has been one of the most important sectors in the East and Southeast Asian countries. Economic growth in this region since the early 1980s has arisen primarily from the rapid expansion in manufacturing exports (Jongwanich, 2007). Moreover, the major problems causing firm-level inefficiency could be obviously observed from the 1997 Asian Financial Crisis. The Crisis highlighted problems of lack of transparency in corporate governance and a corrupt and mismanaged banking system (i.e., excessive lending to non-productive assets, lack of adequate debt monitoring) among the crisis-affected countries in South East Asia as well as Thailand.

The problem of weak corporate governance was related to, for example, the dominance of controlling shareholders, the separation of voting and cash flow rights (or the disparity between control and ownership), and the limited protection of minority rights (Claessens et al., 2000). Not only the inefficient environmental factors discussed above caused manufacturing inefficiency in Thailand but firm-specific factors (i.e., inadequate firm size, lack of business experience, lack of research and development (R&D) investment, inefficient managerial skills, lack of internal competition, and lack of external competition or lack of learning-by-exporting experience) also affected the inefficiency performance of Thai listed manufacturing firms. After the 1997 Asian financial crisis the corporate governance system was strengthened in Thai capital markets, such as through enhancing the institutional framework for accounting and auditing practices, improving the disclosure practice of listed companies, encouraging best practices for directors of listed companies, and relaxing foreign ownership controls (East Asia Analytical Unit, 2000, Talerngsri and Vonkhorporn, 2005, Sally, 2007). However, these environmental and firm-specific factors that affect firm inefficiency have not been empirically examined for Thai listed manufacturing enterprises. This paper aims to fill this gap, and is organized as follows: Section II provides a review of the literature. Sector III describes data sources and data classification. Section IV presents empirical models which consist of the stochastic frontier analysis (SFA) and the two-stage data envelopment analysis (DEA) approaches. Hypothesis tests are analysed in Section V. The empirical results of both approaches are provided and discussed in Section VI. Some conclusions and implications are also provided in the final section.

II. Literature Review

Very few empirical studies have examined the effect of leverage (financial constraints) on a firm's technical efficiency (Dilling-Hansen et al., 2003, Sena, 2006, Mok et al., 2007, Weill, 2008). Sena (2006) and Mok et al. (2007) used the leverage ratio represented by the ratio of total debt to total assets (the D/A ratio) to investigate the effect of financial constraints on firm technical efficiency. This debt ratio captures how much a firm is constrained in its expansion. Their empirical results revealed that firms with high leverage tend to experience a decrease in their technical efficiency. This was confirmed by Goldar et al. (2003) who applied the quick ratio $[(\text{current assets} - \text{inventory})/\text{current liabilities}]$ to examine the importance of the liquidity of Indian engineering firms on their technical efficiency, and found that liquidity has a significantly negative effect on firm technical efficiency. There are a number of theoretical studies focusing on the relative efficiency of internal versus external financing (Jensen, 1986, Gertner et al., 1994, Stein, 1997), the conclusions from which are still controversial. Gertner et al. (1994) and Stein (1997) supported that a firm's capital is allocated more efficiently through internal rather than external financial resources, since internal financing can increase monitoring incentives, decrease entrepreneurial incentives, and result in better asset allocation. However, Jensen (1986) argued that internal financing causes an agency problem, since managers have the opportunity to abuse internal funds, and they can easily mobilize internal funds to maximize their own interests and lack the desire or necessity to maximize shareholders' interests due to the lack of external monitoring from banks or financial institutions. Empirical studies have also revealed inconclusive results. For example, Gökçekus (1995) found no significant effects of the relative efficiency of internal versus external financial resources on a firm's technical efficiency for the Turkish rubber industry. Kim (2003) used the ratio of total interest payments on borrowed capital to total capital as a proxy for external financing. He found that this has a positive effect on a firm's technical efficiency. Focusing on research and development (R&D) a number of empirical studies have found that R&D has a positive effect on a firm's technical efficiency (Aw and Batra, 1998, Kim, 2003, Dilling-Hansen et al., 2003, Sheu and Yang, 2005). Kim (2003) found that the ratio of R&D spending to total output has a significant positive association with a firm's technical efficiency for the textile and chemical industries, but such a relationship was not found in the fabrication industry. Sheu and Yang (2005) also found that R&D, as measured by annual R&D expenditure deflated by the general Wholesale Price Index (WPI), positively influences technical efficiency in Taiwan's electronics industry.

Ownership structure is also one of the important firm-specific factors affecting a firm's performance. A number of empirical studies have examined the effect of controlling ownership on a firm's performance based on accounting or financial measures (Demsetz and Lehn, 1985, McConnell and Servaes, 1990, Leech and Leahy, 1991, Wiwattanakantang, 2001, Yammeesri and Lodh, 2003, Zeitun and Tian, 2007), but their empirical results are still inconclusive. There are both costs and benefits associated with controlling ownership. The presence of controlling ownerships (shareholders with large stakes) can deteriorate firm performance, since the interest of controlling shareholders may not align with those of non-controlling shareholders (Shleifer and Vishny, 1997, Bebchuk et al., 1999). There is a possibility that large shareholders may conduct corrupt activities. On the other hand, according to agency theory, controlling shareholders are likely to perform better than dispersed shareholders, since a high level of ownership concentration can reduce agency costs. In the case of Thailand, Wiwanttanakantang (2001) and Yammeesri and Lodh (2003) found that controlling ownership is positively associated with a firm's performance, as evaluated by accounting or financial measures.

Similarly, managerial ownership[1] can help align the conflict of interests between shareholders and managers (Jensen and Meckling, 1976). If managers' interests coincide more closely with those of shareholders, the conflicts between managers and shareholders are alleviated. Very few empirical studies have examined the effect of managerial ownership on a firm's technical efficiency (see Liao et al. (2010)). Liao et al. (2010) calculated the percentage of equity owned by managers and the percentage of equity owned by the board, and examined the effects of these variables on a firm's technical efficiency as measured by a two-stage DEA. Their results found that managerial and board equities are positively related with a firm's technical efficiency, but their results are not statistically significant. In addition,

[1] Managerial ownership is defined as being the owner manager (Jensen and Meckling, 1976, p.56).

very few empirical studies examined the effect of executive remuneration on a firm's technical efficiency. Baek and Pagán (2003) conducted a stochastic frontier analysis (SFA) to measure a firm's technical efficiency, and found that the level of CEO total compensation is positively associated with a firm's technical efficiency for S&P 1,500 firms.

Focusing upon different types of firm ownership a number of empirical studies have also found a positive association between foreign ownership and technical efficiency (Fukuyama et al., 1999, Goldar et al., 2003, Bottasso and Sembenelli, 2004). Empirical studies focusing upon the relationship between family ownership and firm performance have been examined in the finance literature, but very few studies linked family ownership with a firm's technical efficiency. Lauterbach and Vaninsky (1999) used dummy variables for family and partnership ownership to examine the effect of family and partnership ownership on a firm's technical efficiency, conducted using the two-stage DEA approach. Their results revealed a significantly negative association between family and partnership ownership and firm technical efficiency for 280 Israeli firms. In the case of Thailand, Wiwattanakantung (2001) and Yammeesri and Loadh (2003) investigated the effect of family ownership on a firm's performance based on accounting or financial measures. Both studies, however, used a cut-off shareholding level of at least 25 percent for Thai listed enterprises, since shareholders must have at *least 75 percent* of their voting rights to obtain the absolute power over the public limited firm due to the Public Limited Companies Act B.E. 2535 of Thailand (Section 31).

A number of empirical studies have also investigated the effect of export participation on a firm's technical efficiency (the learning-by-exporting hypothesis). Kim (2003) used the ratio of exports to total revenues as a proxy for export intensity, and found that exports positively affect technical efficiency for the food and paper industries, but such a finding is not found in the textile, chemical, and fabrication industries for Korean manufacturing industries. Dilling-Hansen et al. (2003) used a dummy variable for exports, but found no effect of exports on firm technical efficiency for 2,370 Danish firms. Granér and Isaksson (2007) used a dummy variable as a proxy for export participation, and found that exports significantly increased the technical efficiency of Kenyan manufacturing firms. Many empirical studies have also investigated the effect of firm size on a firm's performance based on a firm's technical efficiency. Their results are quite varied being based on different countries and sectors. Empirical studies have also used different proxies for firm size, which can be represented as either (i) total assets (see Kim (2003), Sheu and Yang (2005), Liao et al (2010)), (ii) the number of employees (see Bottasso and Sembenelli (2004)), and (iii) intermediate inputs (see Lundvall and Battese (2000), Hossain and Karunaratne (2004), Oczkowski and Sharma (2005)).

III. Data Sources and Data Classification

Data Sources

The raw data used in this study was obtained from the Stock Exchange of Thailand. In this study, annually consolidated financial reports are used, since all business activities of listed firms including their subsidiary companies are recorded in annually consolidated financial reports. Form 56-1 is an annual company report required by the Securities and Exchange Commission (SEC), where all Thai listed firms are obligated to disclose their annual business performance for shareholders and investors. Form 56-1 consists of three main parts: (i) executive summary, (ii) company issuing securities, and (iii) confirmation of accuracy. Part (ii) is used for this study.

Data Classification

This study classifies manufacturing listed firms from among listed firms into eight industrial sectors. The SET's eight industrial sectors consist of (1) Agro and Food Industry, (2) Consumer Products, (3) Financials, (4) Industrials, (5) Property and Construction, (6) Resources (energy & utilities), (7) Services, and (8) Technology. With regard to International Standard Industrial Classification of all economic activities (ISIC), it is necessary to remove some listed firms that are not classified as manufacturing firms. In addition, this study also includes listed manufacturing firms that had been delisted from the SET during 2000 to 2008. As a result, 178 listed manufacturing firms over the period 2000 to 2008 will be used to conduct the empirical analysis of this study, which can be summarized in Table 1.

IV. Empirical Models

The Stochastic Frontier Analysis (SFA) and the two-stage Data Envelopment Analysis approaches are used to conduct the empirical analysis. The differences between the SFA and the DEA approaches are that the SFA requires functional forms on the production frontier, and assumes that firms may deviate from the production frontier not only due to technical inefficiency but also from measurement errors, statistical noise or other non-systematic influences (Admassie and Matambalya, 2002). In addition, the SFA requires strong distribution assumptions of both statistical random errors (i.e., normal distribution) and non-negative technical inefficiency random variables (i.e., half-normal distribution for time-invariant inefficiency model (see Pitt and Lee (1981)), and truncated normal distribution for both the time-invariant inefficiency model (see Battese and Coelli (1988)) and the time-variant inefficiency model (see Battese and Coelli (1992,1995)). The DEA approach, however, does not impose functional forms, and uses linear programming to construct a frontier that envelops the observations of all firms. Hence, all firms are compared relative to the "best" performing firms. It also overcomes restrictions on the production and distribution of various residuals.

The Stochastic Frontier Production Function Model

This study follows the model of Battese and Coelli (1995) which allows technical efficiency levels to change over time. The model consists of two main components. The first component is to estimate the time-varying stochastic frontier production function which contains two random errors: (i) random errors (V_{its}) and non-negative random variables (U_{its}). The first random errors, which are assumed to be independently and identically distributed normal random variables with zero means and variances, σ_v^2 ($V_{it} \sim iid\ N(0, \sigma_v^2)$), can be observed, for example, when the problems of omitted variables and model misspecification arise. The second non-negative random variables which are assumed to be independently and identically distributed normal random variables as truncations at zero with $Z_{it}\delta$ means and variances σ_u^2 ($U_{it} \sim iid\ N(0, \sigma_u^2)$) are known as the technical inefficiency effects. In addition, these two random variables are assumed to be independently distributed for all time periods (t=1,2,…..,T) and all firms (i=1,2,….,N).

The second component links firm-specific variables (i.e., types of firm ownership, firm age, and firm size) with the inefficiency effects or non-negative random variables. In other words, this part aims to examine what firm-specific variables significantly affect the firm's inefficiency. The stochastic frontier production function and the inefficiency effects will be simultaneously estimated by the method of maximum likelihood (ML) which has desirable large sample (or asymptotic) properties. More specifically, the ML estimator is consistent and asymptotically efficient (Coelli, 2005, p. 218). FRONTIER Version 4.1 is used to conduct a single - step process in which the stochastic frontier production and the model of technical inefficiency effects are estimated simultaneously by the method of maximum likelihood estimation (Quasi-Newton methods) (see Coelli (1996)). This software utilizes the parameterisation from Battese and Corra (1977) by replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\Upsilon = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$. The technical inefficiency for the i^{th} firm in the Battese and Coelli (1995) model is given by TE_{it} = exp (- U_{it},) = exp (-$Z_{it}\delta$ - W_{it}). Applying the model of Battese and Coelli (1995), the stochastic frontier production functions in the Cobb-Douglas and translog functional forms are tested for adequate functional form. The Cobb-Douglas functional form can be written as:

$$Ln(Y_{it}) = \beta_0 + \beta_1 \ln(L_{it}) + \beta_2 \ln(K_{it}) + \beta_3 \ln(IM_{it}) + \beta_4 (t) + V_{it} - U_{it} \qquad (1.1)$$

The translog functional form can be written as:

$$Ln(y_{it}) = \beta_0 + \beta_1 \ln(L_{it}) + \beta_2 \ln(K_{it}) + \beta_3 \ln(IM_{it}) + \beta_4 (t) + \frac{1}{2}\beta_5 \ln(L_{it}^2) + \frac{1}{2}\beta_6 \ln(K_{it}^2) + \frac{1}{2}\beta_7 \ln(IM_{it}^2) + \frac{1}{2}\beta_8 (t^2) + \beta_9 \ln(L_{it}) * \ln(K_{it}) + \beta_{10} \ln(L_{it}) * \ln(IM_{it}) + \beta_{11} \ln(L_{it}) * \ln(t) + \beta_{12} \ln(K_{it}) * \ln(IM_{it}) + B_{13}(K_{it}) * (t) + B_{14}(IM_{it}) * (t) + V_{it} - U_{it} \qquad (1.2)$$

Where:

Y_{it} = Sales revenue deflated by the manufacturing Producer Price Index (PPI) of firm *i* at time *t*

L_{it} = Employee expenses deflated by the manufacturing Producer Price Index (PPI) of firm *i* at time *t*

K_{it} = Net productive fixed assets deflated by the Producer Price Index (PPI) of capital goods of firm *i* at time *t*

IM_{it} = Intermediate inputs deflated by the Producer Price Index (PPI) of intermediate inputs of firm *i* at time *t*

V_{it} = Random error ($V_{it} \sim N(0, \sigma_V^2)$)

U_{it} = Non-negative random variable (or technical inefficiency) ($U_{it} \sim N(\mathrm{Z_{it}}\delta, \sigma_u^2)$)

The Inefficiency Effects Model can be written as follows:

$$U_{it} = \sigma_0 + \sigma_1 LEV_{it} + \sigma_2 LIQ_{it} + \sigma_3 INF_{it} + \sigma_4 EXF_{it} + \sigma_5 EXC_{it} + \sigma_6 TOP5_{\ it} + \sigma_7 MGR_{it} + \sigma_8 EXP_{it} + \sigma_9 R\&D_{it} + \sigma_{10} FAM_{it} + \sigma_{11} FGR_{it} + \sigma_{12} DOM_{it} + \sigma_{13} HYD_{it} + \sigma_{14} SIZE_{it} + \sigma_{15} AGE_{it} + \sigma_{16} GOVT_{it} + \sigma_{17} FCO_{it} + W_{it} \quad (1.3)$$

Where:

LEV_{it} = Leverage of firm *i* at time *t*, represented by the ratio of total debt to total assets (the D/A Ratio)

LIQ_{it} = Liquidity of firm *i* at time *t*, represented by the ratio of current assets to current liabilities (the Current Ratio)

INF_{it} = Dummy for internal financing;
INF_{it} = 1 if firm *i* at time *t* borrows from related parties.
= 0, otherwise

EXF_{it} = External financing, represented by total interest expenses deflated by the general Producer Price Index (PPI)

EXC_{it} = Executive Remuneration of firm *i* at time *t*, represented by the ratio of top executive and board member remunerations to total employee expenses

$TOP5_{\ it}$ = Controlling ownership of firm *i* at time *t*, represented by the percentage of equity owned by the five largest shareholders

MGR_{it} = Managerial ownership of firm *i* at time *t*, represented by top executives and board members

EXP_{it} = Exports of firm *i* at time *t*, represented by the ratio of export revenue to total sales revenue

$R\&D_{it}$ = Dummy for Research and Development:
$R\&D_{it}$ = 1 if firm *i* at time *t* has R&D.
= 0, otherwise

FAM_{it} = Dummy for a family-owned firm:
FAM_{it} = 1 if firm *i* at time *t* is a family-owned firm.
= 0, otherwise

FGR_{it} = Dummy for a foreign-owned firm:
FGR_{it} = 1 if firm *i* at time *t* is a foreign-owned firm.
= 0, otherwise

DOM_{it} = Dummy for a domestic-owned firm:

DOM_{it} = 1 if firm *i* at time *t* is a domestically-owned firm.

= 0, otherwise

HYD_{it} = Dummy for a hybrid-owned firm

HYD_{it} = 1 if firm *i* at time *t* is a hybrid-owned firm.

= 0, otherwise

$SIZE_{it}$ = Size of firm *i* at time *t*, represented by the logarithm form of total assets

AGE_{it} = Age of firm *i* at time *t*, represented by the number of operating years

$GOVT_{it}$ = Dummy for Government support

$GOVT_{it}$ = 1 if firm *i* at time *t* receives Board of Investment (BOI) support.

= 0, otherwise

FCO_{it} = Dummy for foreign cooperation

FCO_{it} = 1 if firm *i* at time *t* engages in foreign cooperation

= 0, otherwise

W_{it} = Random error (($W_{it} \sim N(0, \sigma_W^2)$))

Basic descriptive statistics for all the variables mentioned above are provided in Appendix 1.

Two-stage Data Envelopment Analysis (DEA)

The non-parametric Data Envelopment Analysis (DEA) can also be used to predict technical efficiency, which involves the use of a linear programming method to construct a non-parametric piece-wise surface (or frontier) over the data (Coelli et al., 2005, p.162). This study applies the variable returns to scale (VRS) linear programming problem to predict the technical efficiency for the first-stage of the two-stage DEA approach (see Färe, Grosskopf, Logan (1983) and Banker, Charnes, and Cooper (1984)). The VRS assumes that firms are not operating at an optimal scale due to imperfect competition, government intervention, and financial constraints (Coelli et al., 2005). In addition, the output orientated model is used, assuming fixed input amounts and maximized output production. The VRS linear programming program under the output orientated model can be written as follows:

$$\begin{aligned} & Max_{\varphi,\lambda} \quad \varphi, \\ \text{st} \quad & -\varphi q_i + Q\lambda \geq 0, \quad \text{i=1,2,….,n}, \\ & x_i - X\lambda \geq 0, \\ & \text{I}1'\lambda \leq 1, \\ & \lambda \geq 0, \end{aligned} \quad (1.4)$$

Where: $\boldsymbol{\varphi}$ is a scalar. $1 \leq \varphi < 0$, and $\boldsymbol{\varphi - 1}$ is the proportional increase in outputs (q_i) which can be obtained for the i^{th} firm, while holding input amounts (x_i) constant. $\frac{\mathbf{1}}{\boldsymbol{\varphi}}$ is the efficiency score for the i^{th} firm. $\boldsymbol{q_i}$ is an output vector for the i^{th} firm. $\boldsymbol{x_i}$ is an input vector for the i^{th} firm. $\boldsymbol{\lambda}$ is a vector of constants. $\mathbf{I1'}\boldsymbol{\lambda} \leq \mathbf{1}$ defines non-increasing returns to scale (NIRS).

The DEA model in linear programming (1.4) also replaces the convexity constraint which is imposed for the VRS: $\text{I}1'\lambda = 1$[2] for $\text{I}1'\lambda \leq 1$. The modified $\text{I}1'\lambda \leq 1$ indicates that the VRS can only be non-increasing. In other words, the constraint: $\text{I}1'\lambda \leq 1$ is set to ensure that the i^{th} firm is compared with firms that are smaller than it (see Coelli et al. (2005, p.174)). The second stage of the two-stage DEA model is conducted by regressing environmental variables on the firm's VRS technical inefficiency scores which are predicted from the first step of the two-stage DEA model. The firm's technical inefficiency scores are used as the dependent variable, which is obtained by subtracting the efficiency scores estimated from the DEA model from "one". The set of environmental variables are used as independent variables for the two-stage DEA model. The estimated inefficiency scores are normally bounded between zero and one. Applying the method of Ordinary Least Squares (OLS) with such a dependent variable that its values are bounded between zero and one will lead to biased and inconsistent estimators, since the OLS method is likely to predict inefficiency scores which are greater than one (Coelli et al., 2005). Therefore, the Maximum Likelihood estimation for a Tobit model is adopted, which is given as follows:

$$(1\text{-}\theta_{it}) = \sigma_0 + \sum_{j=1}^{j=17} \sigma_{jt}\, z_{jt} + \varepsilon_{it} \qquad (1.5)$$

Where:

$1\text{-}\theta_{it}$ = Inefficiency scores of firm *i* and time *t*.

σ_j = Unknown parameter to be estimated for each environmental variable *j* and time *t*

ε_{it} = Random error $((\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2))$

[2] This convexity constraint is set to ensure that an inefficient firm is only "benchmarked" against other firms which have a similar size (see Coelli et al. (2005, p. 172)).

V. Hypothesis Tests

There are a number of null hypotheses for the SFA approach that will be tested (see Table 2). A likelihood-ratio test (LR test) is used to test these hypotheses, which can be conducted as follows:

$$\lambda = -2\{\log[L(H_0)] - \log[L(H_1)]\} \quad (1.6)$$

Where, $\log[L(H_0)]$ and $\log[L(H_1)]$ are obtained from the maximized values of the log-likelihood function under the null hypothesis (H_0) and the alternative hypothesis (H_a), respectively. From Table 2 the null hypothesis (i) is to test whether the Cobb-Douglas production function is adequate for the SET's manufacturing sector including all sub-manufacturing sectors. Following equations (1.1) and (1.2) the null hypothesis ($H_0 : \beta_{LL} = \beta_{KK} = \beta_{MM} = \beta_{TT} = \beta_{LK} = \beta_{LM} = \beta_{LT} = \beta_{KM} = \beta_{KT} = \beta_{MT} = 0$) is strongly rejected at the 5 percent level of significance. Therefore, the Cobb-Douglas production function is not an adequate specification for the case of overall Thai listed manufacturing sector including all SET's sub-manufacturing sectors, compared with the specification of the Translog production function model. This also indicates that input and substitution elasticities are not constant among firms (see Lundvall and Battese, 2000). The null hypothesis (ii) that there is no technical progress $(H_0 : \beta_T = \beta_{TT} = \beta_{LT} = \beta_{KT} = \beta_{MT} = 0)$ is rejected at the 5 percent level of significance for the SET's manufacturing sector including most sub-manufacturing sectors, except Agro & Food Industry in which technical progress is not found in this sub-manufacturing sector. Under the translog specification technology for (1.2), the percentage change in output in each period due to technological change (t) is given by $\frac{\partial lny}{\partial t} = \theta_1 + 2\theta_2$ t (see Coelli et al., 2005).

From Table 3 technological change affects the percentage change to output by *0.091+2* (-0.05)* t* for overall Thai listed manufacturing enterprises. The slope of θ_2 [3] in the translog production function (1.2) is negative, which is given by -0.05, also indicating that technological progress tends to decrease over time for overall Thai listed manufacturing enterprises. Similarly, technical progress is likely to decrease for Consumer Products and Other Sectors, except Industrials. The null hypothesis (iii) that technical progress is neutral

[3] The coefficient θ_2 is not statistically significant at the 5 percent level of significance.

(H_0 : $\beta_{LT} = \beta_{KT} = \beta_{MT} = 0$) is also rejected at the 5 percent level of significance for the SET's manufacturing sector including other sub manufacturing sectors such as Consumer Products, Industry, and Other Sectors. This indicates that technical change not only merely affects average output, but also changes marginal rates of technical substitution[4]. The null hypothesis (iv) which specifies that the inefficiency effects are absent from the model ($\gamma = \delta_0 = \delta_1 \ldots = \delta_{17} = 0$) is strongly rejected at the 5 percent level of significance, which implies that the model of inefficiency effects exists for the case of the SET's manufacturing sector including all sub-manufacturing sectors. The null hypothesis (v) that the inefficiency effects are not "stochastic" ($\gamma = 0$) is strongly rejected, implying that the model of inefficiency effects is not reduced to a traditional mean response function[5]. In addition, if the estimate of the variance parameter (γ) is close to one, it indicates that overall residual variation ($U_{it}s$ and $V_{it}s$) highly results from inefficiency components ($V_{it}s$).

From Table 3 the estimated γ (0.872) is high for the SET's manufacturing sector[6], indicating that much of the variation in the composite error term is due to inefficiency effects ($V_{it}s$). The last null hypothesis specifies that inefficiency effects are not a linear function of all explanatory variables ($H_0 : \delta_1 = \delta_2 = \cdots = \delta_{16} = \delta_{17} = 0$). All LR test statistics are greater than the critical value of an approximately chi-square distribution (see Table 2) at the 5 percent level of significance, implying that the null hypothesis that all coefficients of the explanatory variables are equal to zero is strongly rejected at the 5 percent level of significance for the SET's manufacturing sector including all sub-manufacturing sectors. According to the rejection of the last null hypothesis test, the model of inefficiency effects of the SET's manufacturing sector as well as sub-manufacturing sectors can be assumed to be independently and identically distributed as truncations at zero of the normal distribution with mean, $Z_{it}\delta$ and variance, σ_u^2 (see Battese and Coelli (1995)). For the two-stage DEA model the null hypothesis that all parameters of the explanatory variables are equal to zero is also rejected at the 5 level of significance (see Table 4). In addition, the majority of the estimates

---

[4] The marginal rate of substitution is not dependent on time, indicating that *Hicks* neutral technology does not exist for the SET's manufacturing sector including Consumer Products, Industry, and Other Sectors.

[5] All the explanatory variables in the inefficiency effects model are not included in the production function, implying that the inefficiency effects model exists and therefore the estimated parameters can be identified in the model of inefficiency effects.

[6] Similarly, the estimated γs are also high, which are given by 0.690, 0.995, and 0.697 for Agro & Food Industry, Consumer Products, and Other Sectors, respectively, except Industrials ($\gamma = 0.271$).

of the Translog production frontier parameters are statistically significant at the 5 percent level of significance for the SET's manufacturing sector including sub-manufacturing sectors (see Table 3). It is also common to observe that some of the individual coefficients of the Translog stochastic frontier are not statistically insignificant due to high multicollinearity among the inputs (see Lundvall and Battese (2000), Oczkowski and Sharma (2005)).

VI. Consistency of the Results from Data Envelopment Analysis and Stochastic Frontier Analysis

The empirical results between the two-stage DEA and the SFA are quite consistent (see Table 6). The average technical efficiency scores for Thai listed manufacturing enterprises predicted by the SFA and the DEA are 0.812 and 0.887, respectively (see Appendix 2)[7]. The technical efficiency scores obtained from the SFA should be normally lower than those scores obtained from the DEA, since the technical efficiency scores predicted by the DEA does not separate the non-negative technical inefficiency components (V_{its}) from the systematic errors (u_{it}). However, if the estimated γ is close to 1 this implies that the error variation is mainly due to inefficiency effects. The technical efficiency scores are undoubtedly smaller for SFA than those scores obtained from DEA (see Sirasoontorn, 2004). The empirical results from both estimation approaches also reveal that Thai listed manufacturing enterprises operated under decreasing returns to scale over the period 2000 to 2008. The DEA approach indicates that approximately 86% of Thai listed manufacturing firms, on average, had operated under decreasing returns to scale (DRS) during the period 2000 to 2008, given the specification of the output-orientated model (see Appendix 3). Similarly, the input elasticities given by 0.545 (β_1+β_2+β_3)[8] indicates the existence of moderate decreasing returns to scale for Thai listed manufacturing enterprises (see Table 3). The empirical results of both the SFA and the two-stage DEA approaches are found to produce quite consistent results as summarized in Table 6. Both approaches confirm that leverage (financial constraints) has a significantly positive effect on the firm's technical efficiency for the SET's manufacturing sector including Consumer Products, but such a significantly negative result is found for the Agro & Food Industry and Other Sectors.

---

[7] In addition, the technical efficiency scores predicted by the SFA and the DEA for Agro & Food Industry, Consumer Products, Industrials, and Other Sectors are given by 0.843 and 0.889, 0.767 and 0.854, 0.830 and 0.911, and 0.791 and 0.883, respectively (see Appendix 2).

[8] The coefficientsβ_1 and β_2 are statistically significant at the 5 percent level of significance, but β_3 is not statistically significant.

Significant and positive results imply that financially constrained firms tend to utilize their financial resources and control input costs effectively, leading to an enhancement in their technical efficiency. To confirm this conclusion, both estimation approaches reveal that a firm's leverage is found to be significantly negatively related with the technical efficiency for the SET's manufacturing sector including Consumer Products and Industrials. The empirical evidence from both approaches also confirms that external financing has a significantly negative relationship with a firm's technical efficiency for the SET's manufacturing sector including Industrials. Positive evidence is also found in Consumer Products and Other Sectors, except for a difference in the significance of the results from both approaches. A positive result is also found in the Agro & Food Industry, but empirical results from both approaches are found to be statistically insignificant at the 5 percent level of significance. However, the relationship is weak due to the small size of the external financing coefficients (close to zero) for overall SET's manufacturing sector, including all sub-manufacturing sectors. In addition, "internal financing" is also found to have a negative effect on a firm's technical efficiency for the SET's manufacturing sector including Agro & Food Industry and Consumer Products, except for a difference in the significance of the results for both approaches. A negative result implies that an agency problem exists from the use of internal funds, since managers do not appear to maximize shareholders' interests or have strong incentives to abuse internal funds. This is especially the case in underdeveloped countries where firms' managerial rights are not fully developed and their information is not fully disclosed, and therefore managers attempt to maximize their benefits rather than the firm's value (Kim, 2003, p.134).

The coefficient for "executive remuneration" from both approaches is found to be significantly positive in the SET's manufacturing sector including Consumer Products. A positive effect is also found in the Agro & Food Industry, except the significance results from both approaches are statistically different. A positive result implies that listed manufacturing firms with higher levels of executive remuneration tend to have more technical efficiency. According to the finance literature regarding ownership structure, the empirical results from both approaches confirm that managerial ownership has a significantly positive relationship with the firm's technical efficiency for the SET's manufacturing sector and Industrials. A positive result is also found in the Agro & Food Industry but the significance of the results from both approaches are statistically different. A positive result indicates that the agency problem is reduced, since managerial ownership can help align the conflict of interests between shareholders and managers.

Controlling ownership is also found to have a positive association with firm technical efficiency for the SET's manufacturing sector including Consumer Products, Industrials, and Other Sectors, but the significance of the results from both approaches are statistically different. A positive result supports agency theory that controlling shareholders are likely to perform better than dispersed shareholders, since a high level of ownership concentration can reduce agency costs. Exporting is also found to be significantly positively related with firm technical efficiency for the SET's manufacturing sector. Such a positive relationship is also found in the Agro & Food Industry, Industrials and Other Sector, but the significance of these results from both approaches are statistically different. A positive result implies that export market experience (i.e., new product designs and production methods), which is gained from communication between foreign partners and exporting firms, tends to improve the technical efficiency of exporting firms. Results from both estimation approaches reveal that research & development (R&D) has a significant and negative impact on firm technical efficiency for the SET's manufacturing sector including Consumer Products. Such a negative finding also implies that most listed manufacturing firms doubtfully reported their R&D activities in their annual report, and in fact did not intend to implement them seriously.

Focusing on the classification of different ownership types among listed manufacturing firms the results from both approaches indicate that family-owned firms have a significantly positive impact on firm technical efficiency for the SET's manufacturing sector including Consumer Products, but a significantly positive relationship is found in the industrials sector. A positive result is also found in Other Sectors, but the significance of these results for both approaches are statistically different. The empirical evidence from both approaches reveals that foreign-owned firms have a significant and positive effect on firm technical efficiency for the SET's manufacturing sector including Consumer Products. A positive result is also found for the Agro & Food Industry sector, but the significance of these results for both approaches are statistically different. Domestically-owned firms are found to have a positive impact on firm technical efficiency for the SET's manufacturing sectors, but the significance of these results for both approaches are statistically different. Domestic-owned firms, however, have a significant and negative relationship with firm technical efficiency for Industrials and Other Sectors. Hybrid-owned firms are found to have a significant and positive relationship with firm technical efficiency for the SET's manufacturing sector. The positive relationship is also found in Agro & Food Industry and Consumer Products, but significance results from both approaches are statistically different. Joint-owned firms as indicated by the constant coefficient are found to have a significantly negative relationship with firm technical efficiency for the SET's manufacturing sector including almost all sub-manufacturing sectors, except for Other Sector where both approaches report a positive coefficient but there is a difference in the significance results. For all Thai listed manufacturing enterprises foreign-owned firms perform the best among other types of owned firms, followed by family-owned firms, hybrid-owned firms, and domestic-owned firms, given joint-owned firms as the base firm. Moreover, there is strong evidence from both estimation approaches that a firm's size tends to have a statistically positively effect on its technical efficiency for the SET's manufacturing sector, including almost all sub-manufacturing sectors.

VII. Conclusions and Implications

This study has applied the stochastic frontier analysis (SFA) and two-stage Data Envelopment Analysis (DEA) approaches. Dealing with unbalanced panel data Frontier Version 4.1 can be used to analyse the time-variant efficiency model of Battese and Coelli (1995). The advantage of the stochastic frontier analysis (SFA) approach under the specification of Battese and Coelli (1995) is that it allows investigation of technical progress through an estimated production function. For the DEA approach the investigation for technological progress can be referred, for example, to the use of a Malmquist TFP index which can be decomposed into "*technical efficiency change*" and "*technological change*". A Malmquist TFP index analysed by DEA, however, can only be applied for the case of balanced panel data. The SFA approach can investigate types of returns to scale for the industry-level context through an aggregate of estimated input elasticities (See Coelli et al., 2005, p. 304**),** but the DEA approach can examine types of returns to scale for the firm-level context. The significance coefficients of time interacted with capital (β_{11}) and labour(β_{13}) for all manufacturing enterprises are negative and positive, respectively, indicating that technical change has been labour-using but capital-saving (see Table 3). This result implies that technological progress for Thai listed manufacturing firms still relies on basic production resources, such as labour input. In addition, the negative coefficient of time squared (β_8) also confirms that the technological change of Thai listed manufacturing enterprises has decreased over the period 2000 to 2008 (see Table 3). The empirical results from both estimation approaches are found to produce consistent results. For sub-listed manufacturing sectors both approaches empirically find quite consistent results in coefficient signs, but significance results from both estimation approaches may be different (see Table 6).

According to the empirical evidence from these two approaches, industry-specific policy guidelines are also recommended to promote technical efficiency for Thai listed manufacturing enterprises. First, policy guidelines can be implemented as follows: (i) promote more firm ownership participation for a group of people (i.e., workers, administrative staff, managers, and owners who control or participate in listed manufacturing firms, and encourage listed manufacturing firms to set up attractive rewards for top management and board of directors when firms achieve a certain level of profits as planned; (ii) encourage more foreign participation in listed manufacturing firms; (iii) encourage listed manufacturing firms to engage in more export participation; (iv) promote an increase in firm size; (v) encourage listed manufacturing firms to fully disclose the use of financial resources; (v) encourage listed manufacturing firms to enhance labour skills or focus on more sophisticated technology.

Table 1: Classification of Listed Manufacturing Firms in the SET during 2000 to 2008

No of sectors	Manufacturing Sectors	No of firms	No of firms
1	Agro & Food Industry		
	1.1 Agribusiness	20	
	1.2 Food & Beverage	20	
	Total		**40**
2	Consumer Products		
	2.1 Fashion	18	
	2.2 Home & Office Products	11	
	2.3 Personal Products & Pharmaceuticals	4	
	Total		**33**
3	Industrials		
	3.1 Automotive	12	
	3.2 Industrial Materials & Machinery	19	
	3.3 Packaging	13	
	3.4 Paper & Printing Materials	2	
	3.5 Petrochemicals & Chemicals	13	
	Total		**59**
4	Publishing		**7**
5	Construction Materials		**27**
6	Technology (Computer components)		**12**
	Total listed manufacturing firms		**178**

Source: Authors

Table 2: Statistics for Hypotheses Tests of the Stochastic Frontier and Inefficiency Models for the SET's Manufacturing Sectors

Null Hypothesis	All manufacturing			Agro & Food Industry			Consumer Products			Industrials			Other Sectors**		
	LR Statistics	Critical Value	Decision	LR Statistic	Critical Value	Decision	LR Statistics	Critical Value	Decision	LR Statistics	Critical Value	Decision	LR Statistics	Critical Value	Decision
Cobb-Douglas $(H_0: \beta_{LL} = \beta_{KK} = \beta_{MM} = \beta_{TT} = \beta_{LK} = \beta_{LM} = \beta_{LT} = \beta_{KM} = \beta_{KT} = \beta_{MT} = 0)$	211.94	18.31	Reject H_0	82.26	18.31	Reject H_0	104.31	18.31	Reject H_0	98.07	18.31	Reject H_0	128.33	18.31	Reject H_0
No technical progress $(H_0: \beta_T = \beta_{TT} = \beta_{LT} = \beta_{KT} = \beta_{MT} = 0)$	25.93	11.07	Reject H_0	5.00	11.07	Do not reject H_0	54.88	11.07	Reject H_0	77.46	11.07	Reject H_0	22.69	11.07	Reject H_0
Neutral technical change $(H_0 : \beta_{LT} = \beta_{KT} = \beta_{MT} = 0)$	33.92	7.81	Reject H_0	-	-	-	33.56	7.81	Reject H_0	53.91	7.81	Reject H_0	12.67	7.81	Reject H_0
No inefficiency effects $(H_0: \gamma = \delta_0 = \delta_1 ... = \delta_{17} = 0)$	628.05	29.55*	Reject H_0	217.89	29.55*	Reject H_0	533.99	29.55*	Reject H_0	378.83	29.55*	Reject H_0	75.47	29.55*	Reject H_0
Non stochastic inefficiency $(H_0: \gamma = 0)$	1207.1	2.71*	Reject H_0	207.23	2.71*	Reject H_0	637.85	2.71*	Reject H_0	206.83	2.71*	Reject H_0	308.68	2.71*	Reject H_0
No inefficiency $(H_0: \delta_1 = \delta_2 ... \delta_{16} = \delta_{17} = 0)$	292.66	27.59	Reject H_0	151.40	27.59	Reject H_0	250.20	27.59	Reject H_0	301.81	27.59	Reject H_0	113.71	27.59	Reject H_0

Source: Author's estimates

Note: All critical values of the test statistics are subject to the 5% level of significance; * indicates a mixture of χ^2 distribution (see Kodde and Palrm, 1986);** includes Publishing, Construction Materials, and Technology (Computer components) (see Table 1)

Table 3: Maximum-Likelihood Estimates for Parameters of the Stochastic Frontier

Variable Stochastic frontiers	All Manufacturing	Agro & Food Industry	Consumer Products	Industrials	Other Sectors***
Constant	3.871*	1.071*	-1.454*	22.498*	1.060*
	(0.512)	(0.314)	(0.551)	(2.033)	(0.479)
log(L)******	1.002*	0.612*	0.288	-0.343	0.536*
	(0.132)	(0.094)	(0.186)	(0.390)	(0.122)
log(K)******	-0.700*	0.128	0.563*	0.684	0.079
	(0.109)	(0.087)	(0.144)	(0.533)	(0.091)
log(M)******	0.243	0.282*	0.689*	-3.144*	0.381*
	(0.152)	(0.076)	(0.228)	(0.753)	(0.105)
t	0.091*	-	0.029	-0.227*	0.046
	(0.043)	-	(0.034)	(0.119)	(0.033)
½ ($log(L)^2$)	0.079*	0.088*	-0.097**	0.237*	0.096*
	(0.022)	(0.024)	(0.052)	(0.049)	(0.038)
½ ($log(K)^2$)	-0.101*	0.022	-0.046**	-0.191	-0.054*
	(0.026)	(0.021)	(0.028)	(0.132)	(0.020)
½ ($log(M)^2$)	0.129*	0.165*	0.144*	0.620*	0.179*
	(0.028)	(0.013)	(0.051)	(0.228)	(0.022)
½ (t^2)	-0.005	-	-0.003	0.00007	-0.010**
	(0.005)	-	(0.002)	(0.010)	(0.004)
log(L)*log(K)	0.088*	0.000	0.126*	0.169**	0.056*
	(0.023)	(0.024)	(0.033)	(0.088)	(0.021)
log(L)*log(M)	-0.211*	-0.115*	-0.047*	-0.261*	-0.175*
	(0.026)	(0.014)	(0.030)	(0.100)	(0.021)
log(L)* *t*	-0.020*	-	0.008**	-0.026	0.011**
	(0.008)	-	(0.005)	(0.019)	(0.006)
log(K)*log(M)	0.089*	-0.027**	-0.110*	-0.060	0.006
	(0.019)	(0.015)	(0.027)	(0.161)	(0.017)
log(K)*t*	0.016*	-	-0.015*	0.008	-0.003
	(0.006)	-	(0.004)	(0.024)	(0.004)
log(M)*t*	-0.004	-	0.005	0.040	-0.005
	(0.007)	-	(0.005)	(0.031)	(0.005)

Source: Authors' estimates

Note: Standard Errors (S.E.) are in parentheses; * indicates that the coefficients are statistically significant at the 5% level;**indicates that the coefficients are statistically significant at the 10% level; *** includes Publishing, Construction Materials, and Technology (Computer components) (see Table 1); **** L is the labour input, K is the capital input, and M is intermediate input (see equation (1.2))

Table 4: Maximum-Likelihood Estimates for Parameters of the Inefficiency Models from the Stochastic Frontier Analysis (SFA) approach

Inefficiency Variables	All Manufacturing	Agro & Food Industry	Consumer Products	Industrials	Other Sectors***
Constant	13.257*	1.656*	10.538*	14.159*	1.975*
	(1.850)	(0.599)	(1.682)	(1.097)	(0.567)
Leverage	-0.038*	0.167*	-1.247*	0.017	0.292*
	(0.019)	(0.030)	(0.293)	(0.014)	(0.076)
Liquidity	0.219*	-0.047*	0.120*	0.124*	0.009
	(0.016)	(0.019)	(0.014)	(0.014)	(0.008)
Internal financing	0.635*	0.103*	0.892*	0.100	0.124*
	(0.139)	(0.034)	(0.128)	(0.085)	(0.060)
External financing	0.000*	0.000	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.0008)	(0.000)	(0.000)
Executive remuneration	-0.433*	-0.242	-5.168*	0.014	-0.109
	(0.212)	(0.172)	(0.846)	(0.115)	(0.413)
Controlling ownership	-0.035*	-0.001	-0.011**	-0.015*	-0.004*
	(0.003)	(0.001)	(0.006)	(0.003)	(0.002)
Managerial ownership	-0.023*	-0.001	-0.008*	-0.004*	0.009
	(0.004)	(0.001)	(0.004)	(0.002)	(0.003)
Exports	-0.012*	0.001*	0.008*	-0.005*	-0.001*
	(0.002)	(0.0005)	(0.004)	(0.002)	(0.001)
R&D	0.746*	-0.051	0.878*	0.101	-0.202*
	(0.150)	(0.062)	(0.164)	(0.087)	(0.067)
Family ownership	-3.681*	0.133	-3.319*	0.044	-0.182**
	(0.281)	(0.390)	(0.211)	(0.207)	(0.101)
Foreign ownership	-3.910*	-0.012	-3.268*	0.237	0.631*
	(0.504)	(0.395)	(0.266)	(0.180)	(0.231)
Domestic ownership	-1.420*	0.361	-0.066	0.469*	0.221*
	(0.206)	(0.394)	(0.507)	(0.198)	(0.114)
Hybrid ownership	-2.726*	-0.019	-3.652*	-0.070	0.137
	(0.192)	(0.412)	(0.247)	(0.216)	(0.107)
Firm size	-0.777*	-0.132*	-0.813*	-0.868*	-0.138*
	(0.125)	(0.028)	(0.116)	(0.068)	(0.038)
Firm age	-0.040*	0.002	0.028*	0.008*	0.002
	(0.005)	(0.003)	(0.007)	(0.004)	(0.002)
Government assistance	-0.716*	0.031	-0.494*	0.080	-0.184*
	(0.171)	(0.047)	(0.156)	(0.079)	(0.066)
Foreign cooperation	0.191*	0.194*	0.898*	-0.290*	-0.234*
	(0.097)	(0.053)	(0.165)	(0.114)	(0.116)
Variance parameters					
sigma-square	1.080*	0.009*	0.425*	0.181*	0.055*
	(0.067)	-0.001	-0.032	-0.017	-0.01
gamma	0.872*	0.690*	0.995*	0.271*	0.697*
	(0.012)	-0.065	-0.002	-0.055	-0.09
Log-likelihood function	-745.05	428.12	189.1	-207.01	130.55

Source: Authors' estimates

Note: Standard Errors (S.E.) are in parentheses; * indicates that the coefficients are statistically significant at the 5% level;**indicates that the coefficients are statistically significant at the 10% level; *** includes Publishing, Construction Materials, and Technology (Computer components) (see Table 1)

Table 5: Maximum-Likelihood Tobit Estimates for Parameters of the Two-Stage DEA approach

Firm Specific Variables	All Manufacturing	Agro & Food Industry	Consumer Products	Industrials	Other Sectors***
Left censoring (value) at zero	93	13	1	52	27
Uncensored observations	1214	309	250	345	310
Total observations	1307	322	251	397	337
Dependent variable: Technical inefficiency (VRS)					
Constant	0.5838*	0.6564*	0.7542*	0.3257*	0.4880
	(0.0294)	(0.0509)	(0.0923)	(0.0602)	(0.0541)
Leverage	-0.0048*	0.0129*	-0.0386*	-0.0035*	0.0277*
	(0.0012)	(0.0058)	(0.0141)	(0.0016)	(0.0090)
Liquidity	0.0023*	0.0012	0.0024*	0.0073*	-0.0014
	(0.0006)	(0.0015)	(0.0009)	(0.0016)	(0.0010)
Internal financing	0.0052	0.0028	0.0126	-0.0050	-0.0109**
	(0.0037)	(0.0047)	(0.0064)	(0.0085)	(0.0064)
External financing	0.0000*	0.0000	0.0000	0.0000*	0.0000*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Executive remuneration	-0.1018*	-0.0950*	-0.1990*	-0.0933*	0.0334
	(0.0186)	(0.0289)	(0.0564)	(0.0296)	(0.0415)
Controlling ownership	-0.0002	0.0003*	-0.0001	-0.0001	-0.0005*
	(0.0001)	(0.0001)	(0.0003)	(0.0002)	(0.0002)
Managerial ownership	-0.0004*	-0.0002**	0.0004	-0.0007*	-0.0001
	(0.0001)	(0.0001)	(0.0003)	(0.0002)	(0.0002)
Exports	-0.0001**	-0.0002*	0.0001	-0.0001	-0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
R&D	0.0145*	0.0236*	0.0307*	-0.0081	0.0271*
	(0.0044)	(0.0073)	(0.0120)	(0.0097)	(0.0079)
Family ownership	-0.0272*	-0.0723*	-0.0327*	0.0408**	-0.0093
	(0.0067)	(0.0234)	(0.0086)	(0.0229)	(0.0102)
Foreign ownership	-0.0428*	-0.0769*	-0.0314*	-0.0039	-0.0227*
	(0.0076)	(0.0236)	(0.0119)	(0.0226)	(0.0116)
Domestic ownership	-0.0067	-0.0463**	0.0157	0.0385**	0.0273*
	(0.0083)	(0.0264)	(0.0216)	(0.0234)	(0.0122)
Hybrid ownership	-0.0224*	-0.0641*	-0.0187	0.0117	0.0305*
	(0.0084)	(0.0243)	(0.0145)	(0.0252)	(0.0130)
Firm size	-0.0295*	-0.0369*	-0.0439*	-0.0184*	-0.0240*
	(0.0017)	(0.0026)	(0.0059)	(0.0038)	(0.0032)
Firm age	0.0000	0.0013*	0.0010*	0.0005	-0.0005
	(0.0002)	(0.0003)	(0.0004)	(0.0003)	(0.0003)
Government assistance	0.0076**	0.0168*	0.0117	0.0235*	0.0083
	(0.0040)	(0.0062)	(0.0071)	(0.0087)	(0.0075)
Foreign cooperation	0.0030	-0.0003	0.0070	0.0148**	0.0016
	(0.0033)	(0.0069)	(0.0087)	(0.0089)	(0.0042)
Error Distribution	*0.059**	*0.035**	*0.044**	*0.065**	*0.050**
	(0.001)	*(0.001)*	*(0.002)*	*(0.003)*	*(0.002)*
Log likelihood (unrestricted)	*1594*	*588*	*423*	*401*	*464*
*Log likelihood (restricted)****	*1405*	*445*	*357*	*331*	*362*
LR test	*377**	*286**	*132**	*141**	*204**
Critical value	*27.59*	*27.59*	*27.59*	*27.59*	*27.59*

Source: Authors' estimates

Note: Standard Errors (S.E.) are in parentheses; * indicates that the coefficients are statistically significant at the 5% level;**indicates that the coefficients are statistically significant at the 10% level; *** Inefficiency scores are regressed by a constant;***includes Publishing, Construction Materials, and Technology

Table 6: Comparison of the Results of Maximum-Likelihood Estimates for Parameters between the SFA and the Two-Stage DEA approaches

Dependent variable: Technical inefficiency (Pure or VRS)	All Manufacturing		Agro & Food Industry		Consumer Products		Industrials		Other Sectors ***	
	SFA	DEA	SFA	DEA	SFA	DEA	SFA	DEA	SFA	DEA
Independent variables :										
Constant	+*	+*	+*	+*	+*	+*	+*	+*	+*	+
Leverage	-*	-*	+*	+*	-*	-*	+	-*	+*	+*
Liquidity	+*	+*	-*	+	+*	+*	+*	+*	+	-*
Internal financing	+*	+	+*	+	+*	+	+	-	+*	-**
External financing	+*	+*	+	+	+	+*	+*	+*	+	+*
Executive remuneration	-*	-*	-	-*	-*	-*	**+**	**-***	-	+
Controlling ownership	-*	-	-	+*	-**	-	-*	-	-*	-
Managerial ownership	-*	-*	-	-**	-*	+	-*	-*	+	-
Exports	-*	-**	+*	-*	+*	+	-*	-	-*	-
R&D	+*	+*	-	+*	+*	+*	+	-	**-***	**+***
Family owned firm	-*	-*	+	-*	-*	-*	+*	+**	-**	-
Foreign owned firm	-*	-*	-	-*	-*	-*	+	-	+*	-*
Domestic owned firm	-*	-	+	-**	-	+	+*	+**	+*	+*
Hybrid owned firm	-*	-*	-	-*	-*	-	-	+	+	+*
Firm size	-*	-*	-*	-*	-*	-*	-*	-*	-*	-*
Firm age	-*	+	+	+*	+*	+*	+*	-	+	-
Government assistance	-*	+**	+	+*	-*	+	+	+*	-*	+
Foreign cooperation	+*	+	+*	-	+*	+	**-***	**+****	-*	+

Source: Authors' estimates

Note: * indicates that the coefficients are statistically significant at the 5% level;**indicates that the coefficients are statistically significant at the 10% level; *** includes Publishing, Construction Materials, and Technology (Computer components) (see Table 1).

Appendix 1: Data Summary

Variables	Unit of Variables	Mean	Median	Max	Min	Std. Dev.	Observations
Output							
Ln (Sales revenue)	Natural Logarithm	9.95	9.88	14.56	5.49	1.36	1309
Inputs:							
Ln (Labour expenses)	Natural Logarithm	7.64	7.66	11.84	3.71	1.15	1309
Ln (Fixed productive)	Natural Logarithm	8.84	8.68	13.61	3.57	1.56	1309
Ln (Intermediate inputs)	Natural Logarithm	9.51	9.40	14.26	5.28	1.45	1309
Time trend	No. of years	5	5	9	1	3	1309
Finance:							
Leverage	Ratio	0.57	0.43	29.13	0.01	1.5	1309
Liquidity	Ratio	2.4	1.57	46.2	0	2.81	1309
Internal financing	Dummy (ratio)	0.35	0	1	0	0.48	1309
External financing	000 Baht	1747	203	140304	0	7721	1309
R&D	Dummy (ratio)	0.8	1	1	0	0.4	1309
Ownership structure:							
Controlling ownership	Ratio	58.81	58.82	99.69	5.44	16.51	1309
Managerial ownership	Ratio	20.55	12.70	96.53	0	21.69	1309
Types of owned firms:							
Family-owned firm	Dummy (ratio)	0.53	1	1	0	0.5	1309
Foreign-owned firm	Dummy (ratio)	0.19	0	1	0	0.39	1309
Domestic owned firm	Dummy (ratio)	0.12	0	1	0	0.32	1309
Joint owned firm	Dummy (ratio)	0.07	0	1	0	0.26	1309
Hybrid owned firm	Dummy (ratio)	0.09	0	1	0	0.29	1309
Executive remuneration	Ratio	0.14	0.09	7	0.0032	0.32	1309
Exports	%	32.68	19.32	100	0	33.53	1309
Other factors:							
Ln (total assets)	Natural Logarithm	14.76	14.54	19.47	11.73	1.27	1309
Firm age	No. of years	26	24	95	0	12	1309
Government assistance	Dummy (ratio)	0.62	1	1	0	0.49	1309
Foreign cooperation	Dummy (ratio)	0.31	0	1	0	0.54	1309

Source: Authors' estimates

Appendix 2: Average Technical Efficiency Scores Classified by Estimating Approaches and the SET's Manufacturing Sectors

	All Manufacturing			Agro & Food Industry			Consumer Products			Industrials			Other Sectors		
	CRSTE	VRSTE	SCALE	CRSTE	VRSTE	SCALE	CRSTE	VRSTE	SCALE	CRSTE	VRSTE	SCALE	CRSTE	VRSTE	SCALE
2000															
SFA	-	0.807	-	-	0.846	-	-	0.783	-		0.799	-	-	0.796	-
DEA	0.814	0.871	0.936	0.825	0.885	0.935	0.799	0.851	0.940	0.830	0.885	0.940	0.795	0.858	0.930
2001															
SFA	-	0.803	-	-	0.845	-	-	0.770	-	-	0.798	-	-	0.793	-
DEA	0.838	0.895	0.938	0.838	0.900	0.933	0.827	0.881	0.940	0.860	0.908	0.947	0.825	0.888	0.932
2002															
SFA	-	0.803	-	-	0.843	-	-	0.767	-	-	0.806	-	-	0.789	-
DEA	0.832	0.896	0.93	0.828	0.898	0.923	0.816	0.875	0.933	0.855	0.908	0.942	0.823	0.895	0.922
2003															
SFA	-	0.807	-	-	0.841	-	-	0.767	-	-	0.809	-	-	0.799	-
DEA	0.89	0.927	0.96	0.891	0.927	0.962	0.851	0.899	0.947	0.915	0.944	0.970	0.888	0.928	0.957
2004															
SFA	-	0.821	-	-	0.838	-	-	0.774	-	-	0.851	-	-	0.801	-
DEA	0.826	0.901	0.917	0.817	0.898	0.912	0.804	0.876	0.919	0.855	0.923	0.927	0.813	0.896	0.910
2005															
SFA	-	0.817	-	-	0.843	-	-	0.776	-	-	0.844	-	-	0.790	-
DEA	0.779	0.878	0.889	0.757	0.868	0.875	0.740	0.839	0.883	0.828	0.911	0.910	0.765	0.873	0.880
2006															
SFA	-	0.820	-	-	0.846	-	-	0.769	-	-	0.855	-	-	0.791	-
DEA	0.789	0.878	0.9	0.778	0.875	0.890	0.743	0.833	0.894	0.836	0.910	0.920	0.773	0.874	0.887
2007															
SFA	-	0.816	-	-	0.845	-	-	0.757	-	-	0.853	-	-	0.788	-
DEA	0.784	0.876	0.897	0.769	0.877	0.880	0.736	0.821	0.898	0.832	0.909	0.917	0.772	0.874	0.887
2008															
SFA	-	0.812	-	-	0.844	-	-	0.743	-	-	0.857	-	-	0.776	-
DEA	0.787	0.870	0.906	0.774	0.873	0.889	0.738	0.815	0.906	0.835	0.904	0.925	0.772	0.874	0.887
2000 - 2008															
SFA	-	0.812	-	-	0.843	-	-	0.767	-		0.830	-	-	0.791	-
DEA	0.814	0.887	0.918	0.809	0.889	0.911	0.784	0.854	0.918	0.848	0.911	0.931	0.801	0.883	0.909

Source: Authors' estimates

Note**:** DRS is the decreasing returns to scale technical efficiency; IRS is increasing returns to scale technical efficiency; CRS is constant returns to scale technical efficiency

Appendix 3: Number of Listed Manufacturing Firms Classified by Types of Returns to Scales and the SET's Manufacturing Sectors

	All Manufacturing						Agro & Food Industry						Consumer Products						Industrials						Other Sectors*					
Year	DRS	%	IRS	%	CRS	%	DRS	%	IRS	%	CRS	%	DRS	%	IRS	%	CRS	%	DRS	%	IRS	%	CRS	%	DRS	%	IRS	%	CRS	%
2000	100	73%	33	24%	4	3%	30	81%	7	19%	0	0%	23	77%	6	20%	1	3%	22	59%	13	35%	2	5%	25	76%	7	21%	1	3%
2001	109	81%	23	17%	3	2%	35	95%	2	5%	0	0%	24	86%	4	14%	0	0%	23	64%	11	31%	2	6%	27	79%	6	18%	1	3%
2002	115	85%	18	13%	3	2%	36	97%	0	0%	1	3%	25	89%	3	11%	0	0%	27	71%	9	24%	2	5%	27	82%	6	18%	0	0%
2003	114	83%	18	13%	5	4%	32	97%	0	0%	1	3%	25	93%	1	4%	1	4%	29	73%	9	23%	2	5%	28	80%	6	17%	1	3%
2004	139	95%	5	3%	2	1%	35	100%	0	0%	0	0%	27	100%	0	0%	0	0%	41	89%	3	7%	2	4%	36	95%	2	5%	0	0%
2005	138	91%	12	8%	2	1%	35	97%	1	3%	0	0%	27	100%	0	0%	0	0%	40	82%	7	14%	2	4%	36	90%	4	10%	0	0%
2006	140	89%	15	10%	2	1%	35	97%	1	3%	0	0%	28	97%	1	3%	0	0%	40	78%	9	18%	2	4%	37	90%	4	10%	0	0%
2007	141	91%	12	8%	2	1%	35	100%	0	0%	0	0%	27	96%	1	4%	0	0%	41	82%	8	16%	1	2%	38	90%	3	7%	1	2%
2008	135	88%	14	9%	5	3%	35	100%	0	0%	0	0%	26	93%	2	7%	0	0%	37	74%	9	18%	4	8%	37	90%	3	7%	1	2%

Source: Authors' estimates

Note: DRS is decreasing returns to scale; IRS is increasing returns to Scale; CRS is constant returns to scale; *includes Publishing, Construction Materials, and Technology (Computer components) (see Table 3)

References

Admassie, A. & Matambalya, F. A. S. T. (2002), Technical Efficiency of Small- and Medium-Scale Enterprises: Evidence from a Survey of Enterprises in Tanzania, Eastern Africa Social Science Research Review, Vol.18, No.2, pp. 1-29.

Aigner, D., Lovell, C. A. K. & Schmidt, P. (1977), Formulation and Estimation of Stochastic Frontier Production Function Models, Journal of Econometrics, Vol.6, pp. 21-37.

Aw, B. Y. & Batra, G. (1998), Technological Capability and Firm Efficiency in Taiwan (China), The World Bank Economic Review, Vol.12, No.1, pp. 59-79.

Baek, H. Y. & Pagán, J. A. (2003), Executive Compensation and Corporate Production Efficiency: A Stochastic Frontier Approach, Quarterly Journal of Business and Economics, Vol.41, No.1/2, pp. 27-41.

Banker, R. D., Charnes, A. & Cooper, W. W. (1984), Some Models for Estimating Technical and Scale Inefficiencies in Data Envilopment Analysis, Management Science, Vol.30, No.9, pp. 1078-1092.

Battese, G. E. & Coelli, T. J. (1988), Prediction of Firm-Level Technical Efficiencies with a Generalised Frontier Production Function and Panel Data, Journal of Econometrics, Vol.38, pp. 387-399.

Battese, G. E. & Coelli, T. J. (1992), Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India, Journal of Productivity Analysis, Vol.3, pp. 153-169.

Battese, G. E. & Coelli, T. J. (1995), A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, Empirical Economics, Vol.20, pp. 325-332.

Battese, G. E. & Corra, G. S. (1977), Estimation of a Production Frontier Model: with Application to the Pastoral Zone of Eastern Australia, Australian Journal of Agricultural Economics, Vol.21, No.3, pp. 169-179.

Bebchuk, L., Kraakman, R. & Triantis, G. (1999), Stock Pyramids, Cross-Ownership, and Dual Class Equity: The Creation and Agency Costs of Separating Control from Cash Flow Rights. *Working Paper*. Cambridge, MA, National Bureau of Economic Research.

Bottasso, A. & Sembenelli, A. (2004), Does ownership affect firm's efficiency? Panel data evidence on Italy, Empirical Economics, Vol.29, pp. 769-786.

Claessens, S., Djankov, S. & Lang, L. H. P. (2000), The Separation of Ownership and Control in East Asian Corporations, Journal of Financial Economics, Vol.58, pp. 81-112.

Coelli, T. J. (1996) A Guide to Frontier Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation. *Working Papers*. Armidale, University of New England.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. & Battese, G. E. (2005), An Introduction to Efficiency and Productivity Analysis 2, Springer, New York, USA.

Demsetz, H. & Lehn, K. (1985), The Structure of Corporate Ownership: Causes and Consequences, The Journal of Political Economy, Vol.93, No.6, pp. 1155-1177.

Dilling-Hansen, M., Madsen, E. S. & Smith, V. (2003), Efficiency, R&D and ownership – some empirical evidence, International Journal of Production Economics, Vol.83, pp. 85-94.

East Asia Analytical Unit (2000), Transforming Thailand: Choices For New Millennium, Green Advertising, Australia.

Fare, R., Grosskopf, S. & Logan, J. (1983), The Relative Efficiency of Illinois Electric Utilities, Resources and Energy, Vol.5, pp. 349-367.

Fukuyama, H., Guerra, R. & Weber, W. L. (1999), Efficiency and Ownership: Evidence from Japanese Credit Cooperatives, Journal of Economics and Business, No.51, pp. 473–487.

Gertner, R. H., Scharfstein, D. S. & Stein, J. C. (1994), Internal Versus External Capital Markets The Quarterly Journal of Economics, Vol.109, No.4, pp. 1211-1230.

Gökçekus, Ö. (1995), The Effects of Trade Exposure on Technical Efficiency: New Evidence from the Turkish Rubber Industry, Journal of Productivity Analysis, Vol.6, pp. 77-85.

Goldar, B. N., Renganathan, V. S. & Banga, R. (2003), Ownership and Efficiency in Engineering Firms in India, 1990-91 to 1999-2000. *Working Paper.* Indian Council for Research on International Economic Relations.

Hossain, M. A. & Karunaratne, N. D. (2004), Trade Liberalisation and Technical Efficiency: Evidence from Bangladesh Manufacturing Industries, Journal of Development Studies, Vol.40, No.3, pp. 87-114.

Jensen, M. C. (1986), Agency Costs of Free Cash Flow, Corporate Finance, and Takeovers, American Economic Review, Vol.76, pp. 323-318.

Jensen, M. C. & Meckling, W. H. (1976), Theory of the Firm: Managerial Behaviour, Agency Costs and Ownership Structure, Journal of Financial Economics, Vol.3, pp. 305-360.

Jongwanich, J. (2007), Determinants of Export Performance in East and Southeast Asia. *ERD Working Paper* Manila, Economic and Research Department, Asian Development Bank.

Kim, S. (2003), Identifying and Estimating Sources of Technical Inefficiency in Korean Manufacturing Industries, Contemporary Economic Policy, Vol.21, No.1, pp. 132-144.

Kodde, D. A. & Palm, F. C. (1986), Wald Criteria for Jointly Testing Equality and Inequality Restrictions, The Econometric Society, Vol.54, No.5, pp. 1243-1248.

Lauterbach, B. & Vaninsky, A. (1999), Ownership Structure and Firm Performance: Evidence from Israel, Journal of Management and Governance, Vol.3, pp. 189-201.

Leech, D. & Leahy, J. (1991), Ownership Structure, Control Type Classifications and the Performance of Large British Companies, The Economic Journal, Vol.101, No.409, pp. 1418-1437.

Liao, C.-S., Yang, C.-H. & Liu, D. (2010), Efficiency, Productivity and Ownership Structure for Securities Firms in Taiwan, Journal of Money, Investment and Banking, No.14, pp. 46-58.

Lundvall, K. & Battese, G. E. (2000), Firm Size, Age and Efficiency: Evidence from Kenyan Manufacturing Firms, Journal of Development Studies, Vol.36, No.3, pp. 146-163.

McConnell, J. J. & Servaes, H. (1990), Additional Evidence on Equity Ownership and Corporate Value, Journal of Financial Economics, Vol.27, pp. 595-612.

Meeusen, W. & Broeck, J. v. D. (1977), Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error, International Economic Review, Vol.18, No.2, pp. 435-444.

Mok, V., Yeung, G., Han, Z. & Li, Z. (2007), Leverage, Technical Efficiency and Profitability: an Application of DEA to Foreign-Invested Toy Manufacturing Firms in China, Journal of Contemporary China, Vol.16, No.51, pp. 259-274.

Oczkowski, E. & Sharma, K. (2005), Determinants of Efficiency in Least Developed Countries: Further Evidence from Nepalese Manufacturing Firms, Journal of Development Studies, Vol.41, No.4, pp. 617-630.

Pitt, M. M. & Lee, L.-F. (1981), Measurement and Sources of Technical Inefficiency in the Indonesian Weaving Industry, Journal of Development Economics, Vol.9, pp. 43-64.

Sally, R. (2007), Thai Trade Policy: From Non-discriminatory Liberalisation to FTAs, The World Economy, Vol.30, No.10, pp. 1594-1620.

Sena, V. (2006), The Determinants of Firm's Performance: Can Finance Constraints Improve Technical Efficiency?, European Journal of Operational Research, Vol.172, pp. 311-325.

Sheu, H.-J. & Yang, C.-Y. (2005), Insider Ownership and Firm Performance in Taiwan's Electronics Industry: A Technical Efficiency Perspective, Managerial and Decision Economics, Vol.26, pp. 307-318.

Shleifer, A. & Vishny, R. W. (1997), A Survey of Corporate Governance, Journal of Finance, Vol.52, No.2, pp. 737-783.

Sirasoontorn, P. (2004), Privatisation and Technical Efficiency of Thai Electricity Generation State Owned Enterprise. *Working paper Series.* Bangkok, Faculty of Economics, Thammasat University

Stein, J. C. (1997), Internal Capital Markets and the Competition for Corporate Resources Journal of Finance, Vol.53, pp. 263-92.

Talerngsri, P. & Vonkhorporn, P. (2005), Trade Policy in Thailand: Pursuing a Dual Track Approach, ASEAN Economic Bulletin, Vol.22, No.1, pp. 60-74.

Weill, L. (2008), Leverage and Corporate Performance: Does Institutional Environment Matter?, Small Business Economics, Vol.30, pp. 251-265.

Wiwattanakantang, Y. (2001), Controlling shareholders and corporate value: Evidence from Thailand, Pacific-Basin Finance Journal, Vol.9, pp. 323-362.

World Bank Office -Thailand (2008), Thailand Economic Monitor. Bangkok, Word Bank.

Yammeesri, J. & Lodh, S. C. (2003), The Effects of Ownership Structure on Firm Performance: Evidence from Thailand. *Hawaii International Conference on Business.* Honolulu, Hawaii.

Zeitun, R. & Tian, G. G. (2007), Does Ownership Affect a Firm's Performance and Default Risk in Jordan ?, Corporate Governance, Vol.7, No.1, pp. 66-82.