# An Empirical Study of Thai Manufacturing SMEs: A Stochastic Frontier Analysis (SFA) *

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## ABSTRACT

This paper applies a stochastic frontier production function and technical inefficiency effects model to measure, compare and explain the technical efficiency of Thai manufacturing small and medium-sized enterprises (SMEs) in the pre and post 1997 Asian financial crisis periods. Cross-sectional firm-level data from industrial censuses conducted in 1997 and 2007 are utilized. Average technical efficiency levels in all categories of manufacturing SMEs analyzed in the pre and post crisis periods are found to be low, indicating a high degree of technical inefficiency in the production process. Only medium sized SMEs are found to have improved their technical efficiency and export intensive SMEs have maintained their technical efficiency in the post crisis period, despite reform measures aimed at improving firm performance. Manufacturing SMEs have remained predominantly labor intensive in both periods with no apparent improvement in firm productivity and innovation. The technical inefficiency effects model reveals that small sized enterprises are found be more technically efficient than medium sized enterprises. Firm age, skilled labor, location, ownership type, foreign investment and exporting are key factors contributing to firm technical efficiency in both the pre and post crisis periods. The paper concludes that government policy in the post crisis period have been largely ineffective and should place more attention on creating an enabling environment to foster SME growth, enhance technology and innovation capability, and encourage the development of an environment, infrastructure and facilities conducive to enhancing the business operation of SMEs to enhance their technical efficiency.

**Keywords**: Technical Efficiency; Stochastic Frontier Analysis (SFA); Small and Medium sized Enterprises (SMEs); Manufacturing; Thailand

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**INTRODUCTION**

It commonly acknowledges the significant economic and social role played by SMEs (Newby 2006; Harvie 2007; Harvie 2008; Doern 2009; Le and Harvie 2010). It is also generally recognized that SMEs also play important roles and functions in assisting large enterprises (Regnier 2000; Brimble, Oldfield et al. 2002; Mephokee 2003; OSMEP ; OSMEP 2008; OSMEP 2009). Thai SMEs represent 99 percent of business establishments in the country, and employ more than seven million workers, accounting for 73 percent of total employment during the period 1994 [1] to 2009 (OSMEP 2001; OSMEP 2002; OSMEP 2003; OSMEP 2004; OSMEP 2005; OSMEP 2006; OSMEP 2009). This confirms that SMEs are crucial to the development of the Thai economy. From a regional perspective, around 30 percent of SMEs were concentrated in Bangkok and vicinity areas during 1994 to 2008. The contribution of SMEs to GDP, at current prices, was approximately 38.84 percent of total GDP over the period 1999-2009. An average real output growth of SMEs was 3.91 percent of total SME GDP in this period (OSMEP 2001; OSMEP 2002; OSMEP 2003; OSMEP 2004; OSMEP 2005; OSMEP 2006; OSMEP 2009). Therefore, it is considered that SMEs contribute significantly to the social and economic development of Thailand (Brimble, Oldfield et al. 2002; Mephokee 2003; Sahakijpicharn 2007; OSMEP 2009).

The most common means of defining an SME are based on two measures: the number of employees or the level of fixed assets (OSMEP 2002; Sahakijpicharn 2007). The Ministry of Industry (MOI) of Thailand Regulation of 11 September 2002 adopted employment or fixed assets, excluding land, as criteria in defining SMEs (Brimble, Oldfield et al. 2002; OSMEP 2003). Hence, an enterprise employing less than or equal to 50 workers, or fixed assets, excluding land, not exceeding THB 50 million (approximately US$1.65 million) or equal to THB 50 million (approximately US$1.65 million) in the manufacturing sector is considered a small enterprise. An enterprise employing between 51-200 workers or fixed assets, excluding land, between THB 51-200 million (approximately US$1.68 - 6.6 million) is defined as a medium sized enterprise (Mephokee 2003; OSMEP 2003).

Focusing on Thai manufacturing SMEs, it can be observed that an average number of manufacturing SMEs was approximately 460,002, or 27.14 percent of total SMEs during 1994 to 2009. In term of employment by manufacturing SMEs, they employed around 2,630,800 workers over the period 1994 to 2009 on average equivalent to about 27.13 percent of total employment in the private sector in this period. In term of SME contribution to total SME GDP, manufacturing SMEs had an average THB 748,749 million, or 28.68 percent of total SME output in 1994 - 2009. An average real output growth of manufacturing SMEs was 6.89 percent of total SME GDP in this period (OSMEP 2001; OSMEP 2002; OSMEP 2003; OSMEP 2004; OSMEP 2005; OSMEP 2006; OSMEP

[1] Data collection of Thai SMEs started in 1994.

2009). However, the Office of Small and Medium Enterprises Promotion does not compile statistics on the exports of SMEs by sector. It only identifies the export value of SMEs classified by size of enterprises. Thus, the value of exports by SMEs was approximately THB 1,311,493 million, or 33.02 percent of total exports over the period 2000 to 2009.

The financial crisis in 1997 severely impacted the labor market, resulting in a high unemployment rate, a decline in real income, a crucial reduction in domestic demand, private consumption and investment and severe contraction in economic growth (World Bank 1993; Nukul's Commission Report 1998; Regnier 2000; Phan 2004; Menkhoff and Suwanaporn 2007). The decline of the country's economic growth was mainly influenced by decreasing exports, domestic expenditure, and investment in fixed assets (Nukul's Commission Report 1998; OSMEP 2001). Arunsawadiwong (2007) argued that there were five major causes of the crisis in 1997: the slowdown of export growth, mistakes in financial policies, asymmetric information and over investment, attacks on the currency, and the response to the currency devaluation itself by the authorities. Kraipornsak (2001) stated that the weak structure of the Thai economy and poor economic management were the major problems. The 1997 financial crisis had marked adverse effects on Thai SMEs. The most severe effects on SMEs were a huge decline in sales revenue and tighter liquidity. Retailers and wholesalers encountered higher costs because their imported products cost more with a weaker currency, while product prices experienced a declining trend due to stiff competition (Tapaneeyangkul 2001). The responses by SMEs were to cut costs, impose stricter financial control, retrench staff, expand in to international markets, and enhance new product development (Regnier 2000; OSMEP 2001).

The analysis is conducted utilizing firm-level data obtained from 1997 [2] and 2007 [3] industrial censuses, conducted by the National Statistical Office (NSO) of Thailand, with 32,484 and 73,931 observations, respectively (NSO 2011a; NSO 2011b). The structure of the paper is as follows. Section 2 describes the methodology ant the concept of technical efficiency. Section 4 reviews data and key variables for a stochastic frontier production model and technical inefficiency effects model. Econometric models and formal hypothesis tests are shown in Sections 5 and 6, respectively. The empirical results are summarized and discussed in Section 7. Policy implications and conclusions are presented in Section 8 and Section 9 respectively.

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[2] Firm-level data in the 1997 industrial census covered the operations of firms from 1st January 1996 to 31st December 1996 (the National Statistical Office of Thailand, 2010a).

[3] The 2007 industrial census firm-level data covered the operations of firms from 1st January 2006 to 31st December 2006 (the National Statistical Office of Thailand, 2010b).

## RESEARCH OBJECTIVES

The study aims to measure technical efficiency levels and examine the possible firm-specific factors affecting the technical inefficiency of Thai manufacturing SMEs by comparing between the pre and post financial crisis of 1997. However, these studies have not been empirically examined in the existing literature. Therefore, the primary aim of this study is to rectify a gap in the literature by empirically estimating: 1) the level of technical efficiency of Thai manufacturing SMEs in the pre and post financial crisis periods in three aspects: By aggregate manufacturing SMEs, by size of manufacturing SMEs (small and medium) and by two categories of manufacturing SMEs classified by export intensity: Domestic SMEs (Export ≤ 49%) and exporting SMEs (Export ≥ 50%); 2) Firm-specific factors and explanatory variables that could influence the technical inefficiency of Thai manufacturing SMEs in the pre (1997) and post (2007) financial crisis periods in aggregate, by size of SME and by domestic and exporting SMEs. Potential firm-specific factors contributing to the technical inefficiency of Thai manufacturing SMEs based upon the literature are: firm size, firm age, skilled labor, firm location (municipal and non-municipal areas), region (i.e., Bangkok, central and vicinity, northern and north-eastern provinces), type of ownership (i.e., individual proprietor, juristic partnership, limited company, government and state enterprises, or co-operative), foreign investment, exports, government assistance (via the Board of Investment (BOI)); 3) Identify key factors and appropriate policies to improve Thai manufacturing SMEs as well as to make recommendations to support SMEs in Thailand.

## A CONCEPT OF TECHNICAL EFFICIENCY

The performance of a firm can be measured in terms of economic efficiency, including technical and allocative efficiencies. Technical efficiency is defined as a firm's ability to produce the maximum level of output from a given combination of inputs. In this context the output of a firm can be the level of production in terms of units or value added, while inputs can be resources such as labor and capital (Admassie and Matambalya 2002; Vu 2003; Coelli, Rao et al. 2005; Zahid and Mokhtar 2007). In attempt to measure the technical efficiency level of firms, it is important to determine the maximum level of output or to determine the production frontier (Vu 2003; Coelli, Rao et al. 2005). Allocative efficiency is referred to an ability of the firm to utilize inputs in optimal proportions given their respective prices. Thus, technical and allocative efficiencies can be combined in order to provide a measure of overall economic efficiency (Admassie and Matambalya 2002; Coelli, Rao et al. 2005; Arunsawadiwong 2007; Zahid and Mokhtar 2007). In order to understand the difference between these terms, it is useful to consider the production process in which a single input is used to produce a single output (Coelli, Rao et al. 2005).

## METHODOLOGY

The two most common approaches of estimating the maximum level of output are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Data Envelopment Analysis (DEA) is a non-parametric approach that makes no assumptions concerning the form of the production function. Instead, the best practice production function is created empirically from observed input and output. DEA does not identify the difference between technical inefficiency and random error (Admassie & Matambalya 2002; Vu 2003; Coelli, Rao et al. 2005; Arunsawadiwong 2007; Zahid & Mokhtar 2007). SFA is a parametric approach where the form of the production function is assumed to be known or is estimated statistically. SFA also allows other parameters of the production technology to be explored (Coelli 1996a; Coelli, Rao et al. 2005). The advantages of this approach are that hypotheses can be tested with statistical rigour, and that relationships between inputs and outputs follow known functional forms. SFA is only program that can simultaneously estimate the technical efficiency and technical inefficiency effects model (Admassie and Matambalya 2002; Coelli, Rao et al. 2005; Arunsawadiwong 2007; Zahid and Mokhtar 2007). Therefore, SFA is utilized to conduct the empirical analysis for this study. SFA employs the method of maximum likelihood to calculate a wide variety of stochastic frontier models, based on Cobb-Douglas and Transcendental-logarithm (Translog) production functions, using cross-sectional firm level data from industrial censuses in 1997 and 2007 (Coelli 1996a; Coelli, Rao et al. 2005).

## DATA AND KEY VARIABLES

This study utilized firm-level data from industrial censuses in the period 1997 and 2007, conducted by the National Statistical Office (NSO) of Thailand every ten years. The establishments under the scope of these censuses were those engaged primarily in manufacturing industry (category D International Standard Industrial Classification of All Economic Activities; ISIC: Rev.3). The scope of these censuses consists of enterprises engaged in manufacturing industry activities (Category D International Standard Industrial Classification of all Economic Activities, ISIC: Rev.3). An interview method was used in the data collection (NSO 2011a; NSO 2011b). However, this study only focuses upon manufacturing SMEs. Therefore, total numbers of manufacturing SMEs in 1997 and 2007 industrial censuses are 22,685 and 56,441, respectively. Data for Thai manufacturing SMEs is categorized into three aspects: By aggregate manufacturing SMEs, by size of manufacturing SMEs (small and medium) and by domestic and exporting SMEs.

**Key Variables**

Data extracted for manufacturing SMEs in 1997 and 2007 periods was based on that required estimate Cobb-Douglas and Translog production functions and examine the technical inefficiency effects model and included output value added (*Y*), labor input (*L*), capital input (*K*).

**Output value added (*Y*)** is measured as the value of gross output minus intermediate consumption and is utilized for the production of output.

**Labour input (*L*)** is measured as the number of workers in the establishment, including owner or partner, unpaid workers, skilled labour and unskilled labour. The total number of workers is used as the proxy for labour.

**Capital input (*K*)** is measured as the net value of fixed assets after deducting accumulated depreciation at the end of the year. The net value of fixed assets for each firm in 1997 and 2007 industrial censuses is utilized as a proxy for capital. The net value of fixed assets is a combination of land, buildings, construction, machinery and equipment, vehicles, office appliances and software.

**MODEL SPECIFICATION**

Coelli (1996a) highlighted that Cobb-Douglas and Translog production functions are the most often used functional forms for Stochastic Frontier Analysis (Coelli, Rao et al. 2005). Both the Cobb-Douglas and Translog production functions are tested in this study for an adequate functional form (Kim 2003; Vu 2003; Tran, Grafton et al. 2008; Amornkitvikai & Harvie 2010; Amornkitvikai & Harvie 2011). Thus, the two factors Cobb-Douglas production function utilizing cross-sectional data can be written as follows (Coelli 1996a):

$$lnY_i = \beta_0 + \beta_1 ln(K_i) + \beta_2 ln(L_i) + (V_i - U_i) \text{ ,i=1,…,N,} \quad (1)$$

The Transcendental-logarithm (Translog) production function using cross-sectional data can be expressed as follows (Coelli 1996a):

$$lnY_i = \beta_0 + \beta_1 ln(K_i) + \beta_2 ln(L_i) + \beta_3 ln(K_i)^2 + \beta_4 ln(L_i)^2 + \beta_5 ln(K_i) ln(L_i) + (V_i - U_i) \quad (2)$$

Where:

$Y_i$ = Value added of firm *i*

$K_i$ = The net value of fixed assets of firm *i*

$L_i$ = The total number of employees of firm *i*

$V_i$ = A random variable which is assumed to be independently and identically distributed normal variable with zero means and variances, $\left(v_i \sim iidN\left(0,\sigma_v^2\right)\right)$, and is assumed to be independently distributed of $U_i$ (Vu 2003; Coelli, Rao et al. 2005; Tran, Grafton et al. 2008).

$U_i$ = A non-negative random variable is assumed to account for technical inefficiency in the production function ,and is assumed to be independently and identically distributed as truncations at zero of normal distribution, $\left(u_i \sim iidN^+\left(0,\sigma_u^2\right)\right)$ (Vu 2003; Coelli, Rao et al. 2005; Tran, Grafton et al. 2008).

To examine the determinants of technical inefficiency, $U_i$ is assumed to be a function of the explanatory variables. This can be defined as the technical efficiency effects model as follows:

$$U_i = \delta_0 + \delta_1 Size_i + \delta_2 Age_i + \delta_3 Skill_i + \delta_4 Location_i + \delta_5 Bangkok_i + \delta_6 Central_i + \delta_7 Northern_i$$

$$+\delta_8 North-eastern_i + \delta_9 Individual_i + \delta_{10} Juristic_i + \delta_{11} Limited_i + \delta_{12} State_i$$

$$+\delta_{13} Co-operative_i + \delta_{14} Foreign_i + \delta_{15} Export_i + \delta_{16} Government-assis\tan ce_i + \omega_i \qquad (3)$$

Where:

$Size_i$ = Dummy for firm size;

$Size_i$ = 1 for small enterprises employing up to 50 workers

= 0 for medium enterprises employing between 51-200 workers

$Age_i$ = Age of firm *i*, represented by of operating years

$Skill_i$ = Skilled labour of firm *i*, represented by the ratio of skilled labor to total workers

$Location_i$ = Dummy for municipal area;

$Location_i$ = 1 if firm *i* is located in a municipal area

= 0, otherwise

$Bangkok_i$ = Dummy for Bangkok;

$Bangkok_i$ = 1 if firm *i* is located in Bangkok

= 0, otherwise

$Central_i$ = Dummy for central region;

$Central_i$ = 1 if firm *i* is located in the central region

= 0, otherwise

$Northern_i$ = Dummy for northern region;

$Northern_i$ = 1 if firm *i* is located in the northern region

= 0, otherwise

$North-eastern_i$ = Dummy for north-eastern;

$North-eastern_i$ = 1 if firm *i* is located in the north-eastern region

= 0, otherwise

$Individual_i$ = Dummy for individual;

$Individual_i$ = 1 if firm *i* is an individual proprietor

= 0, otherwise

$Juristic\ partnership_i$ = Dummy for juristic partnership;

$Juristic\ partnership_i$ = 1 if firm *i* is a juristic partnership

= 0, otherwise

$Limited_i$ = Dummy for limited liability company;

$Limited_i$ = 1 if firm *i* is a limited liability company

= 0, otherwise

$State_i$ = Dummy for state and government enterprises;

$State_i$ = 1 if firm *i* is a state or government enterprise

= 0, otherwise

$Co-operative_i$ = Dummy for co-operative;

$Co-operative_i$ = 1 if firm *i* is a cooperative

= 0, otherwise

$Foreign_i$ = Dummy for foreign investment;

$Foreign_i$ = 1 if firm *i* has foreign investment

= 0, otherwise

$Export_i$ = Dummy for exporting SMEs;

$Export_i$ = 1 if firm *i* exports more than 50 percent of its total sales revenue

= 0, otherwise

$Government\ assistance_i$ = Dummy for government assistance;

$Government\ assistance_i$ = 1 if firm *i* obtains promotional privileges from the BOI

= 0, otherwise

$\delta_i$ = A vector of unknown parameters to be estimated

$\omega_i$ = A random error is defined as the truncation of the normal distribution $N(0,\sigma_\omega^2)$, the position of truncation is $-(\delta_0 + z_i\delta)$ (Coelli, Rao et al. 2005; Tran, Grafton et al. 2008).

The estimated coefficients of the stochastic frontier production function and technical inefficiency effects model can be measured utilizing the maximum likelihood method under the assumption of a normal distribution for $U_i$ (Coelli, Rao et al. 2005; Arunsawadiwong 2007; Tran, Grafton et al. 2008). The validity of the technical inefficiency term and a stochastic frontier production function can be tested by calculating the value of the gamma parameter (γ) (Battese and Corra 1977; Coelli, Rao et al. 2005; Arunsawadiwong 2007). The parameter γ must contain value between 0 and 1 and depends upon two variance parameters of the stochastic frontier function. This can be defined as (Battese and Corra 1977; Coelli, Rao et al. 2005; Arunsawadiwong 2007; Tran, Grafton et al. 2008):

$$\gamma = \sigma_u^2 + \sigma^2 \text{ and } \sigma^2 = \sigma_v^2 / \sigma_u^2 \quad (4)$$

Where:

$\sigma_v^2$ = A variance parameter of random error

$\sigma_u^2$ = A variance parameter of technical efficiency effects

If the value of γ is close to zero deviations from the stochastic frontier function are ascribed to random error, whereas a value of γ close to unity indicates that deviations are due to technical inefficiency (Coelli, Rao et al. 2005; Arunsawadiwong 2007; Tran, Grafton et al. 2008).

**HYPOTHESIS TESTS**

The estimation of a stochastic frontier production function and technical inefficiency effects model can be used to test the validation of four null hypotheses: 1) Adequacy of the Cobb-Douglas production functional form; 2) Absence of technical inefficiency effects; 3) Absence of stochastic inefficiency effects; 4) Insignificance of joint inefficiency variables. Formal hypotheses tests associated with stochastic frontier and technical inefficiency effects models are represented in Tables 1, 2 and 3, respectively. Four hypotheses tests are conducted by utilizing the generalized likelihood-ratio test, which can be expressed as (see Kim 2003; Coelli, Rao et al. 2005; Arunsawadiwong 2007; Tran, Grafton et al. 2008; Amornkitvikai and Harvie 2010; Amornkitvikai and Harvie 2011):

$$\lambda = -2\{log[L(H_0)] - log[L(H_1)]\} \qquad (5)$$

Where:

$log[L(H_0)]$ and $log[L(H_1)]$ are the values of a log-likelihood function for the stochastic frontier model under the null hypothesis $(H_0)$ and the alternative hypothesis $(H_1)$.

Coelli (1996a) emphasized  that the LR test statistic contains an asymptotic chi-square distribution with parameters equal to the number of restricted parameters imposed under the null hypothesis $(H_0)$, except hypotheses (2) and (3) which contain a mixture of a chi-square distribution (Kodde and Palm 1986). Hypotheses (2) and (3) involve the restriction that $\lambda$ is equal to zero which defines a value on the boundary of the parameter space (Coelli 1996a, p6).

Table 1 exhibits results for hypothesis tests for aggregate manufacturing SMEs in the pre (1997) and post (2007) crisis period. From Table 1 the first null hypothesis $(H_0)$ is to test whether a Cobb-Douglas or Translog production function is adequate for aggregate manufacturing SMEs. Following equations (1) and (2) the first null hypothesis is strongly rejected at the 1 percent level of significance for aggregate manufacturing SMEs in the period 1997 and 2007. Thus, the Cobb-Douglas production function is not an adequate specification for aggregate manufacturing SMEs in both periods, given the assumption of the Translog production function, as defined by equation (2). However, the Translog production function generated inadequate [4] estimation of returns to scale for the case aggregate manufacturing SMEs in 1997 and 2007. Therefore, this study is employed a Cobb-Douglas production function for aggregate manufacturing SMEs in 1997 and 2007, as specified by equation (1).

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[4] It is significant to note that due to the magnitude of the estimated coefficients is too large for the case of aggregate manufacturing SMEs in 1997 and 2007. Therefore, this study is used a Cobb-Douglas production function as a preferred functional form in its empirical analysis.

The second null hypothesis $(H_0)$ which specifies that technical inefficiency effects are absent from the model is strongly rejected at the 1 percent level of significance. This implies that the technical inefficiency effects model exists for aggregate manufacturing SMEs in 1997, as defined by equations (1) and (3). It also specifies that the technical inefficiency effects model exists for aggregate manufacturing SMEs in 2007. The third null hypothesis $(H_0)$ is that the inefficiency effects are not stochastic which is strongly rejected at the 1 percent level of significance. The last null hypothesis $(H_0)$ specifies that all estimated parameters of the explanatory variables in the inefficiency effects model are equal to zero.

**Table 1: Statistics for Hypothesis Tests of the Stochastic Frontier Model and Technical Inefficiency Effects Model by Aggregate Manufacturing SMEs**

| Years | Pre Crisis (1997) Period | Post Crisis (2007) Period |
|---|---|---|
| | **Aggregate Manufacturing SMEs** | |
| **Null Hypothesis** | **(1) Cobb-Douglas Production Function** | **(1) Cobb-Douglas Production Function** |
| | $(H_0 = \beta_3 = \beta_4 = \beta_5 = 0)$ | $(H_0 = \beta_3 = \beta_4 = \beta_5 = 0)$ |
| LR Statistics | 343.34 | 45.60 |
| Critical Value | **11.34** | **11.34** |
| Decision | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(2) No technical inefficiency Effects** | **(2) No technical inefficiency Effects** |
| | $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{15} = 0)$ | $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{16} = 0)$ |
| LR Statistics | 4239.44 | 19961.49 |
| Critical Value | **32.77*** | **34.17*** |
| Decision | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(3) Non stochastic Inefficiency** | **(3) Non stochastic Inefficiency** |
| | $(H_0 : \gamma = 0)$ | $(H_0 : \gamma = 0)$ |
| LR Statistics | 754.48 | 2364.34 |
| Critical Value | **5.41*** | **5.41*** |
| Decision | Reject $H_0$ | Reject $H_0$ |

| Null Hypothesis | (4) No joint Inefficiency Variables | (4) No joint Inefficiency Variables |
|---|---|---|
| | $(H_0: \delta_1 = \delta_2 = \cdots = \delta_{15} = 0)$ | $(H_0: \delta_1 = \delta_2 = \cdots = \delta_{16} = 0)$ |
| LR Statistics | 2874.81 | 16415.22 |
| Critical Value | **30.58** | **32.00** |
| Decision | Reject $H_0$ | Reject $H_0$ |

Note: All critical values of the test statistic are presented at the 1% level of significance, obtained from a chi-square distribution, except those indicated by *, which contain a mixture of a chi-square distribution, obtained from Table 1 of Kodde and Palm (1986).

In Table 2 the first null hypothesis $(H_0)$ tests whether a Cobb-Douglas or Translog production functions is an adequate functional form for the size of manufacturing SME (small and medium) in the pre (1997) and post (2007) crisis periods. The null hypothesis $(H_0)$ is strongly rejected at the 1 percent level of significance for size of manufacturing SMEs in the period 1997 and 2007, except for medium enterprises in 1997. Therefore, this study is used a Cobb-Douglas production function for the size of manufacturing SMEs in the period 1997 and 2007, as specified by equation (1). The second null hypothesis $(H_0)$ which specifies that technical inefficiency effects are absent from the model is strongly rejected at the 1 percent level of significance. The third null hypothesis $(H_0)$, that inefficiency effects are not stochastic, is strongly rejected at the 1 percent level of significance. The last null hypothesis $(H_0)$ specifies that all estimated parameters of the explanatory variables in the inefficiency effects model are equal to zero. The null hypothesis is strongly rejected at the 1 percent level of significance for size of manufacturing SMEs, as defined by equations (1) and (3).

**Table 2: Statistics for Hypothesis Tests of the Stochastic Frontier Model and Technical Inefficiency Effects Model by Size of Manufacturing SMEs**

| Years | Pre Crisis (1997) Period | | Post Crisis (2007) Period | |
|---|---|---|---|---|
| | Small Enterprises | Medium Enterprises | Small Enterprises | Medium Enterprises |
| **Null Hypothesis** | **(1) Cobb-Douglas Production Function** | | **(1) Cobb-Douglas Production Function** | |
| | $(H_0 = \beta_3 = \beta_4 = \beta_5 = 0)$ | | $(H_0 = \beta_3 = \beta_4 = \beta_5 = 0)$ | |
| LR Statistics | 245.65 | 0.8 | 558.30 | 25.82 |
| Critical Value | **11.34** | | **11.34** | |
| Decision | Reject $H_0$ | Do not reject $H_0$ | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(2) No technical inefficiency Effects** | | **(2) No technical inefficiency Effects** | |
| | $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{14} = 0)$ | | $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{15} = 0)$ | |
| LR Statistics | 3886.51 | 441.62 | 18120.21 | 2073.68 |
| Critical Value | **31.35*** | | **32.77*** | |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(3) Non stochastic Inefficiency** | | **(3) Non stochastic Inefficiency** | |
| | $(H_0 : \gamma = 0)$ | | $(H_0 : \gamma = 0)$ | |
| LR Statistics | 711.14 | 69.96 | 2132.77 | 328.23 |
| Critical Value | **5.41*** | | **5.41*** | |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(4) No joint Inefficiency Variables** | | **(4) No joint Inefficiency Variables** | |
| | $(H_0 : \delta_1 = \delta_2 = \cdots = \delta_{14} = 0)$ | | $(H_0 : \delta_1 = \delta_2 = \cdots = \delta_{15} = 0)$ | |
| LR Statistics | 2651.95 | 287.22 | 15011.08 | 1416.28 |
| Critical Value | **29.14** | | **30.58** | |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |

Note: All critical values of the test statistic are presented at the 1% level of significance, obtained from a chi-square distribution, except those indicated by *, which contain a mixture of a chi-square distribution, obtained from Table 1 of Kodde and Palm (1986).

Table 3 presents results for hypothesis tests for domestic and exporting SMEs in the pre (1997) and post (2007) crisis periods. In Table 3 the first null hypothesis $(H_0)$ tests whether a Cobb-Douglas or Translog production functions is an adequate functional form for domestic and exporting SMEs in the period 1997 and 2007. The null hypothesis is strongly rejected at the 1 percent level of significance for both periods, except for exporting SMEs in 2007. Hence, a Cobb-Douglas production function is not an adequate functional form for domestic and exporting SMEs in the years 1997 and 2007, whereas an adequate functional form for exporting SMEs in 2007 is a Cobb-Douglas production function.

The second null hypothesis $(H_0)$ which specifies that technical inefficiency effects are absent from the model is strongly rejected at the 1 percent level of significance. This specifies that the technical inefficiency effects model exists for domestic and exporting SMEs in the years 1997 and 2007, given by equations (1) and (3). The third null hypothesis $(H_0)$ is that the inefficiency effects are not stochastic which is strongly rejected at the 1 percent level of significance. The last null hypothesis $(H_0)$ specifies that all estimated parameters of the explanatory variables in the inefficiency effects model are equal to zero. The null hypothesis is strongly rejected at the 1 percent level of significance for domestic and exporting SMEs in the period 1997 and 2007 (see Table 3).

**Table 3: Statistics for Hypothesis Tests of the Stochastic Frontier Model and Technical Inefficiency Effects Model by Domestic and Exporting SMEs**

| Years | Pre Crisis (1997) Period | | Post Crisis (2007) Period | |
|---|---|---|---|---|
| | **Domestic SMEs** | **Exporting SMEs** | **Domestic SMEs** | **Exporting SMEs** |
| **Null Hypothesis** | **(1) Cobb-Douglas Production Function** $(H_0 = \beta_3 = \beta_4 = \beta_5 = 0)$ | | **(1) Cobb-Douglas Production Function** $(H_0 = \beta_3 = \beta_4 = \beta_5 = 0)$ | |
| LR Statistics | 355.82 | 28.30 | 88.33 | 2.92 |
| Critical Value | **11.34** | **11.34** | **11.34** | **11.34** |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Do not reject $H_0$ |
| **Null Hypothesis** | **(2) No technical inefficiency Effects** $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{15} = 0)$ | **(2) No technical inefficiency Effects** $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{14} = 0)$ | **(2) No technical inefficiency Effects** $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{16} = 0)$ | **(2) No technical inefficiency Effects** $(H_0 : \gamma = \delta_0 = \delta_1 = \cdots = \delta_{15} = 0)$ |
| LR Statistics | 4037.52 | 151.67 | 19375.02 | 245.14 |
| Critical Value | **32.77*** | **31.35*** | **34.17*** | **32.77*** |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(3) Non stochastic Inefficiency** $(H_0 : \gamma = 0)$ | | **(3) Non stochastic Inefficiency** $(H_0 : \gamma = 0)$ | |
| LR Statistics | 747.25 | 11.90 | 2357.54 | 13.67 |
| Critical Value | **5.41*** | **5.41*** | **5.41*** | **5.41*** |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |
| **Null Hypothesis** | **(4) No joint Inefficiency Variables** $(H_0 : \delta_1 = \delta_2 = \cdots = \delta_{15} = 0)$ | **(4) No joint Inefficiency Variables** $(H_0 : \delta_1 = \delta_2 = \cdots = \delta_{14} = 0)$ | **(4) No joint Inefficiency Variables** $(H_0 : \delta_1 = \delta_2 = \cdots = \delta_{16} = 0)$ | **(4) No joint Inefficiency Variables** $(H_0 : \delta_1 = \delta_2 = \cdots = \delta_{15} = 0)$ |
| LR Statistics | 2712.63 | 114.53 | 15893.11 | 210.03 |
| Critical Value | **30.58** | **29.14** | **32.00** | **30.58** |
| Decision | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |

Note: All critical values of the test statistic are presented at the 1% level of significance, obtained from a chi-square distribution, except those indicated by *, which contain a mixture of a chi-square distribution, obtained from Table 1 of Kodde and Palm (1986).

## EMPIRICAL RESULTS

The maximum likelihood estimates for parameters of stochastic frontier and technical inefficiency effects models, as specified by equations (1) and (3), and equations (2) and (3), respectively, and were estimated simultaneously with the econometric package Frontier 4.1 utilizing firm-level industrial census data for 1997 and 2007. The estimated results for equations (1) and (3) and equations (2) and (3), are provided in Tables 4 and 5. The estimation of the technical inefficiency effects model is presented in Table 6. A summary for the average technical efficiency of manufacturing SMEs in the pre crisis (1997) period and the post crisis (2007) period is shown in Table 7.

### Results of Input Elasticities and Gamma Parameters

Table 4 presents the results of the maximum likelihood estimation for aggregate manufacturing SMEs and the size of manufacturing SME (small and medium) in the pre (1997) and post (2007) crisis periods. In 1997 the main Cobb-Douglas production function, it is indicated that aggregate manufacturing SMEs and the size of manufacturing SMEs have positive signs for both capital $(\beta_1)$ and labor $(\beta_2)$ and they are also highly significant at the 1 percent level of significance.

In the pre crisis (1997) period the gamma parameter (γ) determines that all deviations from the stochastic frontier model are due to random error or technical inefficiency. If the gamma parameter (γ) is close to zero this specifies that all deviations from the model are caused by random error.

In the post crisis (2007) period the main Translog production function the elasticity of capital $(\beta_1)$ and labor $(\beta_2)$ reveals decreasing returns to scale for aggregate manufacturing SMEs, which is 0.83. This number can be calculated as the sum of the elasticity of output with respect to capital input and $\frac{lnY_i}{\partial K_i} = \beta_1 + \beta_3 \ln(K_i) + \beta_5 \ln(L_i)$ the elasticity of output with respect to labor input $\frac{lnY_i}{\partial L_i} = \beta_2 + \beta_4 \ln(L_i) + \beta_5 \ln(K_i)$ from an estimated Translog frontier production function, as specified by equations (2) (see Kim, (1992)). The estimate of variance parameter gamma (γ) is 0.650 (see Table 4), meaning that all deviations are caused by technical inefficiency (Coelli, Rao et al. 2005).

Table 4 also exhibits the results of maximum likelihood estimation by size of SME (small and medium) in the post crisis (2007) period. It is found that small enterprises have positive signs for both capital $(\beta_1)$ and labor $(\beta_2)$, which are 0.219 and 1.042, respectively. They are also highly significant at the 1 percent level of significance. The small enterprises are found to have increasing returns to scale, because the combined values of the estimated input coefficient (1.26) is higher than unity. The estimated gamma parameter of small enterprises is 0.65 (see Table 4), indicating that all deviations from the model are ascribed to technical inefficiency. For medium enterprises the coefficients of capital ($\beta_1$) and labor ($\beta_2$) have positive signs, which are 0.307 and 0.653, respectively, and they are statistically significant at the 1 percent level of significance. Medium enterprises tend to have constant returns to scale because the summed value of the estimated input coefficients (0.96) is close to unity. The estimate of the variance parameter of gamma is 0.770.

**Table 4: Maximum Likelihood Estimates for Parameters of the Stochastic Frontier Model and Technical Inefficiency Effects Model by Aggregate Manufacturing SMEs and Size of SMEs**

| **Years** | **Pre Crisis (1997) Period** | | | **Post Crisis (2007) Period** | | |
|---|---|---|---|---|---|---|
| **Variables** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** |
| **Number of Observations** | **22685** | **18214** | **4471** | **56441** | **49835** | **6606** |
| | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients |
| **Stochastic Frontier Model** | | | | | | |
| Constant | 6.139*** | 6.453*** | 5.219*** | 5.070*** | 5.407*** | 5.956*** |
| | (0.045) | (0.054) | (0.159) | (0.056) | (0.039) | (0.144) |
| Capital | 0.222*** | 0.194*** | 0.343*** | 0.273 | 0.219*** | 0.307*** |
| | (0.004) | (0.004) | (0.011) | (0.894) | (0.003) | (0.007) |
| Labour | 0.837*** | 0.825*** | 0.724*** | 3.132*** | 1.042*** | 0.653*** |
| | (0.009) | (0.012) | (0.032) | (0.894) | (0.007) | (0.028) |
| $Capital^2$ | | | | -0.000 | | |
| | | | | (0.447) | | |
| $Labour^2$ | | | | -1.004** | | |
| | | | | (0.447) | | |
| Capital*Labour | | | | -0.014*** | | |
| | | | | (0.001) | | |

| Years | Pre Crisis (1997) Period | | | Post Crisis (2007) Period | | |
|---|---|---|---|---|---|---|
| **Variables** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** |
| **Number of Observations** | **22685** | **18214** | **4471** | **56441** | **49835** | **6606** |
| | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients |
| **Technical Inefficiency Effects Model** | | | | | | |
| Constant | 3.146*** | 2.761*** | 3.523*** | 2.995*** | 2.586*** | 1.719*** |
| | (0.163) | (0.142) | (0.386) | (0.067) | (0.045) | (0.214) |
| Firm Size (dummy) | -0.386*** | N/A | N/A | -0.463*** | N/A | N/A |
| | (0.105) | | | (0.060) | | |
| Firm Age (years) | -0.005* | 0.001 | -0.064*** | -0.002** | -0.002* | -0.023*** |
| | (0.003) | (0.003) | (0.013) | (0.001) | (0.001) | (0.004) |
| Skilled Labour (ratio) | N/A | N/A | N/A | -0.819*** | -0.854*** | 0.411*** |
| | | | | (0.030) | (0.026) | (0.111) |
| Municipality (dummy) | -0.559*** | -0.774*** | 0.402*** | -0.349*** | -0.385*** | 0.090 |
| | (0.073) | (0.099) | (0.134) | (0.026) | (0.025) | (0.103) |
| Bangkok Area (dummy) | -3.202*** | -2.893*** | -3.425*** | -2.188*** | -2.343*** | -2.055*** |
| | (0.336) | (0.281) | (0.773) | (0.162) | (0.193) | (0.518) |
| Central & Vicinity Regions | -0.176** | -0.157* | 0.021 | -0.010 | 0.009 | -0.425** |
| (dummy) | (0.076) | (0.091) | (0.189) | (0.038) | (0.037) | (0.207) |
| Northern Region (dummy) | -0.286*** | -0.335*** | 0.377* | 0.661*** | 0.641*** | 2.330*** |
| | (0.085) | (0.104) | (0.230) | (0.036) | (0.035) | (0.212) |

| **Years** | **Pre Crisis (1997) Period** | | | **Post Crisis (2007) Period** | | |
|---|---|---|---|---|---|---|
| **Variables** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** |
| **Number of Observations** | **22685** | **18214** | **4471** | **56441** | **49835** | **6606** |
| | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients |
| North-eastern Region (dummy) | 0.376*** | 0.358*** | 0.684*** | 0.364*** | 0.389*** | -0.129 |
| | (0.084) | (0.121) | (0.246) | (0.037) | (0.033) | (0.195) |
| Individual Proprietor (dummy) | -2.606*** | -2.594*** | -3.300*** | -1.163*** | -1.245*** | -1.584*** |
| | (0.171) | (0.180) | (0.536) | (0.032) | (0.034) | (0.196) |
| Juristic Partnership (dummy) | -4.821*** | -5.000*** | -4.110*** | -2.893*** | -2.960*** | -3.429*** |
| | (0.302) | (0.355) | (0.574) | (0.088) | (0.101) | (0.300) |
| Limited & Public Limited | -5.753*** | -5.959*** | -5.114*** | -4.208*** | -4.469*** | -4.545*** |
| company (dummy) | (0.346) | (0.434) | (0.763) | (0.142) | (0.191) | (0.356) |
| Government & State Enterprises | -1.789*** | -3.191*** | -1.736*** | 0.607*** | 0.009 | 1.383*** |
| (dummy) | (0.390) | (0.711) | (0.469) | (0.145) | (0.198) | (0.242) |
| Cooperatives (dummy) | -2.151*** | -2.069*** | -15.257*** | -1.718*** | -1.901*** | -0.727* |
| | (0.210) | (0.224) | (4.129) | (0.150) | (0.163) | (0.443) |
| Foreign Investment (dummy) | -1.431*** | -0.854** | -1.176*** | -0.802*** | -0.258 | -0.951*** |
| | (0.184) | (0.396) | (0.281) | (0.284) | (0.396) | (0.217) |
| Exports (dummy) | -0.608*** | -1.020*** | -0.226** | -0.449** | -0.621** | -0.194 |
| | (0.094) | (0.177) | (0.106) | (0.199) | (0.264) | (0.333) |

| Years | Pre Crisis (1997) Period | | | Post Crisis (2007) Period | | |
|---|---|---|---|---|---|---|
| **Variables** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** | **Aggregate Manufacturing SMEs** | **Small Enterprises** | **Medium Enterprises** |
| **Number of Observations** | **22685** | **18214** | **4471** | **56441** | **49835** | **6606** |
| | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients | Coefficients |
| Government Assistance (BOI) | -0.054 | 0.228 | -0.397** | -0.343 | -0.353 | -1.270*** |
| (dummy) | (0.140) | (0.210) | (0.168) | (0.226) | (0.327) | (0.369) |
| **Variance Parameters** | | | | | | |
| Sigma-squared | 3.594*** | 3.581*** | 3.142*** | 1.798*** | 1.782*** | 2.664*** |
| | (0.246) | (0.255) | (0.517) | (0.028) | (0.031) | (0.237) |
| Gamma | 0.797*** | 0.803*** | 0.756*** | 0.650*** | 0.652*** | 0.770*** |
| | (0.014) | (0.014) | (0.042) | (0.006) | (0.007) | (0.022) |
| Log-likelihood Function | -33204.03 | -26595.03 | -6483.26 | -83114.64 | -73972.99 | -8800.36 |
| **Mean Technical Efficiency** | 0.59 | 0.58 | 0.62 | 0.44 | 0.42 | 0.65 |
| **Returns to scale** | 1.06 | 1.02 | 1.07 | 0.83 | 1.26 | 0.96 |

Note: Standard errors are in brackets; *, ** and *** indicate that the coefficients are statistically significant at 10%, 5% and 1%, respectively

Table 5 shows the results for domestic and exporting SMEs in the pre crisis (1997) period and the post crisis (2007) period. In 1997 the estimated coefficients of capital $(\beta_1)$ and labor $(\beta_2)$ are positive and they are strongly significant at the 1 percent level of significance in domestic and exporting manufacturing SMEs. The input elasticities of capital $(\beta_1)$ and labor $(\beta_2)$ reveal increasing returns to scale in domestic manufacturing SMEs, because the sum of the estimated input coefficients (1.06) obtained from the stochastic frontier models is higher than unity, whereas exporting SMEs exhibit decreasing returns to scale because the combined value of the estimated input coefficients (0.89) is less than unity (see Table 5).

In the post crisis (2007) period the main Cobb-Douglas production function, it is implied that domestic and exporting SMEs have positive signs for both capital $(\beta_1)$ and labor $(\beta_2)$ and they are also strongly significant at the 1 percent level of significance. Domestic SMEs are found to have increasing returns to scale, because the combined values of the estimated input coefficient obtained from the stochastic frontier models is higher than unity, which is 1.22, whereas exporting SMEs are found to present decreasing returns to scale because the sum of estimated input coefficients (0.84) is less than unity. However, it is significant to state that there are different elasticities in domestic and exporting manufacturing SMEs. The elasticities of labor $(\beta_2)$ in the stochastic production functions are much higher than capital$(\beta_1)$.

**Table 5: Maximum Likelihood Estimates for Parameters of the Stochastic Frontier Model and Technical Inefficiency Effects Model by Domestic and Exporting SMEs**

| Years | Pre Crisis (1997) Period | | Post Crisis (2007) Period | |
|---|---|---|---|---|
| **Variables** | **Domestic SMEs** | **Exporting SMEs** | **Domestic SMEs** | **Exporting SMEs** |
| **Number of Observations** | **20791** | **1894** | **54676** | **1765** |
| | Coefficients | Coefficients | Coefficients | Coefficients |
| **Stochastic Frontier Model** | | | | |
| Constant | 6.144*** | 6.684*** | 5.425*** | 6.925*** |
| | (0.045) | (0.217) | (0.033) | (0.271) |
| Capital | 0.219*** | 0.254*** | 0.231*** | 0.260*** |
| | (0.004) | (0.015) | (0.002) | (0.017) |
| Labour | 0.842*** | 0.640*** | 0.984*** | 0.589*** |
| | (0.009) | (0.042) | (0.006) | (0.049) |

| Years | Pre Crisis (1997) Period | | Post Crisis (2007) Period | |
|---|---|---|---|---|
| **Variables** | **Domestic SMEs** | **Exporting SMEs** | **Domestic SMEs** | **Exporting SMEs** |
| **Number of Observations** | **20791** | **1894** | **54676** | **1765** |
| | Coefficients | Coefficients | Coefficients | Coefficients |
| **Technical Inefficiency Effects Model** | | | | |
| Constant | 3.154*** | 1.672** | 3.006*** | -0.096 |
| | (0.182) | (0.724) | (0.067) | (0.970) |
| Firm Size (dummy) | -0.433*** | 0.764** | -0.483*** | 0.271 |
| | (0.098) | (0.329) | (0.057) | (0.182) |
| Firm Age (years) | -0.004 | -0.050*** | -0.002** | 0.005 |
| | (0.004) | (0.019) | (0.001) | (0.007) |
| Skilled Labour (ratio) | N/A | N/A | -0.867*** | 0.316 |
| | | | (0.027) | (0.209) |
| Municipality (dummy) | -0.553*** | -0.733** | -0.361*** | -0.040 |
| | (0.080) | (0.345) | (0.027) | (0.121) |
| Bangkok Area (dummy) | -3.317*** | -1.874* | -2.290*** | 1.352 |
| | (0.347) | (1.096) | (0.163) | (0.793) |
| Central & Vicinity Regions (dummy) | -0.188** | 0.301 | -0.024 | 1.829 |
| | (0.080) | (0.323) | (0.037) | (1.079) |
| Northern Region (dummy) | -0.332*** | 0.436 | 0.658*** | 2.299** |
| | (0.091) | (0.341) | (0.035) | (1.126) |
| North-eastern Region (dummy) | 0.392*** | 0.351 | 0.362*** | 2.360** |
| | (0.093) | (0.410) | (0.035) | (1.198) |
| Individual Proprietor (dummy) | -2.687*** | -1.302** | -1.141*** | -0.541 |
| | (0.199) | (0.586) | (0.029) | (0.335) |
| Juristic Partnership (dummy) | -5.016*** | -2.111*** | -2.953*** | -1.267*** |
| | (0.349) | (0.659) | (0.092) | (0.352) |
| Limited & Public limited company (dummy) | -5.997*** | -2.659*** | -4.213*** | -1.556*** |
| | (0.411) | (0.768) | (0.131) | (0.329) |
| Government & State Enterprises (dummy) | -1.834*** | -3.109 | 0.631*** | -5.384 |
| | (0.387) | (1.950) | (0.149) | (4.480) |

| Years | Pre Crisis (1997) Period | | Post Crisis (2007) Period | |
|---|---|---|---|---|
| **Variables** | **Domestic SMEs** | **Exporting SMEs** | **Domestic SMEs** | **Exporting SMEs** |
| **Number of Observations** | **20791** | **1894** | **54676** | **1765** |
| | Coefficients | Coefficients | Coefficients | Coefficients |
| Cooperatives (dummy) | -2.191*** | -11.717 | -1.751*** | 0.533 |
| | (0.237) | (9.582) | (0.149) | (0.995) |
| Foreign Investment (dummy) | -1.983*** | -0.194 | -0.380* | -0.289 |
| | (0.289) | (0.168) | (0.211) | (0.191) |
| Exports (dummy) | -0.239** | N/A | -0.525* | N/A |
| | (0.118) | | (0.270) | |
| Government Assistance (BOI) (dummy) | 0.141 | -0.945** | -0.473 | -0.096 |
| | (0.151) | (0.397) | (0.296) | (0.970) |
| **Variance Parameters** | | | | |
| Sigma-squared | 3.696*** | 2.258*** | 1.815*** | 0.946*** |
| | (0.280) | (0.599) | (0.029) | (0.198) |
| Gamma | 0.805*** | 0.648*** | 0.660*** | 0.239 |
| | (0.015) | (0.097) | (0.006) | (0.232) |
| Log-likelihood Function | -30449.14 | -2715.88 | -80691.46 | -2346.28 |
| **Mean Technical Efficiency** | 0.58 | 0.64 | 0.44 | 0.63 |
| **Returns to scale** | 1.06 | 0.89 | 1.22 | 0.84 |

Note: Standard errors are in brackets; *, ** and *** indicate that the coefficients are statistically significant at 10%, 5% and 1%, respectively

**Results of Technical Inefficiency Effects Model**

The model defined by equations (1) and (3) and equations (2) and (3), were estimated simultaneously using the econometric Frontier version 4.1. The estimated results, in terms of the signs of the coefficients and their significance, for equations (1) and (3) and equations (2) and (3) are represented in Table 6. All negative coefficient signs of the technical inefficiency effects model represent technical inefficiency. However, all negative signs must be converted to positive for their relationship to technical efficiency.

**Firm-Specific Factors**

Many empirical have found that firm size is one of the important firm-specific factors contributing to a firm's technical efficiency (Lundvall & Battese 2000; Admassie & Matambalya 2002; Kim 2003; Yang 2006; Tran, Grafton et al. 2008; Park, Shin et al. 2009; Amornkitvikai and Harvie 2010; Amornkitvikai & Harvie 2011). In the pre crisis (1997) period the estimated coefficients for firm size in the technical inefficiency effects model have negative signs for aggregate manufacturing SMEs and domestic SMEs, and they are strongly significant at the 1 percent level of significance. This specifies that firm size has a positive correlation with a firm's technical efficiency. However, the coefficient of exporting SMEs in 1997 has a positive sign and it is significant at the 5 percent level of significance.

A number of empirical studies have investigated that the age of a firm has a positive and significant association with the technical efficiency (Admassie & Matambalya 2002; Batra & Tan 2003; Phan 2004; Tran, Grafton et al. 2008; Park, Shin et al. 2009; Amornkitvikai and Harvie 2010). In the pre crisis (1997) period the estimates of the coefficients for firm age have negative signs for aggregate manufacturing SMEs, medium sized enterprises, domestic SMEs and exporting SMEs. The significance level of the negative coefficients varies among these categories. The coefficient of medium enterprises and exporting SMEs are highly significant at the 1 percent level, while the coefficient of aggregate manufacturing SMEs is significant at the 10 percent level, and the coefficient of domestic SMEs is not statistically significant.

Skilled labor is another firm-specific factor affecting to a firm's technical efficiency. In 2007 the estimated coefficients for skilled labor, represented by the ratio of skilled labor to total workers, are negative and highly significant at the 1 percent level of significance in three categories, including aggregate manufacturing SMEs, small enterprises and domestic SMEs. This implies that skilled labor has a positive association with a firm's technical efficiency. *Many empirical studies have examined that* skilled labor is positively related to a firm's technical efficiency (Admassie and Matambalya 2002; Zahid and Mokhtar 2007; Amornkitvikai and Harvie 2010).

In the pre crisis (1997) period the estimates for the coefficients for municipality contain negative signs for four categories, comprising aggregate manufacturing SMEs, small enterprises, and domestic and exporting SMEs. The coefficients for four categories are statistically significant and the levels of significance are different. The coefficients for aggregate manufacturing SMEs, small enterprises and domestic SMEs are strongly significant at the 1 percent level of significance, while the coefficient of exporting SMEs is significant at 5 percent level. These results suggest that firm that municipality has a positive impact on a firm's technical efficiency. Several empirical studies reveal that a municipal area has a positive relationship to technical efficiency (Krasachat 2000; Li and Hu 2002; Yang 2006; Park, Shin et al. 2009; Le and Harvie 2010).

In the pre crisis (1997) period results of the dummy variable for the Bangkok area show the negative signs for all categories. The coefficient of aggregate manufacturing SMEs, small and medium sized enterprises and domestic SMEs are strongly significant at the 1 percent level of significance, while the coefficient of exporting SMEs is significant at the 10 percent level. This implies that the Bangkok area has a positive correlation with a firm's technical efficiency. The Bangkok area contained the highest number of SMEs over the period 1994 to 2009, accounting for around 30 percent of total SMEs on average. Bangkok area is also recognized as the major economic centre of the nation (Office of Small and Medium Enterprises Promotion, 2001-2009).

In the pre crisis (1997) period the results of the estimated coefficients for this dummy variable exhibit mixed results, with negative signs in aggregate manufacturing SMEs, small enterprises and domestic SMEs, and positive signs medium enterprises and exporting SMEs. The coefficients for aggregate manufacturing SMEs, domestic SMEs are significant at the 5 percent level of significance, and the coefficient of small enterprises is significant the 10 percent level of significance, whereas the coefficients of medium enterprises and exporting SMEs are insignificant. From these results it can be suggested that central and vicinity regions are positively related with a firm's technical efficiency. The central and vicinity regions contain many of Thailand's large businesses (OSMEP 2008). In the post crisis (2007) period the estimates of the coefficients for central and vicinity regions are investigated to be negative for aggregate manufacturing SMEs, medium enterprises and domestic SMEs.

In the pre crisis (1997) period the estimates of the coefficient for northern region are found to be negative for aggregate manufacturing SMEs, small enterprises and domestic SMEs and they are highly significant at the 1 percent level of significance. This specifies that northern region has a positive relationship with a firm's technical efficiency. The Northern area had 311,681 SMEs equivalent to 17 percent of all SMEs on average during 1994 to 2008 (Office of Small and Medium Enterprises Promotion, (2001-2008).

For north-eastern region, in the pre crisis (1997) period the estimates of the coefficients for the north-eastern region have positive signs for all categories, and they are strongly significant at the 1 percent level of significance, except exporting SMEs which is insignificant. This specifies that the north-eastern region has a negative correlation with a firm's technical efficiency. According to the Office of Small and Medium Enterprises Promotion, (2001-2008) , the second highest number of SMEs in the nation can be found in the North-eastern area, having 514,498 SMEs equivalent to 27.41 percent of all SMEs on average during 1994 to 2008.

In the pre crisis (1997) period the negative coefficients for individual proprietor in all categories confirm a positive relationship between individual proprietor and a firm's technical efficiency. The coefficients of aggregate manufacturing SMEs, small and medium sized enterprises and domestic SMEs are strongly significant at the 1 percent level of significance, while the coefficient of exporting SMEs is significant at the 5 percent level. From these results it can be indicated that individual proprietor is highly positively related to a firm's technical efficiency. For juristic partnership estimation, the coefficients for juristic partnership in the period 1997 and 2007 have negative signs for all categories, and they are highly significant at the 1 percent level of significance. This implies that there is a positive relationship between juristic partnership and the technical efficiency of firms. As compared to an individual or sole proprietorship, a juristic partnership has the advantage of allowing the owner to draw on resources and expertise of co-partners. It can be easy formed by an oral agreement between two or more people. With a juristic partnership partners share risk and management, and solve barriers to doing business (Cooper and Dunkelberg 2006; Fernández and Nieto 2006; Ha 2006).

Finally, estimates of the coefficients for limited and public limited companies in the period 1997 and 2007 have negative signs for all categories. The negative coefficients of these categories are strongly significant at the 1 percent level of significance. This can be interpreted to mean that limited and public limited companies in 1997 and 2007 are positively related with technical efficiency in all categories (see Table 6).. A number of studies highlighted that the advantages of limited and public limited companies are (Cooper & Dunkelberg 2006; Fernández & Nieto 2006; Ha 2006): 1) It has a legal existence which separates management from shareholders; 2) A company can continue despite the resignation or bankruptcy of management and its members; 3) It gives personal liability protection for members; 4) Members can draw up their own contact that allows flexibility in responsibility and management.

**Results of Average Technical Efficiency of Thai manufacturing SMEs**

Table 6 exhibits the mean technical efficiency of Thai manufacturing SMEs in the pre (1997) and post (2007) crisis periods. As presented in the table, the mean technical efficiency in all categories decrease in the post crisis (2007) period compared to the pre crisis (1997) period, with the exception of medium enterprises. Aggregate manufacturing SMEs, small enterprises, and domestic and exporting SMEs in the post crisis period show a decline in their technical efficiency levels, whereas medium enterprises present an improvement in the technical efficiency. The overall average technical efficiency ranges from 58 percent in the pre crisis period to 50 percent in the post crisis period, indicating a deterioration of technical efficiency of Thai manufacturing SMEs in the post crisis. This also signifies that Thai manufacturing SMEs face a high level of technical inefficiency in the production process in both 1997 and 2007.

**Table 6: Average Technical Efficiency of Thai manufacturing SMEs**

| Years | Pre Crisis (1997) Period | Post Crisis (2007) Period |
|---|---|---|
| **Categories** | **Mean Technical Efficiency** | **Mean Technical Efficiency** |
| Aggregate manufacturing SMEs | 0.59 | 0.44 |
| Small Enterprises | 0.58 | 0.42 |
| Medium Enterprises | 0.62 | 0.65 |
| Domestic SMEs | 0.58 | 0.44 |
| Exporting SMEs | 0.64 | 0.63 |
| **Overall Average Technical Efficiency** | **0.58** | **0.50** |

## CONCLUSIONS

Thai SMEs have played an important role in the Thai economy in terms of numbers, employment and economic growth during the period 1994 to 2009 (OSMEP 2007b; OSMEP 2008; OSMEP 2009). SMEs are the backbone of Thai economy and contributed a great distribute to social and economic development of the country (Regnier 2000; Brimble, Oldfield et al. 2002; Wiboonchutikula 2002; Sahakijpicharn 2007; OSMEP 2009). This study contributes the first empirical study to apply a stochastic frontier production function and technical inefficiency effects model to estimate and compare the technical efficiency of Thai manufacturing SMEs in the pre (1997) and post (2007) financial crisis periods, utilizing cross-sectional data from industrial censuses for Thailand covering the period 1997 and 2007, classified into five categories - aggregate manufacturing SMEs, small and medium sized enterprises, domestic and exporting SMEs. These categories of Thai manufacturing SMEs were estimated individually to predict technical efficiency and examine whether technical efficiency is positively or negatively related to firm-specific factors, including firm size, firm age, skilled labor, location (municipal and non-municipal areas), regional effect, type of ownership, foreign investment, exports and government assistance.

The empirical evidence from a stochastic frontier production function highlights that the average technical efficiency of all categories of Thai manufacturing SMEs in the pre (1997) and post (2007) financial crisis periods are 58 percent and 50 percent, respectively. This signifies that there are high levels of technical inefficiency in the production process of Thai manufacturing SMEs in both periods. It also indicates that Thai manufacturing SMEs experience no technical efficiency improvement in the post crisis (2007) period. The Thai government should target policies aimed at rationalizing the number of government agencies that provide incentives and services for SME development (Harvie and Lee 2005b; OSMEP 2007b; Amornkitvikai and Harvie 2010). The empirical evidence also indicates that the production in all categories of Thai manufacturing SMEs in the pre (1997) and post (2007) crisis periods remain heavily dependent upon unskilled labor input and the production of low skill and low value adding output. Capital input remains of lesser importance in both periods, but it will be critical, if SMEs are to become more efficient, competitive and to move into higher value adding areas of activity that they adopt higher levels of technology and are more innovative in their activities (i.e., new product standards, processes, managerial and technological upgrading, marketing and management) (Dhanani & Scholtès 2002; Chirasirimongkol & Chutimaskul 2005; Punyasavatsut 2007; OSMEP 2007b; Thai Industrial Standards Institute 2009).

The empirical evidence of the technical inefficiency effects model specifies that firm size and firm age are positively and significantly correlated with the technical efficiency for the majority of categories of Thai manufacturing SMES in both pre (1997) and post (2007) crisis periods. Skilled labor has a significantly positive correlation with the technical efficiency for aggregate manufacturing SMEs, small enterprises and domestic SMEs in the post crisis (2007) period. Location in a municipal and Bangkok areas is positively and significantly correlated with the technical efficiency for the majority of categories of manufacturing SMEs in both pre (1997) and post crisis (2007) periods. However, location in northern and north-eastern regions is negatively and significantly correlated with the technical efficiency for the majority of categories of Thai manufacturing SMEs in both periods. In addition, central and vicinity regions has a positive and significant correlation with the technical efficiency for aggregate manufacturing SMEs, small enterprises and domestic SMEs in the pre crisis (1997) period, and is positively and significantly correlated with the technical efficiency for only medium enterprises in the post crisis (2007) period. Type of ownership of Thai manufacturing SMEs - individual proprietor, juristic partnership, public and limited company is highly positive and significant correlation with the technical efficiency for all categories of Thai manufacturing SMEs in the pre (1997) and post (2007) crisis periods.

Government and state enterprises are positively and significantly with the technical efficiency for all categories of Thai manufacturing SMEs in the pre crisis (1997) period, whereas they are negative and significant correlation with the technical efficiency for the majority of categories of manufacturing SMEs in the post crisis (2007) period. Cooperatives are positively and significantly correlated with the technical efficiency for all categories of manufacturing SMEs in both pre (1997) and post (2007) crisis periods, with the except for exporting SMEs in 2007. Foreign investment have a positive and significant correlation with the technical efficiency for all categories of manufacturing SMEs in the pre (1997) and the post (2007) crisis periods. Exports are positively and significantly correlated with the technical efficiency for all categories of manufacturing SMEs in both pre (1997) and post (2007) crisis periods. Finally, the government assistance via the Office of Board of Investment (BOI) has a positive and significant correlation with the technical efficiency for medium enterprises and exporting SMEs in the pre crisis (1997) period, and is positively and significantly correlated with the technical efficiency for only medium enterprises in the post crisis (2007) period.

Therefore, it is recommended that Thai government agencies should strengthen technical assistance and practical policy in an attempt to improve the technical efficiency level in all categories of Thai manufacturing SMEs. It is also suggested that specific policy implications should place more emphasis on providing market access, access to credit facilities, promote the utilization of information technology and communication (ICT), provide financial assistance to avoid management risks and financial problems, provide knowledge of marketing and to improve the quality and competency of SME employees will be critical to enhance the technical efficiency of manufacturing SMEs, provide appropriate distribution of equity in terms of the political operation and extensive infrastructural development (Brimble, Oldfield et al. 2002; Huang 2003; Mephokee 2003; Arunsawadiwong 2007; OSMEP 2007b; OSMEP 2008). Furthermore, the government should place more focus upon the encouragement of encourage public and private partnerships at the local level to improve the business environment for SMEs with continual monitoring and assessing of existing policy measures and enhancing the effectiveness of their delivery, expand the coverage and the impact of government programs by utilizing the private sector to distribute services, and focus on scarce public resources in an attempt to facilitate market transactions and invest in public goods (Hallberg 2000; Asasen, Asasen et al. 2003; Harvie and Lee 2005b; Hussain, Hussain et al. 2009).

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