Technological Innovation, CEO Characteristics and Firm Cost Efficiency:
An Application of the Stochastic Cost Frontier Model to Thai Manufacturers

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Abstract

This study employs the World Bank's 2006 Enterprise Survey (Manufacturing Survey) and the stochastic cost frontier and cost inefficiency effects models to empirically examine the significant sources of technological innovation and CEO characteristics, as well as other factors related to the cost efficiency of Thai manufacturers. Technological innovation, CEO education and firm size are significantly and positively related to Thai manufacturers' cost efficiency. Their production costs also see decreasing returns to scale with a high level of cost inefficiency. In addition, the maximum likelihood tobit regression model is used to empirically investigate the determinants of CEO characteristics and other factors affecting Thai manufacturers' technological innovation. The results reveal that CEO education and gender, firm size, exports and the supply of professional workers have a significant and positive correlation with a firm's technological innovation. Empirically evidence-based policies and recommendations to enhance the cost efficiency and technological innovation of Thai manufacturers are provided.

Keywords: technological innovation, CEO characteristics, cost efficiency, Stochastic Frontier Analysis

1. Introduction

Thailand has become a middle-income country with a small, open economy. Its economic performance has been expanding through exports since the 1980s (OECD, 2013), but it now faces a middle-income trap as it comes under pressure from low-cost, more dynamic economies such as those in China, India, Viet Nam and Indonesia. It is also threatened by more technological, learning-intensive economies such as those in Singapore, Korea, Hong Kong, China and Taipei (OECD, 2013, p. 255). In addition, Thailand's economic performance, which is based on manufacturing exports, has been lower than that of other Southeast Asian countries, and its economic expansion is directly threatened by competition in labour-intensive manufactured goods from countries such as India, China, Viet Nam and Indonesia. Thailand's innovation performance is relatively below that of leading high-income countries and increasingly weaker than that of middle-income Southeast Asian nations (OECD, 2003, p. 262). Technological capabilities, research and development (R&D) spending, and the number of patents and science and technology workers in Thailand are relatively lower than those of its main competitors such as Malaysia and Singapore (OECD, 2013). More importantly, during the period 2005-2010 the growth rate in Thailand's labour productivity declined considerably, from 5.9 percent to 2.1 percent. Similarly, total factor productivity growth fell from 3.6 percent during 1975-1990 to 3.2 percent between 2005 and 2010 (see APO (2013)). The lack of a large, skilled workforce in Thailand worsens the problem of insufficient human capital, which ultimately constrains innovation. Moreover, education and entrepreneurs increasingly become an important factor in enhancing a country's productivity and efficiency, since the shortage of technological innovation, engineers, skilled technical workers and local entrepreneurs can limit future productivity growth as mentioned in Liefner and Schiller (2008) and OECD (2013). Focusing on Thailand's innovative performance, the OECD (2013, p. 262) suggests that the country is far below that of leading high-income economies and is falling further behind that of other middle-income nations in Southeast Asia because it has one of the lowest levels of R&D spending and workers in the region.

2. Objectives

Given the prominent problems mentioned above, this paper aims to empirically investigate: i) the significant factors that affect a firm's cost efficiency and ii) the significant sources of technological

innovation that have not been empirically examined in the context of Thai manufacturing enterprises. This study specifically examines the significant impact of technological innovation and CEO characteristics (education, gender, nationality and experience) on a firm's cost efficiency, as well as other significant factors such as firm size and age, domestic ownership and unskilled foreign labour. In contrast, studies such as Charoenrat et al. (2013) have focused on a firm's performance only as measured by technical efficiency. Finally, factors such as i) CEO characteristics, ii) exports, iii) professional workers, iv) firm size and v) domestic ownership affecting Thai manufacturers' technological innovation are also examined; these factors have not been investigated empirically in other studies of Thailand. This paper also provides evidence-based policy implications and recommendations to enhance Thai manufacturers' efficiency and competitiveness. This paper's structure is as follows: Section 3 provides the background of the Thai manufacturing sector and its importance; Section 4 reviews the literature; Sections 5 and 6 provide the methodology and empirical models used in this study, respectively; Section 7 examines the study's data source and data classification; Section 8 provides the hypothesis tests and empirical results; and the final section contains the conclusion and policy implications.

3. Thai Manufacturing Sector and Its Importance

Thailand is a lower middle-income country with a small, open economy (Punyasavasut, 2008). The economy's GDP structure has changed gradually over the past decades. The manufacturing sector contributed significantly to Thailand's economy, with its share of GDP gradually increasing from 27 percent in 1990 to 29 percent in 2012 (NESDB, 2014). The manufacturing sector has been one of the most important sectors among East and Southeast Asian countries, as a significant contribution to regional economic growth since the early 1980s arose from the rapid expansion in manufacturing exports (Jongwanich, 2007). Exports play a significant role in the Thai economy; its economic expansion before the Asian financial crisis was underpinned by rapid export growth[1] (Athukorala and Suphachalasai, 2004). Agricultural and processed food were the major goods exported from Thailand between 1981 and 1985, accounting for almost half of annual average export value (Athukorala and Suphachalasai, 2004). Between 1991 and 1995, a substantial shift occurred from traditional agricultural exports[2] toward manufactured exports. This upward trend continued with manufactured exports accounting for 86.31 percent of total export value during the period 1996 to 2012. According to the Ministry of Industry (2009), a significant contribution to economic growth has also resulted from export-oriented large enterprises. Goods manufactured with medium and high technology comprise the majority of Thailand's manufacturing exports. Manufacturers, however, still import large quantities of components, capital goods and technology from foreign markets for their export production processes. This implies that manufacturers in Thailand have a comparative advantage in using cheap labour and capital even though they must import components and technology to produce for export (ILO, 2012). Punyasavasut (2008) also points out that exports and foreign direct investment (FDI) are the main drivers of Thailand's industrialization. Manufacturing FDI accounted for 47.85 percent of FDI between 2006 and 2012 (BOT, 2014a).

Regarding the number of employees classified by economic activity in 2012, manufacturing contributed the most to Thailand's employment (OSMEP, 2013). The sector employed 4.62 million workers out of 14.66 million workers, or 31.53 percent of national employment, followed by wholesale, retail trade and repairs of motor vehicles (29.84 percent); hotels and restaurants (8.37 percent); and real estate activities (8.06 percent). As for the number of enterprises classified by economic activity, manufacturing had the second-largest share of enterprises at 17.52 percent, followed by hotels and restaurants (10.98 percent); real estate activities (9.55 percent); and other community, social and personal service activities (8.53 percent) (OSMEP, 2013). In terms of labour productivity, manufacturing enjoys a high level compared with other sectors. The labour index per employed persons in manufacturing averaged about 143 between 2006 and

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[1] A number of empirical studies of the region, however, fail to reveal a statistically significant association between trade/exports and economic growth (Sinha, 1999; Ekanayake, 1999).

[2] Even though manufacturing contributed most to this development, agricultural products still accounted for a fairly important share of exports even though its relative importance was diminishing significantly (Lombaerde, 2008, p. 250).

2012, followed by transport, storage, and communication (130.6); other community, social and personal service activities (125.6); and electricity, gas, and water supplies (122.2). Financial intermediation had the highest level of labour productivity, with the least level of labour productivity found in construction (BOT, 2014b).

In contrast, Thailand's productivity for value-creation production is still relatively low, since manufacturing development has relied heavily on value-added production rather than value-creation production. This is due to the lack of accumulated knowledge, endogenous efforts, a strong value chain and synergy. According to Thailand's industrial master plan (2012-2030), Thai manufacturing enterprises enjoy a comparative advantage with cheap labour and foreign direct investment without enhancing their productivity. They lack (i) new technology, (ii) product and process innovation, (iii) financial access, (iv) skilled labour, (v) raw materials, (vi) high value-added production and (vii) managerial skills (Ministry of Industry, 2012). More importantly, business segments have been under pressure from the so-called nut-cracker effect, implying that Thailand is now trapped between countries with lower price competitiveness, such as China, Viet Nam and Indonesia, and countries with higher value-added production and services (OSMEP, 2007). Similarly, the World Bank (2008) points out that with intensifying global competition and higher commodity prices, Thailand confronts a serious challenge to sustain its growth and become a higher-income country while escaping the middle income trap[3]. At present, Thailand is in a difficult competitive position as it cannot continue to depend on cheap labour for its competitiveness; therefore, it must move up the technology hierarchy and improve the efficiency and productivity of its enterprises. Measuring the sources of cost efficiency and inefficiency of firms will be emphasized: it is important to examine how firms can enhance their efficiency, which has a direct impact on the economy's growth and will be discussed in later sections. A review of empirical studies, however, is crucial to establish this study's foundational knowledge.

4. A Review of Literature

4.1 Innovation and firm performance

4.1.1 Definition of innovation

According to the OECD (2005, p. 46), an innovation is defined as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations." It indicates that the minimum requirement for an innovation is that the product, process, marketing method or organizational method must be new or significantly improved by a firm (OECD, 2005, p. 48). Similarly, technological innovation comprises new products and processes and significant technological changes of products and processes (OECD, 2013). Innovation is essential for increasing productivity in most developing nations so as to increase per capita income levels similar to those of the richest nations, since it can lead to a more effective use of productive resources. In addition, the transformation of new ideas into new economic solutions through new products, processes and services is fundamental to a firm's sustainable competitive advantages (Crespi and Zuniga, 2011).

4.1.2 Innovation

According to Lee (2011), innovation plays a crucial role in modern growth theories such as those of Solow (1956), Romer (1986) and Romer (1990). Solow (1956) suggests that exogenous technological innovation augments labour productivity to sustain long-term growth. Romer (1986) states that technological innovations are modelled endogenously by incorporating spill-overs from investment in physical and human capital (see Lee (2011)). Focusing on firm-level analysis, several empirical studies such as Cohen and Klepper (1996), Griffith et al. (2006), Mairesse & Mohnen (2010), Díaz and Sánchez (2014), Sánchez and Díaz (2013), Lee (2011), Cassiman et al. (2010) and Crespi and Zuniga (2011) have

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[3] Thailand had moved rapidly from a low-income country to a middle-income country from the 1970s to mid-1990s due to rapid growth in per capita income. However, in recent years Thailand's real GDP growth has slowed and has lagged that of other developing countries in East Asia (World Bank Office-Thailand, 2008, p. 4).

found a positive association among R&D, innovation and productivity in different industrialized countries as follows: Griffith et al. (2006) use firm-level data from the internationally harmonized Community Innovation Surveys (CIS3) during 1998-2000 to examine the role of innovation on productivity across four European countries (France, Germany, Spain and the U.K.). Their econometric results suggest that the systems driving innovation and productivity are remarkably correlated across these countries. Díaz and Sánchez (2014) use a micro-panel data set of Spanish manufacturing enterprises for the years 2004 to 2009 to simultaneously estimate a stochastic frontier production function and inefficiency determinants. Their results reveal that innovative firms are more efficient than non-innovative firms. In addition, small and medium-sized enterprises tend to be more efficient than large enterprises. Cohen and Klepper (1996) employ sales data from the FTA's Line of Business Program. They find that process innovation is less saleable and has less growth than product innovation. Sánchez and Díaz (2013) use the 1990 Innovation Survey of French manufacturing firms covering 1986-1990 to study the links between productivity, innovation and research at the firm level. Their results suggest that firm productivity correlated positively with higher innovation output. Lee (2011), using firm-level datasets of three national surveys, found that process innovation and product innovation are not significantly correlated with productivity in the case of Malaysian manufacturing enterprises. Cassiman et al. (2010) use a panel of Spanish manufacturing small and medium-sized firms between 1990 and 1998 to investigate the relation between innovation, productivity and export decisions. They find strong evidence that product innovation affects productivity and induces small non-exporting firms to enter the export market. Crespi and Zuniga (2011) employ micro data from innovation surveys to examine the determinants of technological innovation and their impact on firm labour productivity across Latin American countries (Argentina, Chile, Colombia, Costa Rica, Panama and Uruguay). Their results reveal that firms in all countries that invest in knowledge are more likely to introduce new technological advances that can increase labour productivity than those that do not. The review of literature reveals that entrepreneurs, especially CEOs, can play a crucial role in determining an enterprise's progress, as discussed below.

4.2 CEO Characteristics and Firm Performance

The chief executive officer (CEO) plays an important role in leading an enterprise in line with its board of directors' objectives. A CEO's abilities can be characterized into factual attributes such as education, work experience, nationality and gender, as well as non-quantifiable characteristics such as leadership and team-building skills (Bhagat et al., 2010). Bhagat et al. (2010) point out that the measurement of a CEO's abilities is a difficult, imprecise and expensive process. Therefore, a number of empirical studies have examined the association between a firm's performance and the characteristics of its CEO's characteristics (education, experience, gender and nationality) as follows:

4.2.1 CEO education

Education is often used as a proxy for human capital in the literature, such as in Barro and Lee (2010), since it is a known driver of production and economic growth. Barro and Lee (2010) use a sample of the largest 1,500 U.S. firms between 1992 and 2007. They find no evidence of a systematic association between CEO education and long-term firm performance. Jalbert et al. (2002) use a large sample of firms obtained from the Forbes 800 list between 1987 and 1996 to examine firm performance (ROA and Tobin's Q) based on the CEO's educational background. They empirically reveal mixed results that the quality of a CEO's graduate school is negatively associated with return on assets, but positively associated with Tobin's Q.

4.2.2 CEO experience

Another CEO characteristic is the amount of experience as a CEO in a firm's business sector; an experienced CEO can help turn around a troubled firm (Elsaid et al., 2011). Wasserman et al. (2001) also pointed out that CEOs with long tenure are able to establish a management team who can enhance firm performance through capable, effective collaboration. Jalbert et al. (2002) reveal that a CEO with long tenure has a significant and positive association with return on assets, but a significant and negative correlation is found between a CEO with long tenure and Tobin's Q. Bhagat et al. (2010) also find that

CEO tenure has a significant positive association with firm performance as measured by Tobin's Q, but a significant negative association was found for firm performance measured by return on assets.

4.2.3 CEO gender

A CEO's gender can affect a firm's operations management, which in turn can affect its performance due to gender differences. A number of empirical studies have also examined the relationship between a CEO's gender and firm performance (Khan and Vieito (2013) and Lam et al. (2013)). For example, Khan and Vieito (2013) use a panel data of U.S. firms from 1992 to 2004 to evaluate whether firms managed by female CEOs show the same performance as firms managed by male CEOs. Their empirical results reveal that a firm's risk level is smaller when the CEO is a female, resulting in a performance increase as measured by return on assets. Lam et al. (2013), however, find no such performance link for Chinese-listed enterprises.

4.2.4 CEO nationality

More interestingly, a CEO's national origins can affect the manner in which the CEO operates a firm, which in turn can affect its performance due to differences in cultural backgrounds (Jalbert et al., 2007). Jalbert et al. (2007) use the Forbes 800 CEO compensation data from 1991 to 1997 to investigate the effect of a CEO's national origin on a firm's performance. They suggest that CEOs born in Central and South America and those born in Australian and New Zealand earn a higher return on assets than those born in other countries. Factors other than CEO characteristics that significantly affect a firm's performance are discussed in sections 4.3, 4.4 and 4.5.

4.3 Firm size and firm performance

Firm size can contribute to firm efficiency due to the economies of scale and scope of larger enterprises (Charoenrat et al., 2013). Several empirical studies have explored the effects of firm size and age on efficiency (Charoenrat et al. (2013); Kim (2003); Alvarez and Crespi (2003)). For instance, Charoenrat et al. (2013) use cross-sectional data from the 2007 manufacturing census to investigate the significant sources of SMEs' technical efficiency. They reveal that firm size is significantly and positively related to technical efficiency. Similarly, Kim (2003) finds that firm size has a significant and positive effect on the technical efficiency of Korean manufacturing industries.

4.4 Firm age and firm performance

Firm age can contribute significantly to firm efficiency, since older firms learn from past mistakes through the learning-by-doing process and improve managerial skills from accumulated experience (Charoenrat et al., 2013). Several empirical studies have also investigated the correlation between firm age and performance as measured by efficiency (Charoenrat et al. (2013); Tran et al. (2003); Le and Harvie (2010)). Charoenrat et al. (2013) reveal mixed results that firm age is positively related to technical efficiency of aggregate Thai SMEs and sub-manufacturing industries (SITC 0 and SITC 5). Estimates of firm-age coefficients in sub-manufacturing industries such as SITC 1, SITC 7 and SITC 8, however, are not significantly correlated with technical efficiency. Firm age is also negatively related to technical efficiency of SMEs in SITC 6. Similarly, Tran et al. (2003) reveal mixed results between firm age and technical efficiency in the case of non-state manufacturing industries in Viet Nam.

4.5 Foreign unskilled labour

Industrialization demands more foreign workers in a country's labour force; therefore, foreign labour is likely to affect the domestic labour market and productivity. Several studies have investigated the association between foreign workers and productivity, such as Noor et al. (2011), Llull (2008) and Peri (2009). Noor et al. (2011) find that foreign labour is positively and significantly associated with labour productivity in the Malaysian manufacturing sector. Llull (2008) also suggests that immigration has a significantly negative impact on productivity, but a positive impact on labour participation and employment in OECD countries. Peri (2009) finds no evidence across U.S. states that migrants crowd out domestic employment, but they help promote efficient task specialization that increases the total factor of production.

4.6 The Determinants of innovation

Several studies have empirically investigated the internal and external determinants of innovation (Romijn and Albalajejo (2002); Lee (2011); Bhattacharya and Bloch (2002); de Mel et al. (2009)). Romijn and Albalajejo (2002) identify possible internal and external sources of innovation capability as follows: potentially external sources can be classified by i) the networking intensity, ii) the proximity advantages related to networking and iii) the receipt of institutional support. Moreover, potentially internal sources can be, for instance, i) the professional background of founders or managers, ii) the workforce's skills and iii) the internal effort to improve technology. A number of empirical studies examined these internal and external sources of innovation capability.

Lee (2011) explores the relationship among trade, productivity and innovation in Malaysian manufacturing. He finds that capital intensity and human capital significantly affect the productivity of both innovating and non-innovating firms. Romijn and Albaladejo (2002) explore the determinants of innovation capability in small U.K. electronics and software firms. Focusing on internal determinants of innovation capability, an owner or entrepreneur with an academic degree is not associated with high innovation capability. Prior work experience in a scientific environment, however, is found to have a significant positive correlation with innovation capability as measured by the number of patents and the product innovation index. Research and development, as measured by R&D expenditure per employee and as a percentage of sales, is also found to have a significant and positive impact on innovation capability. With regard to external drivers of innovation, frequency of interaction and proximity advantage related to interaction with R&D institutions as well as suppliers are found to have a significantly positive association with innovation capability.

Bhattacharya and Bloch (2002) reveal that i) firm size, ii) R&D intensity, iii) market structure and iv) trade shares are significantly related to innovative activity in small to medium-sized Australian manufacturing businesses. De Mel et al. (2009) use the Sri Lanka Longitudinal Survey of Enterprise (SLLSE) of more than 2,800 firms to empirically investigate the determinants of innovation in micro, small and medium-sized firms. They classify innovation by i) product innovation, ii) process innovation, iii) marketing innovation and iv) organization innovation. The results in their study reveal that more than one-quarter of microenterprises engage in innovation. Firm size is strongly found to have a significant and positive correlation with process and organization innovations. More interestingly, they reveal that three measures of human capital (an owner's years of education, higher digit-span recalls and higher scores on the Raven test) have a significantly positive association with the likelihood of innovation. The owner's optimism is positively correlated with firm innovation. However, the owner's gender, age and marital status are not significantly related to firm innovation.

Several studies have found that firms participating in foreign markets are likely to be more innovative than those that do not export (Palangkaraya (2012); Damijan et al. (2010); Girma et al. (2008)). In other words, exporting firms can benefit from the learning-by-exporting hypothesis. For instance, Palangkaraya (2012) finds that exports are significantly and positively related with innovation in Australia's small and medium-sized enterprises. Damijan et al. (2010) find that exports improve a firm's efficiency by stimulating process innovations in Slovenia's manufacturing and non-manufacturing firms. Girma et al. (2008) find that past exporting experience improves the innovative capability of Irish firms, but not of British firms; the difference lies in cross-country exporting patterns that Irish firms have because of their greater interface with OECD markets. Skilled labour also plays a vital role in enhancing innovation. Several empirical studies have found that skilled labour relates significantly to innovation. For instance, Kerr et al. (2013) concludes that highly skilled immigrants play an important role in promoting U.S. innovation and entrepreneurship. Albaladejo and Romijn (2000) show that the skills of a workforce are significantly and positively associated with innovation capability in small U.K. firms.

All reviewed literature will be used to identify significant variables in the models used in this study, but a review of methodology is also important to identify the empirical models used for this study's analysis, as discussed in the next section.

5. Methodology

5.1 The Measurement of cost efficiency

In the presence of input price information obtained from the 2006 manufacturing survey, this paper can measure the cost efficiency that can be estimated by employing, for example, the Cobb-Douglas cost function. Cost efficiency can be estimated using input-orientated measures that analyze how much costs can be minimized by proportionally reducing all input prices without changing the output produced (Coelli et al., 2005). The concept of cost efficiency can be explained in the graphical presentation as shown in Figure 1.
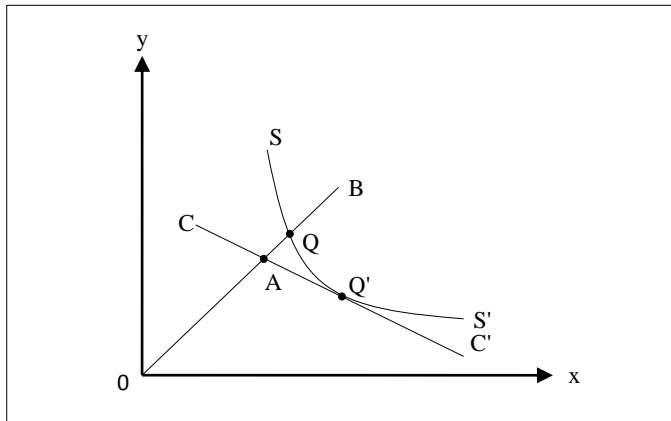

Figure 1 Technical and allocative efficiencies from an input orientation

Note: Point B is associated with the vector of input x; Point Q is associated with the vector of input $\hat{x}$; Point Q' (or A) is associated with the vector of input x*; the vector of input prices (w) is given to estimate cost efficiency, but it cannot be observed in Figure 1.

Source: Farrell (1957, p. 254)

When the information of input prices is available, the vector of input prices (w) is introduced and the observed vector of inputs (x, $\hat{x}$, and x*) is associated with point (B), the technical efficiency point (Q) and the cost-minimising point (Q'), respectively, as indicated in Figure 1 (Coelli et al., 2005, p. 53). Cost efficiency, therefore, is technically defined as the ratio of input costs (w) associated with input vectors, x (at point B) and x* (at point Q' or A). Therefore,

$$\text{Cost Efficiency} = \frac{w'x^*}{w'x} = \frac{OA}{OB} \tag{1}$$

Furthermore, the product of technical and allocative efficiency measures can equal the total cost efficiency (CE) as shown in Equation (2) (Coelli et al., 2005, p. 53):

$$TE \times AE = \left(\frac{0Q}{0B}\right) \times \left(\frac{0A}{0Q}\right) = \left(\frac{0A}{0B}\right) = CE \tag{2}$$

where, technical efficiency and allocative efficiency[4] can be estimated using the isocost line (CC') as follows:

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[4] Technical efficiency refers to the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices and production technology (Coelli et al., 2005, p. 51).

$$\text{Technical Efficiency (TE)} \quad = \frac{w'\hat{x}}{w'x} = \frac{0Q}{0B} \tag{3}$$

$$\text{Allocative Efficiency (AE)} = \frac{w'x^*}{w'\hat{x}} = \frac{0A}{0Q} \tag{4}$$

According to Equations (1) and (2), the defined concept of cost efficiency will be used to measure a firm's performance in this study, but a stochastic cost frontier model must be discussed as it is needed to measure a firm's cost efficiency as discussed in section 5.2 below.

5.2 Stochastic cost frontier model

When price information is available and firms are assumed to minimize their costs, cost efficiency can be estimated using a cost frontier that can be written in the general form as follows (Coelli et al., 2005):

$$c_i \geq c(w_{1i}, w_{1i}, iw_{Ni}, q_{1i}, q_{2i},..., q_{Mi}) \tag{5}$$

where c_i is the observed firm's cost i; w_{ni} is the nth input price; q_{mi} is the mth output; and c($\bullet$) is a cost function that is non-decreasing, linearly homogeneous and concave in prices (Coelli et al., 2005). Equation (5) indicates that the observed cost is greater than or equal to the minimum cost. According to Equation (5), a functional form represents a cost function c($\bullet$). The Cobb-Douglas cost frontier model is applied in this study, which can be written in Equation (6) as follows (Coelli et al., 2005):

$$lnc_i \geq \beta_0 + \sum_{n=1}^{N} \beta_n lnw_{ni} + \sum_{n=1}^{M} \theta_n lnq_{mi} + v_i \tag{6}$$

where v_i is a symmetric random variable that indicates the estimation's errors and statistical noise. In addition, the inefficiency variable can be introduced in Equation (7) as follows (Coelli et al., 2005):

$$lnc_i \geq \beta_0 + \sum_{n=1}^{N} \beta_n lnw_{ni} + \sum_{n=1}^{M} \theta_n lnq_{mi} + v_i + u_i \tag{7}$$

where u_i is a non-negative variable indicating inefficiency. As shown in Equation (7), this function is non-decreasing, linearly homogenous and has concave inputs if $\beta_n \geq 0$ for all n and the constraint constraint, $\sum_{n=1}^{N} \beta_n = 1$, are substituted in Equation (7). This yields the homogeneity-constrained Cobb-Douglas cost frontier model indicated in Equation (8) as follows (Coelli et al., 2005):

$$\ln(\frac{c_i}{w_{ni}}) = \beta_0 + \sum_{n=1}^{N} \beta_n \ln\left(\frac{w_{ni}}{w_{ni}}\right) + \sum_{m=1}^{M} \theta_m \ln q_{mi} + v_i + u_i \tag{8}$$

Equivalently, Equation (8) can be written in the compact form indicated in Equation (9) as follows (Coelli et al., 2005):

$$\ln \left(\frac{c_i}{w_i}\right) = X_i' \beta + v_i + u_i \quad \text{or} \quad -\ln \left(\frac{c_i}{w_i}\right) = X_i' \beta + v_i + u_i \tag{9}$$

Moreover, cost efficiency is measured by the ratio of minimum cost to observed cost as follows (Coelli et al., 2005):

$$CE_i = \exp(-u_i) \tag{10}$$

With respect to the equations mentioned above, especially equations (9) and (10), a firm's cost efficiency can be measured, which is treated as a dependent variable for the study of the significant sources of a firm's cost efficiency. However, an inefficiency effects model is important as it can link a set of significant factors to a firm's cost efficiency, as discussed in section 5.3 below.

5.3 Inefficiency effects model

This study examines the significant sources that influence a firm's cost inefficiency as indicated in the following inefficiency effects model (see Coelli et al.(1995)):

$$m_i = z_i\delta + w_i \qquad (11)$$

where m_i is a p×p vector of inefficiency effects that can be measured from Equations (9) to (10);

z_i is a p×1 vector of variables that may influence the efficiency of a firm;

and δ is a 1×p vector of parameters to be estimated.

Sections 5.2 and 5.3 can be estimated simultaneously using FRONTIER 4.1 as suggested by Collie et al. (1996) and Battese and Coelli (1995). Section 5.4 will discuss the simultaneous estimation of the stochastic cost frontier model and the inefficiency cost effects model, which will be used for this paper's analysis.

5.4 The estimation of the stochastic cost frontier model and the inefficiency cost effects model

The Battese and Coelli (1995) model specification, which conducts a single-step process in which the stochastic frontier production and the model of inefficiency effects are estimated simultaneously by the method of maximum likelihood estimation (Quasi-Newton methods) (Coelli (1996); Battese & Coelli (1995)), can be applied in a simultaneous estimation of these two models for cross-sectional data obtained from the 2006 manufacturing survey collected by the World Bank. It can be rewritten as follows (Coelli et al., 2005):

$$\ln\left(\frac{c_i}{w_i}\right) = x_i\beta + v_i + u_i \qquad (12)$$

where c_i, w_i, x_i, and β are defined as cost, labour price, input prices and output, and unknown parameters, respectively;

v_i are random variables that are assumed to be iid. $N(0,\sigma_V^2)$, and independent of u_i, which are non-negative random variables that are assumed to account for cost inefficiency in production and are assumed to be independently distributed as truncations at zero of the $N(m_i,\sigma_U^2)$ distribution; where the following equation is the cost inefficiency effects model:

$$m_i = z_i\delta, \qquad (13)$$

where z_i is a p×1 vector of variables that may influence the efficiency of a firm; and

δ is an 1×p vector of parameters to be estimated.

The parameterisation from Battese and Corra (1977) is used in this paper, replacing σ_V^2 and σ_U^2 with $\sigma^2 = \sigma_V^2 + \sigma_U^2$ and $\gamma = \sigma_U^2/(\sigma_V^2 + \sigma_U^2)$. The log-likelihood function of this model is presented in the appendix of the working paper Battese and Coelli (1993). FRONTIER Version 4.1 is used to conduct a single-step process in which the stochastic frontier production and the model of cost inefficiency effects are estimated simultaneously by employing maximum likelihood estimation (Quasi-Newton methods) (Coelli, 1996). This software uses 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 $\Upsilon = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$ (Coelli (1996); Battese & Coelli (1995)).

5.5 The tobit model for the study of significant sources of technological innovation

This study empirically investigates the significant sources of technological innovation. The values of technological innovation are bounded between zero and one. Applying the method of ordinary least squares (OLS) will lead to biased and inconsistent estimators, since the OLS method is likely to predict values greater than one (Kumbhakar and Lovell, 2000; Coelli et al., 2005). Therefore, the maximum

likelihood estimation for a two-limit tobit model is adopted and given as follows (Hoff, 2006; McDonald, 2009):

$$\theta_i^* = \beta_0 + \sum_{j=1}^{j=n} \beta_i x_i + \varepsilon_i \qquad (14)$$

$$\theta_i = \begin{cases} \theta_i^* & if \ 0 < \theta_i^* < 1 \\ 0 & if \ \theta_i^* \le 0 \\ 1 & if \ \theta_i^* \ge 1 \end{cases}$$

where θ_i^* = Unobserved variables of firm i
θ_i = Observed variables of firm i
β_i = Unknown parameter to be estimated for each independent variable of firm i
x_i = Independent variables of firm i
ε_i = Random error ($\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$)

6. Empirical Models

According to the methodology mentioned in Section 5, this paper estimates the stochastic frontier cost function and simultaneously estimates the inefficiency effects by the method of maximum likelihood (ML)[5], which has desirable large sample (or asymptotic) properties. More specifically, the ML estimator is consistent and asymptotically efficient (Coelli, 2005, p. 218). The stochastic frontier cost function in the Cobb-Douglas functional form is used in this study as follows (Coelli et al. (2005); Coelli (1996)):

$$\ln\left(\frac{c_i}{w_i}\right) = \beta_0 + \beta_1 \ln(R_i/W_i) + \beta_2 \ln(Q_i) + v_i + u_i \qquad (15)$$

where C_i = the cost, represented by total cost of firm *i*
Q_i = the output, represented by total revenue of firm *i*
R_i = the capital price, represented by total fixed cost of firm *i*
W_i = the labour price, represented by total wage and salary of firm *i*
V_i = random variables, which are assumed to be iid. $N(0,\sigma_V^2)$ and independent of the U_i
U_i = non-negative random variables, which are assumed to account for the cost of inefficiency in production and are assumed to be independently distributed as truncations at zero of the $N(m_i, \sigma_u)$ distribution; where: $m_i = z_i \delta$; where z_i is a p×1 vector of variables that may influence a firm's efficiency; and where δ is an 1×p vector of parameters to be estimated.

The Inefficiency Effects Model can be written as follows:

$$U_i = \delta_0 + \delta_1 Tech\_Innovation_i + \delta_2 CEO\_Gender_i + \\ \delta_3 CEO\_Nationality_i + \delta_4 CEO\_Experience_i + \\ \delta_5 CEO\_Education_i + \delta_6 Firm\_Size_i + \delta_7 Foreign\_Unskilled_i + \\ \delta_8 Domestic\_Ownership_i + \delta_9 Firm\_Age_i + w_i \qquad (16)$$

where $Tech\_Innovation_i$ = Firm *i*'s capability to undertake technological innovation's initiatives, measured by the percentage in completing all technologically innovative initiatives;

CEO_Gender_i = Dummy for the gender of a CEO in firm *i*;

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[5] According to Coelli et al. (2005, p.245), the method of maximum likelihood is preferred to other estimation techniques in computing measures of cost efficiency, such as ordinary least squares (OLS) and corrected ordinary least squares (COLS). The OLS estimates cannot be used to compute the firm's cost efficiency since the estimated "intercept" coefficient obtained from the OLS is "biased downwards" even though the estimated "slope" coefficients are consistent.

CEO_Gender_i = 1 if the gender of a CEO is male.
= 0, otherwise;
$CEO\_Nationality_i$ = Dummy for the nationality of a CEO in firm i;
$CEO\_Nationality_i$ = 1 if the nationality of CEO is Thai.
= 0, otherwise;
$CEO\_Experience_i$ = The working experience of a CEO, represented by the CEO's working years;
$CEO\_Education_i$ = Dummy for a CEO education of firm i;
$CEO\_Education_i$ = 1 if a CEO obtains at least a bachelor's degree.
= 0, otherwise;
$Firm\_Size_i$ = Size of firm i, represented by total number of employees;
$Foreign\_Unskilled_i$ = Foreign unskilled workers at firm i, represented by number of foreign skilled workers;
$Domestic\_Ownership_i$ = Domestic ownership of firm i, represented by the percentage of domestic ownership of firm i;
W_i = Random error $((W_i \sim N(0, \sigma_W^2))$

Equations (15) and (16) are estimated simultaneously by the method of maximum likelihood estimation (Quasi-Newton methods) as previously mentioned in Section 5.4.

According to Equation (14), the significant sources of technological innovation can be examined using the maximum likelihood tobit model written as follows:

$$Tech\_Innovation_i^* = \beta_0 + \beta_1 CEO\_Nationality_i + \beta_2 CEO\_Education_i +$$
$$\beta_3 CEO\_Gender_i + \beta_4 CEO\_Experience_i + \beta_5 Exports_i + \beta_6 Professional_i +$$
$$\beta_7 Domestic\_Ownership_i + \beta_8 Firm\_SIZE_i + \varepsilon_i \qquad (17)$$

$$Tech\_Innovation_i = \begin{cases} Tech\_Innovation_i^* & if\ 0 < Tech\_Innovation_i^* < 1 \\ 0 & if\ Tech\_Innovation_i^* \leq 0 \\ 1 & if\ Tech\_Innovation_i^* \geq 1 \end{cases}$$

where $Tech\_Innovation_i^*$ = Unobserved technological innovation of firm i.
$Tech\_Innovation_i$ = Observed technological innovation of firm i.

$Exports_i$ = Dummy for exports of firm i;
$Exports_i$ = 1 if firm i exports.
= 0, otherwise;
$Professional_i$ = Trained and certified specialists outside of management.

$CEO\_Nationality_i, CEO\_Education_i, CEO\_Gender_i, CEO\_Experience_i, and\ Firm\_SIZE_i$ are previously defined (see Equation (6))

ε_i = Random error $(\varepsilon_i \sim N(0, \sigma_\varepsilon^2))$

7. Data Source and Data Classification

This study employs the 2006 Enterprise Survey (Manufacturing Sector Survey) for Thailand collected by the Foundation of Thailand Productivity Institute (FTPI) in collaboration with the World Bank. Business owners and top managers in 1,043 firms were interviewed between April and November 2007. This survey contains three parts: i) a questionnaire administered to CEOs, general managers or business owners; ii) a questionnaire administered to the finance manager or accountant; and iii) a questionnaire administered to workers sampled from each establishment. Due to a number of missing data in the survey,

30 firms are deleted from the sample. Finally, 1,019 firms are used to conduct the empirical analysis in this paper. More importantly, the questionnaire administered to the CEOs, general managers or business owners makes this survey more useful than the 2007 Thai Industrial Census conducted by the National Statistical Office of Thailand because that census does not provide personal data regarding CEOs, general managers or business owners.

8. Hypothesis Tests and Empirical Results

8.1 Hypothesis tests of the stochastic frontier model and inefficiency effects model

With respect to Equations (15) and (16), three null hypothesis tests are required: (i) the absence of inefficiency effects, (ii) the absence of stochastic inefficiency effects and (iii) the insignificance of joint inefficiency variables (see Table 1). A likelihood-ratio test (LR test) is used to test these hypotheses as follows:

$$\lambda = -2\{\log[L(H_0)] - \log[L(H_1)]\} \tag{18}$$

where $\log r[L(H_0)]$ and $\log e[L(H_1)]$ are obtained from the maximized values of the log-likelihood function under the null hypothesis (H_0) and the alternative hypothesis (H_1), respectively. The LR test statistic has an asymptotic chi-square distribution with parameters equal to the number of restricted parameters imposed under the null hypothesis.

Table 1 Statistics for Hypothesis Tests of the Stochastic Frontier Model and Inefficiency Effects Model

Thai manufacturing enterprises	
Null hypothesis (i) No cost inefficiency effects ($H_0: \gamma = \delta_0 = \cdots = \delta_9 = 0$)	
LR statistics	160.86
Critical value	24.05*
Decision	Reject
Null hypothesis (ii) Non-stochastic inefficiency ($H_0: \gamma = 0$)	
LR statistics	151.54
Critical value	5.41*
Decision	Reject
Null hypothesis (iii) No joint inefficiency variables ($H_0: \delta_1 = \delta_2 = \cdots = \delta_9 = 0$)	
LR statistics	142.30
Critical value	21.67*
Decision	Reject

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

From Table 1, the null hypothesis (i), which specifies that the inefficiency effects are absent from the model $(H_0: \gamma = \delta_0 = \cdots = \delta_9 = 0)$, is strongly rejected at the one-percent level of significance, since the LR statistic test is greater than the critical value of approximately chi-square distribution at the one-percent level of significance. This result implies that the model of inefficiency effects exists in the case of Thai manufacturing enterprises. Furthermore, the estimate for the variance parameter γ in Table 2 is 0.9017, which is close to one and indicates that the inefficiency effects tend to be highly significant in the analysis for the value of production costs of Thai manufacturers (see Battese and Coelli (1995)). The null hypothesis (ii) that the inefficiency effects are not "stochastic" ($\gamma = 0$) is strongly rejected in the case of Thai manufacturing enterprises. The rejection of this hypothesis indicates that the model of inefficiency

effects is not reduced to a traditional mean response function since the variance of the inefficiency effects is not zero Battese & Coelli (1995). In other words, all the explanatory variables in the inefficiency effects model are not included in the cost function in this study, implying that the inefficiency effects model is applicable, and therefore the estimated parameters can be identified in the model of inefficiency effects.

The last null hypothesis examines the significance of the joint effects of all inefficiency variables on the inefficiencies of production costs. From Table 1, the last null hypothesis, which specifies inefficiency effects are not a linear function of all explanatory variables or all parameters of the explanatory variables equal zero, $(H_0: \delta_1 = \delta_2 = \cdots = \delta_9 = 0)$ is strongly rejected at the 1 percent level of significant. Due to the rejection of the last null hypothesis test, it indicates that the inefficiency effects are a linear function of a set of explanatory variables, although the individual effects of one or more variables might be statistically insignificant Battese & Coelli (1995).

Table 2 Maximum Likelihood Estimates for Parameters of the Stochastic Cost Frontier Model and Inefficiency Effects Model

	Parameter	Coefficient	Standard error	t-ratio
Stochastic Cost Frontier Model				
Constant		-4.3813*	(0.5564)	-7.8750
$\ln(R_i/W_i)$	β_1	0.1587*	(0.0151)	10.5064
$\ln(Q_i)$	β_2	0.3177*	(0.0240)	13.2351
Inefficiency Effects Model				
Constant	δ_0	1.0729*	(0.2712)	3.9556
$Tech\_Innovation_i$	δ_1	-0.0097*	(0.0024)	-4.0579
CEO_Gender_i	δ_2	-0.0357	(0.0685)	-0.5207
$CEO\_Nationality_i$	δ_3	0.1022	(0.0880)	1.1615
$CEO\_Experience_i$	δ_4	-0.0006	(0.0057)	-0.1031
$CEO\_Education_i$	δ_5	-0.1837*	(0.0730)	-2.5165
$Firm\_Size_i$	δ_6	-0.0008*	(0.0000)	-25.5793
$Foreign\_Unskilled_i$	δ_7	0.0033**	(0.0020)	1.6876
$Domestic\_Ownership_i$	δ_8	0.0056	(0.0014)	3.8340
$Firm\_Age_i$	δ_9	-0.0014	(0.0046)	-0.3166
sigma-square	σ^2	0.5533*	(0.0737)	7.5125
Gamma	γ	0.9017*	(0.0140)	64.4805

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

8.2 Empirical results, the maximum likelihood estimates for parameters of the stochastic cost frontier model and inefficiency effects model

From Table 2, the sum of significantly estimated coefficients of $\ln(R_i/W_i)$ and $\ln(Q_i)$ obtained from the stochastic cost frontier model is 0.4764, indicating that a high level of decreasing returns to scale exists in Thai manufacturing firms. This evidence also implies that a firm's average cost increases when its output increases. From the cost inefficiency models shown in Table 2, the estimated negative coefficient of technological innovation is statistically significant at the five percent level of significance, indicating a significant and negative association with a firm's cost inefficiency. In other words, technological innovation is significantly and positively correlated with a firm's cost efficiency, implying that technological innovation can reduce a firm's cost of production due to better productivity and efficiency. This empirical result is similar to the findings of Le & Harvie (2010), Griffith et al. (2006), Mairesse & Mohnen (2010), Díaz & Sánchez (2014), Sánchez & Díaz (2013), Cassiman et al. (2010) and Crespi & Zuniga (2011).

Focusing on the estimated coefficients of CEO characteristics such as education, gender, experience and nationality, a CEO with at least a bachelor's degree is found to be significant and negatively related with a firm's cost inefficiency. Alternatively, a CEO with at least a bachelor's degree has a significant and positive association with a firm's cost efficiency, indicating that a CEO's educational background plays a vital role in promoting the cost efficiency of Thai manufacturers. More specifically, a CEO who obtains at least a bachelor's degree performs better in the manner of controlling the firm's costs more efficiently than those who do not. This significant result is consistent with the findings of Jalbert et al. (2002), except their findings were measured by a financial ratio (Tobin's Q).

The results in Table 2 reveal that a CEO's gender has no significant impact on a firm's cost inefficiency due to an insignificant estimated coefficient of the CEO gender variable. This result reflects the findings of Lam et al. (2013), suggesting that male CEOs perform similarly to female CEOs. The estimated coefficient of the CEO experience is not found to be significantly related to a firm's cost inefficiency. An insignificant result of its estimated coefficient implies that the CEO's working years do not affect the cost efficiency of Thai manufacturing firms. This evidence contradicts the findings of previous studies such as Wasserman et al. (2001), Jalbert et al. (2002) and Bhagat et al. (2010). A CEO's nationality is not found to be significant with a firm's cost inefficiency, implying no significant evidence that Thai CEOs perform differently from foreign CEOs. This result differs from the findings of Jalbert et al. (2007).

Table 3 The cost efficiency estimation of Thai sub-manufacturing sectors

Sub-manufacturing sectors	Weighted* average cost efficiency	Max	Min	Stdev	Number of firms
Auto components	2.566	5.845	1.110	1.190	109
Electrical appliances	4.273	22.488	1.283	4.291	28
Electronic components	2.835	31.372	1.081	3.903	64
Food processing	4.293	30.517	1.072	3.964	103
Furniture and wood products	3.636	14.195	1.236	2.411	98
Garments	3.088	18.272	1.163	2.161	152
Machinery and equipment	3.605	13.808	1.066	2.110	81
Rubber and plastics	6.179	52.918	1.068	7.583	253
Textiles	4.249	23.925	1.071	3.240	131
All manufacturing sectors	**4.181**	**52.918**	**1.066**	**4.685**	**1019**

Note: *In the case of a cost frontier function, the cost efficiency will take a value between one and infinity (see Coelli (1996)). The levels of cost inefficiency are indicated by the increase in cost away from the cost frontier, and therefore cost efficiency that equals one indicates the highest efficiency (see Hughes (1988)).

The estimated coefficient of firm size is found to be significantly and negatively associated with a firm's cost inefficiency, indicating that firm size contributes significantly to a firm's cost efficiency, since larger firms can benefit from economies of scale and scope, reduced production costs, and improved efficiency and competitiveness (Phan (2004); Charoenrat et al. (2013)). This result is similar to the findings of Alvarez and Crespi (2003), Kim (2003) and Charoenrat et al. (2013). The estimated coefficient of firm age is not significantly correlated with its cost efficiency, suggesting no significant evidence to conclude that the learning-by-doing hypothesis exists in Thai manufacturing enterprises. This insignificant result is similar to the findings of Charoenrat et al. (2013) in two sub-manufacturing sectors.

Finally, foreign unskilled labour is found to be positively related to a firm's cost inefficiency, indicating that foreign unskilled labour has a significant and negative impact on a firm's cost efficiency. This result implies that Thai manufacturers do not benefit from hiring foreign unskilled labour, since it does not enhance cost efficiency despite what may appear to be an inexpensive source of workers. This finding is

consistent with the results of Llull (2008), but contradicts the empirical results of Peri (2009) and Noor et al. (2011).

8.3 The cost efficiency estimation of Thai manufacturers

Table 3 shows the weighted average cost efficiency estimation of Thai manufacturing firms in aggregation and sub-manufacturing sectors, which can be predicted by Equations (9) and (10) using FRONTIER 4.1. The weighted average cost efficiency score of Thai manufacturing enterprises is about 4.181, indicating that their weighted mean cost efficiency is about four times above the cost frontier. This result shows a high level of cost inefficiency existing in Thai manufacturers, since the weighted average cost efficiency is not close to one, indicating an increase in cost away from the cost frontier (Hughes, 1998). A cost efficiency equal to one indicates the highest cost efficiency (Hughes, 1988).

Comparing the weighted average cost efficiency among sub-manufacturing sectors, the weighted average cost efficiency ranges from 2.566 for auto components to 6.179 for rubber and plastics. The highest weighted average cost efficiency is found in auto components (2.566), followed by electronic components (2.835), garments (3.088), machinery and equipment (3.605), furniture and wood products (3.636), textiles (4.249), electrical appliances (4.273), food processing (4.293), and rubber and plastics (6.179). Furthermore, this finding is similar to the results of Charoenrat et al. (2013), except they focus on technical efficiency to measure a firm's performance, and also find that Thai manufacturing SMEs have high levels of technical inefficiency due to 50 percent of their weighted average technical efficiency. Focusing on sub-manufacturing sectors, the study's results support the OECD report (2013) indicating that electronics and automobiles are the leading manufacturing sectors to offer a strong base for the country's future development (see OECD (2013, p. 277)). The OECD (2013) also suggests that food processing is a growing industry for Thailand's development, but its weighted average cost efficiency found in this study is low compared with other sub-manufacturing sectors. Specific government policies, therefore, should focus on this industry as this can enhance their cost efficiency, which in turn can promote the country's development as suggested by the OECD (2013).

8.4 The determinants of innovation

According to the maximum-likelihood estimates for parameters of the tobit model obtained from Equation (17) in Table 4, the estimated coefficient of CEO education is found to be significantly and positively related with a firm's technological innovation, implying that CEOs who receive at least bachelor's degree tend to engage in more technological innovation than non-degree CEOs. This result is similar to the findings of Lee (2011) and de Mel (2009) that suggest human capital plays a vital role in promoting innovation. More interestingly, male CEOs are likely to engage more in a firm's technological innovation than female CEOs due to a significant and positive sign of CEO gender. This can be explained with analysis of the 2006 manufacturing survey data collected by the World Bank (2006) and used in this study. It is found that 29.29 percent of male CEOs who receive at least a bachelor's degree obtained a science or engineering education, but only 4.15 percent of female CEOs who obtain at least a bachelor's degree obtained a science or engineering education. Therefore, a male CEO is more likely to have a science or engineering background than a female CEO.

In addition, CEO experience is not significantly related to technological innovation, implying that CEO experience does not influence the technological innovation of Thai manufacturing enterprises. This result, however, differs from the findings of Romijn and Albaladejo (2002). Similarly, CEO nationality has no significant impact on a firm's technological innovation, implying no significant conclusion about the likelihood of engaging in a firm's technological innovation between Thai and foreign CEOs. Export is found to be significantly and positively related to a firm's technological innovation, since exporters can benefit from the learning-by-exporting hypothesis. Such firms become more innovative than firms that focus only on domestic markets (Palangkaraya, 2012). This evidence is consistent with the studies of Palangkaraya (2012), Damijan et al. (2007) and Girma et al. (2007).

Table 4 Maximum-likelihood estimates for parameters of the tobit model

Independent variable		Coefficient	(Std. error)	z-statistic
Tech_Innovation$_i$				
Left censored obs	43			
Right censored obs	0			
Uncensored obs	976			
Total obs	1019			
Dependent variables:	**Parameter**			
Constant	β_0	0.2292*	(0.0212)	10.7927
CEO_Nationality$_i$	β_1	-0.0023	(0.0117)	-0.1959
CEO_Education$_i$	β_2	0.0360*	(0.0109)	3.2877
CEO_Gender$_i$	β_3	0.0312*	(0.0102)	3.0450
CEO_Experience$_i$	β_4	0.0003	(0.0006)	0.4498
Export$_i$	β_5	0.0591*	(0.0112)	5.2658
Domestic_Ownership$_i$	β_6	-0.0002	(0.0002)	-1.3092
Professional$_i$	β_7	0.0011*	(0.0003)	3.5854
Firm_Size$_i$	β_8	0.00001**	(0.00001)	1.7487
Error Distribution				
SCALE: C(10)		0.1511*	(0.0039)	38.4906

Note: Huber/White robust standard errors (S.E.) are in parentheses; * and ** indicate that the coefficients are statistically significant at the 1% level and 10% levels, respectively.

Moreover, the variable for professionals is found to have a significant and positive association with a firm's technological innovation, implying that firms with more professionals are likely to engage in greater technological innovation than those that hire fewer professionals. According to the 2006 manufacturing survey collected by the World Bank and used in this paper, professionals are defined as workers who generally hold a university-level degree. They are trained and certified specialists outside of management, such as engineers, accountants, lawyers, chemists, scientists and software programmers. This result is similar to the findings of Kerr (2013) and Albaladejo and Romijn (2000). Firm size is found to be significantly and positively associated with a firm's technological innovation, implying that larger firms are likely to join more innovative activities due to better access to finance, technology, human resources and information. This result is also consistent with the findings of Bhattacharya and Bloch (2002) and de Mel et al. (2009). Finally, domestic ownership is not significantly related to innovation, implying no significant conclusion that more domestic ownership will lead to more technological innovation in the case of Thai manufacturers. This finding does not support the statement in the OECD (2013) that "Thai firms are mostly owned by ethnic Chinese interests throughout generations. Some of them are in a better position to learn and exploit technological developments in other parts of the world due to their trade links, expansion and diversification into foreign operations at the centers of technological innovation via direct investment and the establishment of foreign production plants" (OECD (2013, p. 271)).

9. Conclusion and Policy Implications

This study employs the 2006 manufacturing sector survey collected by the Foundation of Thailand Productivity Institute (FTPI) in collaboration with the World Bank to empirically investigate the significant importance of technological innovation and CEO characteristics, such as education, experience, gender and nationality, on the cost efficiency of Thai manufacturing firms. The effects of other factors, such as i) unskilled foreign labour, 2) firm size, 3) firm age and 4) domestic ownership on their cost efficiency, are also examined. The one-stage procedure introduced by Battese and Coelli (1995) are applied in this study, except the stochastic cost frontier model and the cost inefficiency effects models are estimated simultaneously and a firm's cost efficiency is predicted. More importantly, this study's analysis had never

been conducted previously, especially in the context of the Thai manufacturing sector. Previous empirical studies focusing on Thailand have employed only the stochastic production frontier and production inefficiency effects models, and have measured a firm's technical efficiency (see Charoenrat et al. (2013)). In addition, the maximum likelihood tobit regression model is applied to investigate the significant sources of technological innovation for Thai manufacturers.

This study finds that technological innovation plays an important role in enhancing the cost efficiency of Thai manufacturers. Innovative activities such as product innovation, process innovation and technological changes of products and processes, therefore, could be promoted for Thai manufacturers. More importantly, the government might promote ICT infrastructure and better coordinate and implement national science and technology policies as suggested by the OECD (2013). Examining CEO characteristics, education can be seen as helping to improve the cost efficiency of Thai manufacturing firms. Other CEO characteristics such as gender, experience and nationality, however, do not significantly influence cost efficiency. These results suggest that there is no significant difference in terms of cost efficiency performance between i) male and female CEOs, ii) more experienced and less experienced CEOs and iii) Thai and foreign CEOs. This study also reveals decreasing returns to scale and a high level of cost inefficiency in Thai manufacturers. Focusing the effects of significant sources of technological innovation for Thai manufacturing enterprises, CEO education and gender play a key role in promoting technological innovation. Government policy, which focuses on improving CEO knowledge and training, particularly for female CEOs, should be implemented to reduce cost inefficiency and increase technological innovation. In parallel with current government programs such as the Thai Woman Empowerment Fund, the government might establish a new program that focuses on developing female CEOs or entrepreneurs' knowledge on how to initiate technologically innovative businesses across Thailand. Firm size is significantly and positively correlated with the cost efficiency and technological innovation of Thai manufacturing enterprises, implying that economies of scope and scale of larger enterprises can reduce their cost inefficiency and increase their technological innovation. Increased firm size could be encouraged for Thai manufacturers, since larger firms can lead to economies of scale and scope, reduced production costs and enhanced efficiency and competitiveness (Pham, 2004; Charoenrat et al., 2013). For instance, the government can facilitate Thai manufacturing enterprises to obtain affordable interest payments or new equity via listings on the Market for Alternative Investment and the Stock Exchange of Thailand. In addition, government agencies such as the Board of Investment can encourage an increase in Thai manufacturing enterprises' investments by offering tax and non-tax incentives for potential investment projects. Enhancing the skills of workers, especially those of foreign unskilled workers through education and job training programs, is crucial to raise the cost efficiency and technological innovation of Thai manufacturers. More specifically, linkages between educational institutions and industry in Thailand could be encouraged to promote a skilled labour supply in the industry, especially those workers who have an educational background in science and engineering. This can help stimulate technological innovation among Thai manufacturers, since the study finds a significant and positive correlation between professionals and technological innovation of these firms. Government policies focusing on the export participation of Thai manufacturing enterprises, therefore, could be promoted due to a significant and positive association between exports and technological innovation. Government agencies such as the Department of International Trade Promotion can play an important role in encouraging more export participation of Thai manufacturing enterprises.

10. References

Albaladejo, M., & Romijn, H. (2002). Determinants of Innovation Capability in Small Electronics and Software Firms in Southeast England, *Research Policy*, *31*, 1053-1067.

Alvarez, R., & Crespi, G. (2003). Determinants of Technical Efficiency in Small Firms. *Small Business Economics*, *20*(1), 233-244.

APO (2013). *APO Productivity Databook*, Tokyo: Asian Productivity Organization. Retrieved January 5, 2014, from http://www.apo-tokyo.org/publications/files/APO_Productivity_Databook_2013.pdf

Athukorala, P-C., & Suphachalasai, S. (2004). Post-Crisis Export Performance in Thailand, *ASEAN Economic Bulletin*, *21*(2), 19-36.

Barro, R.J., & Lee. J.W. (2010). *A New Data Set of Educational Attainment in the World, 1950-2010* (NBER Working Paper 19502): Cambridge, MA: National Bureau of Economic Research. Retrieved April 21, 2014, from http://www.nber.org/papers/w15902.pdf

Battese, G.E., & Coelli, T.J. (1993). *A Stochastic Frontier Production Function Incorporating a Model for Technical Inefficiency Effects* (Working Papers in Econometrics and Applied Statistics No. 69), Armidale: Department of Econometrics, University of New England, Armidale.

Battese, G.E., & Coelli, T.J. (1995). A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics*, *20*(2), 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*, *21*(3), 19-179.

Bhattacharya, M., & Bloch, H. (2002). Determinants of Innovation, *Small Business Economics*, *22*, 155-162.

Bhagat, S., Bolton, B., & Subramanian, A. (2010). *CEO Education, CEO Turnover, and Firm Performance*. Retrieved July 5, 2014, from http://www.unh.edu/news/docs/bolton_CEOEducation.pdf

BOT (2014a). *Foreign Direct Investment Classified by Business Sector of Thai Enterprises*. Retrieved February 2, 2014, from the Bank of Thailand website: http://www2.bot.or.th/statistics/BOTWEBSTAT.aspx?reportID=655&language=ENG

BOT (2014b). *Labour Productivity Index Per Employed Persons*. Retrieved February 2, 2014, from http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=634&language=eng

Cassiman, B., Golovko, E., & Martínez, E. (2010). Innovation, Exports, and Productivity, *International Journal of Industrial Organization*, *28*, 372-376.

Charoenrat, T., Harvie, C., & Amornkitvikai, Y. (2013). Thai Manufacturing Small and Medium Sized Enterprise Technical Efficiency: Evidence from Firm-Level Industrial Census Data. *Journal of Asian Economics*, *27*, 42-56.

Coelli, T.J. (1996). *A Guide to Frontier Version 4.1: A computer Program for Stochastic Frontier Production and Cost Estimation* (CEPA Working Paper No. 7/96). Armidale: Centre for Efficiency and Productivity Analysis (CEPA), Department of Econometrics, 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* (2nd ed.), New York, USA: Springer.

Cohen, W. & Klepper, S., (1996). Firm Size and the Nature of Innovation within Industries: The Case of Process and Product R&D, *The Review of Economics and Statistics*, *78*(2), 232-243.

Crespi, G., & Zuniga, P. (2011). Innovation and Productivity: Evidence from Six Latin American Countries, *World Economy*, *40*(2), 273-290.

Damijan, J., Kostevc, C., & Polanec, S. (2010). From Innovation to Exporting or Vice Versa?, *The World Economy*, *33*(3), 374-398.

De Mel, S., McKenzie, D., & Woodruff, C. (2009). *Innovative Firms or Innovative Owners?: Determinants of Innovation in Micro, Small, and Medium Enterprises* (WB Policy Research Working Paper 4934). Washington, DC: The World Bank. Retrieved March 22, 2014, from http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-4934

Díaz, M., & Sánchez, R. (2014). Innovation, *Exports and Technical Efficiency in Spain* (MPRA Paper No. 53230). Spain: Munich Personal RePEc Archive. Retrieved March 22, 2014, from http://mpra.ub.uni-muenchen.de/53230/

Ekanayake, E. (1999). Exports and Economic Growth in Asian Developing Countries: Cointegration and Error-Correction Models. *Journal of Economic Development*, *27*(2), 43-56.

Elsaid, E., Wang., X., & Davidson, W. (2011). Does Experience Matter? CEO Successions by Former CEOs, *Managerial Finance*, *37*(10), 915-939.

Farrell, M. (1957). The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society*, *120*(3), 253-290.

Girma, S., Görg, H., & Hanley, A. (2008). R&D and Exporting: A Comparison of British and Irish Firms, *Review of World Economics*, *144*(4), 750-773.

Girma, S., Kneller, R., & Pisu, M. (2007). Do exporters have anything to learn from foreign multinationals?, *European Economic Review*. *51*(4), 993-1010.

Griffith, R., Huergo, E., Mairesse, J., & Peters, B. (2006). Innovation and Productivity Across Four European Countries, *Oxford Review of Economic Policy*, *22*(4), 483-498.

Hoff, A. (2006). Second Stage DEA: Comparison of Approaches for Modelling the DEA Score, *European Journal of Operational Research*, *181*(1), 425-435.

Hughes, M.D. (1988). A Stochastic Frontier Cost Function for Residential Child Care Provision, *Journal of Applied Econometrics*, *3*(3), 203-214.

ILO (2012). *Sectoral Country - Thailand* (Research Report). Retrieved 15 May, 2014, from International Labour Organization website: http://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_161290.pdf

Jalbert, T., Rao, R., & Jalbert, M. (2002). Does School Matter? An Empirical Analysis of CEO Education, Compensation, and Firm Performance, *International Business and Economics Research Journal*, *1*(1), 83-98.

Jalbert, T., Chan, C., Jalbert, M., & Landry, S. (2007). The Interrelationship of CEO Nationality with Financial Management, Firm Performance, and CEO Compensation, *The Journal of Diversity Management*, *2*(2), 7-23.

Jongwanich, J. (2007). *Determinants of Export Performance in East and Southeast Asia* (ERD Working Paper no.140). Manila: Asian Development Bank. Retrieved April 18, 2014, from http://www.adb.org/sites/default/files/pub/2007/WP106.pdf

Kerr, P., Kerr, R., & Lincoln, F. (2013). *Skilled Immigration and the Employment Structures of U.S. Firms*. (Harvard Business School Working Papers 14-040). Cambridge, MA: Harvard Business School. Retrieved January 23, 2014, from http://www.hbs.edu/faculty/Publication%20Files/14-040_96933ceb-3097-4432-97d1-0b32625889f9.pdf

Mairesse, J., & Mohnen, P. (2010). *Using Innovations Surveys for Econometric Analysis* (NBER Working Paper 15857). Cambridge, MA: National Bureau of Economic Research. Retrieved January 23, 2014, from http://www.nber.org/papers/w15857.pdf

Khan, W., & Vieito, J. (2013). CEO Gender and Film Performance, *Journal of Economics and Business*, *67*, 55-66.

Kim, S. (2003). Identifying and Estimating Sources of Technical Inefficiency in Korean Manufacturing Industries. *Contemporary Economic Policy*, *21*(1), 132-144.

Kodde, D., & Palm, F. (1986). Wald criteria for jointly testing equality and inequality restrictions, *Econometrica*, *54*(1), 1243-1248.

Kumbhakar, S.C., & Lovell, C.A.K. (2000). *Stochastic Frontier Analysis*, Cambridge, UK: Cambridge University Press.

Lam, K., McGuinness, P., & Vieito, J. (2013). CEO Gender, Executive Compensation and Firm Performance in Chinese-Listed Enterprises, *Pacific-Basin Finance Journal*, *21*, 1136-1159.

Le, V., & Harvie, C. (2010). How do Vietnamese SMEs perform? Technical Efficiency of SMEs in the Manufacturing Sector and Its Sub-Sectors (pp. 1-37). In *Korea and the World Economy, IX Conference*. University of Incheon, Korea: The Association of Korean Economic Studies, 1-37. Retrieved June 12, 2012, from http://ro.uow.edu.au/cgi/viewcontent.cgi?article=3243&context=commpapers

Lee, C. (2011). Trade, Productivity, and Innovation: Firm-level evidence from Malaysian Manufacturing, *Journal of Asian Economics*, *22*, 284-294.

Liefner, I. & Schiller, D. (2008). Academic Capabilities in Developing Countries - A Conceptual Framework with Empirical Illustrations from Thailand, *Research Policy*, *37*(2), 276-293.

Llull, J. (2008). The *Impact of Immigration on Productivity* (CEMFI Working Paper No. 0802). Madrid: Center for Monetary and Financial Studies. Retrieved May 12, 2014, from ftp://ftp.cemfi.es/wp/08/0802.pdf

Lombaerde, P. (2008). The Paradoxes of Thailand's Pre-crisis Export Performance. *Global Economic Review*, *37*(2), 249-264.

Mairesse, J., & Mohnen, P. (2010). *Using Innovations Surveys for Econometric Analysis* (NBER Working Paper 15857). Cambridge, MA: National Bureau of Economic Research. Retrieved January 23, 2014, from http://www.nber.org/papers/w15857.pdf

McDonald, J. (2009). Using Least Squares and Tobit in Second Stage DEA Efficiency Analyses. *European Journal of Operational Research*, *197*(2), 792-798.

Ministry of Industry (2009). *The 5-Year Master Plan for Thai Industry Development Policy* (research report in Thai). Retrieved October 26, 2013, from http://www.industry.go.th/5/Forms/AllItems.aspx?PageView=Shared

Ministry of Industry (2012). *National Industry Development Master Plan (2012-2031)*. Retrieved October 26, 2013, from http://www.oie.go.th/sites/default/files/attachments/industry_plan/National_ Industrial_Development_Master_Plan.pdf

NESDB (2014). *Table of National Accounts*. Retrieved, February 1, 2014, from NESDB Database.

Noor, Z., Isa, N., & Jalil, S. (2011). The Impact of Foreign Workers on Labour Productivity in Malaysian Manufacturing Sector. *International Journal of Economics and Management*, *5*(1), 169-178.

OECD (2005). *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, (3rd ed). Retrieved April 14, 2014, from http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/OSLO/EN/OSLO-EN.PDF

OECD (2013). *OECD Reviews of Innovation Policy: Innovation in Southeast Asia* (Research Report). Retrieved April 15, 2014, from Organization for Economic Cooperation and Development website: http://www.oecd-ilibrary.org/science-and-technology/innovation-in-southeast-asia-2012_9789264128712-en

OSMEP (2007). *The 2nd SMEs Promotion Plan (2007-2011)* (Research Report). Retrieved April 10, 2014, from http://eng.sme.go.th/SiteCollectionDocuments/SMEs%20Promotion%20Plan/SME-Master-Plan-2.pdf

OSMEP (2013). *Executive Summary: White Paper on SMEs 2013* (Research Report). Retrieved April 10, 2014, from http://www.sme.go.th/SiteCollectionDocuments/White%20Paper/2556/สสว.%20บทสรุป%20Eng%202013%20รวมเล่ม.pdf

Palangkaraya, A. (2012). *The Link between Innovation and Export: Evidence from Australia's Small and Medium Enterprises* (ERIA Discussion Paper 2012-08). Jakata: Economic Research Institute for ASEAN and East Asia. Retrieved April 26, 2014, from http://www.eria.org/ERIA-DP-2012-08.pdf

Peri, G. (2009). *The Effect of Immigration on Productivity: Evidence from US States* (NBER Working Paper 15507). Cambridge, MA: National Bureau of Economic Research. Retrieved April 10, 2014, from http://www.nber.org/papers/w15507.pdf

Punyasavatsut, C. (2008). SMEs in The Thai Manufacturing Industry: Linking with MNEs. In Lim, H. (Ed.), SME in Asia and Globalization (pp. 287-321). Jakarta: Economic Research Institute for ASEAN and East Asia.

Romer, P. (1986). Increasing Returns and Long-Run Growth, *Journal of Political Economy*, *94*(5), 1002-1037.

Romer, P. (1990). Endogenous Technological Change, *Journal of Political Economy*, *98*(5), S71-S102.

Romer, P. (1994). The Origins of Endogenous Growth. *Journal of Economic Perspectives*, *8*(1), 3-22.

Sánchez R., & Díaz, M. (2013). *Are Large Innovative Firms More Efficient?* (MPRA Paper No. 44592). Spain: Munich Personal RePEc Archive. Retrieved March 29, 2014, from http://mpra.ub.uni-muenchen.de/44592

Singha, D. (1999). Export Instability, Investment and Economic Growth in Asian Countries: A Time Series Analysis (Center Discussion Paper no. 799). New Haven, CT: Economic Growth Center, Yale University. Retrieved January 4, 2014, from http://www.econ.yale.edu/growth_pdf/cdp799.pdf

Solow, R. (1956). A Contribution to the Theory of Economic Growth, *The Quarterly Journal of Economics*, *70*(1), 65-94.

Tran, T., Grafton, R., & Kompas, T. (2008). Firm Efficiency in a Transitional Economy: Evidence from Vietnam. *Asian Economic Journal, 22*(1), 47-66.

Wasserman, N., Nohria, N., & Anand, N. (2001). *When Does Leadership Matter? The Contingent Opportunities View of CEO Leadership* (Harvard Business School Working Paper No. 01-063). Cambridge, MA: Harvard Business School. Retrieved March 24, 2014, from http://dx.doi.org/10.2139/ssrn.278652

World Bank Office -Thailand (2008). *Thailand Economic Monitor April 2008* (Research Report). Retrieved March 29, 2014, from http://siteresources.worldbank.org/INTTHAILAND/Resources/Economic-Monitor/TEM-April-2008.pdf