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Thai Manufacture's Efficiency Improvement: A Stochastic Frontier Analysis

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The manufacturing industry in Thailand has played an important role in the economic development during 1960-2015. In this study, we have applied a *Stochastic Frontier Analysis* to explore the technical efficiency in their production and cost system applying a cross-section data of the Manufacture Census 2012.

Thai manufacturing has consistent efficiency in ascending order of firm sizes. The larger firms have efficiency than the medium and small enterprises respectively. The overall efficiency of firms has reduced significantly when a firm employs less than 51 persons.

The Thick Frontier Approach (TFA) has found that the cost of inefficiency firms is 35.2 percent higher than the efficient firms. The Quantile Regression Approach, firms with low cost has the average cost of 26.49 percent of the inefficient firm. Finally, firms that are located around the capital city BMR have superiority of efficiency at the

Thai manufacturing is widely efficient. This is a reason to explain the power of penetration to the Global Value Chain recently. The marginal spatial effect on the firm's efficiency is found when they are located around the Bangkok Metropolitan Region.

Thai manufacture's efficiency can be improved by (1) promote the enlargement of small enterprises to reach the optimal size. (2) Establishment of Industrial Development Zone that can be accessed from the BMR's vicinity. (3) The allocative efficiency has not been addressed in this study and needs further study to explain the decomposition of a firm's efficiency.

JEL: L6, O4, O14, O25, C3, C54, C55

Keywords: Stochastic Frontier, production and cost efficiency, marginal spatial effect of firms' location, firm sizes effect.

1. Introduction

The Ministry of Industry, the Thai Government has drafted the National Industrial Development Plan 2012 -2031. The direction of the plan has aimed to draw future development of Thai industries. The main content has concentrated on how to develop the green and clean industry with environmental friendly that can reach the global standard in business ethic. Here, modern technology based on the knowledge would be aimed, executing through the collaborative network and cluster. The plan has cited the new mode of production that can climb up through a global value chain.

Despite the ambitious dream mentioned above, it has not been clear what would be the specialized core competency of the Thai industry at present. Currently, it is widely known that the world is venturing through a global risk of geopolitics and climate change and the tendency of rising competitiveness of export industrial products from a large developing country like China PRC. The changing landscape of the digital payment system through a new platform of the Internet of Things and BlockChain has fastened the digital divide between countries in terms of industrial efficiency in production and export competitiveness.

In the new environment of wealth creation, the role of human wisdom in Thailand would be necessary for value creation and innovation. For Thailand, the industrial structure would need to be upgraded and internationalized by her capable entrepreneurs to seek global opportunities. Thailand is aiming to drive away from labor-intensive, low-technology to a new epoch of industrial development despite a severe lack of capable human resources. Thailand has the ambition to build *10 targets 10 industries*[1], *including biotechnology, aerospace, and automation and robotics.*[2] The Thai parliament passed the Eastern Economic Corridor law to facilitate this industrial development in the area. The Thai government aims to attract at least 300 billion baht ($9.4 billion) of new investment to the corridor approximately 40% of Thailand's total new investment target for 2018. The EEC law will help ensure that five major infrastructure projects go ahead -- a high-speed train, the expansion of the deep seaport, the development of new commercial airport and maintenance facility near airport scheduled to finish by 2022.

This paper has tried to investigate the structure of the manufacture sub-sector in Thailand by analyzing technical efficiency from the point of production and cost. We have applied a stochastic frontier model to surveyed data of the manufacturing sector. A firm-level data of manufacture sub-sector is applied in our study. The sample data is from the Manufacture Industrial Census of Thailand in 2012. We have applied econometric model estimation following the standard Stochastic Frontier Analysis (SFA) to calibrate technical and allocative efficiencies indices of both production and cost structure. The recommendation will be later derived for industry policy formulation in Thailand.

2. A Brief Overview of the Structure of Thai Manufacture

Under the National Accounts[3], contribution to the Gross Domestic Product (in constant price and reference year 2002, CVM) from agriculture activities have been declined substantially since 1985. It was replaced by the contribution from the manufacturing and services sector when measured in terms of value-added. During 1990-2016, the share of value-added produced from agriculture sector has been decreased from 9.7 in 1990 to 6.0 percent in 2016. The share of manufacture value-added has increased from 24.7 in 1990 to reach its peak at 30.4 percent of the gross domestic product in 2008. It should be noted that the share has surpassed the turmoil from the Asian Financial Crisis in 1997-1998 and reach its peak in 2008 which was the year which the Global Financial Crisis outbreak. The share has declined from 30.8 percent to 27.3 percent in 2016.

We may explain the structural change of manufacture value-added by investigating the growth cycle of manufacture in Thailand during 1990-2016. We have found that the

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[1] This entails upgrading five existing industries: automotive; smart electronics; advanced agriculture and biotechnology; food processing; and tourism. Five new industries including robotics and mechatronics for both industrial and daily life; the integrated aviation industry, comprising aviation repair, spare parts, and training; medical hubs and integrated wellness centers; the bio-economy, particularly bio-chemicals and bio-fuels; and advanced petrochemical industries.

[2] https://asia.nikkei.com/Economy/Thailand-aims-for-next-industrialization-wave, February 09, 2018 21:58 JST

[3] Throughout the paper, we have applied data from the National Accounts Statistics, NESDB. Data series are recorded in both current market price and at reference year price of 2002 as a CVM calculation method. The data from 2012-2015 are subjected to revision and 2016 is projected one. It will not significantly change any conclusion of this study.

manufacturing growth was sensitive to financial crises especially the Asian Financial Crisis (AFC) in 1997-98 and the Global Financial Crisis (GFC) 2007-08 respectively. Figure 1, we have applied the filter and estimate the 'cycle' from the trend and found that the Thai manufacture sector has recovered from AFC, expanding to its next phase of a cyclical peak during before the GFC. The cyclical growth has declined thereafter and has submerged by a further political crisis in 2014- until the present day.

Figure 1: Growth Cycle of Manufacture in Thailand 1990-2016

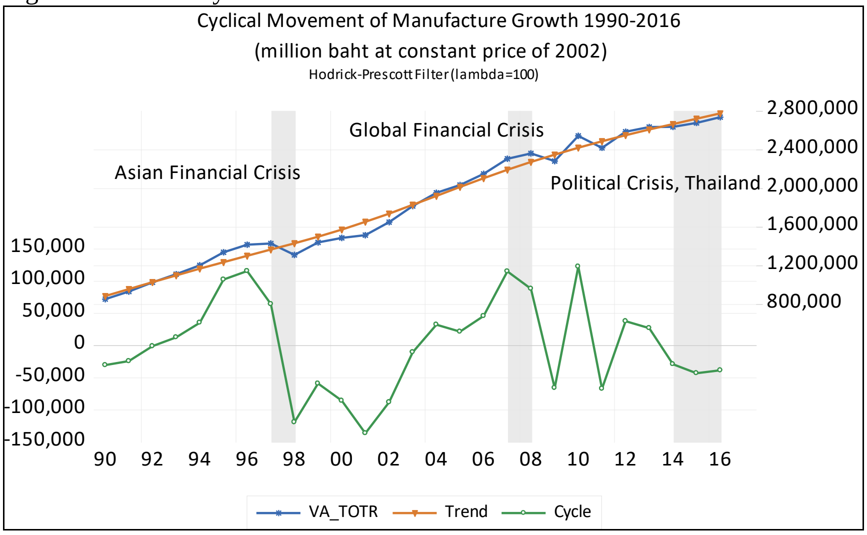
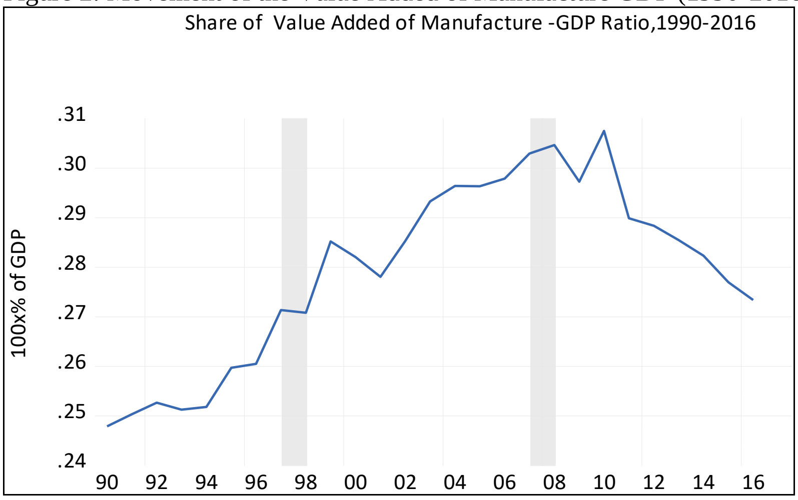


Figure 2: Movement of the Value Added of Manufacture GDP (1990-2016)



Source: National Account Statistics, NESDB, Thai government.

Table 1: Classification of Manufacture Sub-sector

No.	Original Sub-sector in the National Ac.	Regrouping Variables Name	Sector No. List
1	Food products	Food_bev	1
2	Beverages	Food_bev	1

3	Tobacco products	Food_bev	1
4	Textiles	Textiles_Wears	2
5	Wearing apparel	Textiles_Wears	2
6	Leather and related products	Textiles_Wears	2
7	Wood and products of wood and cork	Wood_furn	3
8	Paper and paper products	Paper_Print	4
9	Printing and reproduction of recorded media	Paper_Print	4
10	Coke and refined petroleum products	Chem_process	5
11	Chemicals and chemical products	Chem_process	5
12	Basic pharmaceutical products and pharmaceutical preparations	Chem_process	5
13	Rubber and plastics products	Chem_process	5
14	Non-metallic mineral products	Non_Metal	6
15	Basic metals	Metal_Basic_Fabric	7
16	Fabricated metal products, except machinery and equipment	Metal_Basic_Fabric	7
17	Computer, electronic and optical products	Elect_machine	8
18	Electrical equipment	Elect_machine	8
19	Machinery and equipment not elsewhere classified	Elect_machine	8
20	Motor vehicles, trailers and semi-trailers	Motor_tran_equip	9
21	Other transport equipment	Motor_tran_equip	9
22	Furniture	Wood_furn	4
23	Other manufacturing	Mfg_services	10
24	Repair and installation of machinery and equipment	Mfg_services	11

Source: National Accounts of Thailand, NESDB.

2.1 Brief Summary of Recent Development of Selected Manufacture Sub-Sector

Here is a summary of the selected manufacture sub-sector in Thailand as a background for further analysis.

Food Industry

The demand for food products from Thailand has increased most for the large fresh and frozen food, semi-cooked food industrial products. Thai food export ranks among the top world's food-producing countries. Main export products are rice, cassava, sugar, boneless chicken, canned fish, and fruits. There 1,500 medium to large firms producing for export and domestic market. A recent requirement of higher food standards and rising wages have forced firms to choose a more capital-intensive investment. They have turned to invest in modern technology and pieces of equipment to suppress labor costs and complying with food standards in the markets. Consumers with rising incomes have demanded higher quality and standards. The capital investment comprises the automation processing, a modern refrigerating and freezing equipment, machinery and laboratory paraphernalia for treating materials and machinery for food containers.

Textile and Wearing Apparel

The textile industry which was the largest labor absorption manufacture in the last decades has faced rising wage costs recently. The industry is fully integrated backward to synthetic fiber and yarns, fabric, spinning, and weaving, knitting, bleaching, and dyeing as well as forward linkages to apparel and wearing. Thailand has relied on the import of intermediates inputs of cotton and yarns and quality fabric from Japan, Taiwan, and South Korea respectively. The textile used to be the main export earner for Thailand in the early 1980s and 1990s. Recently, the textile industry has faced competition from China and Vietnam as well as other emerging exports.

Automobile Industry

Thailand is a hub of transport equipment and motor vehicle production in Southeast Asia. Production has reached 90% of complete knock-down (CKD) with a vast domestic market for cars. The production has surpassed 1.5 cars a year capacity and aiming to 2 million units in the future. Thailand is the main exporter after Japan, and South Korea, and China.

Electronics and Electrical Machinery

The openness of the Thai industry to foreign direct investment and a favorable investment climate in Thailand has driven global value chains in this industry. The electronic industry has surpassed the textile industry and automobiles industry in export earning to Asian countries in 1999. The value chain of this industry has generated assembly work of finished products as well as subcontracting production networks in intermediates products in Thailand. Electronics manufacturing in Thailand is outsourced from the global value chains. Major imported products include hard disk drives, integrated circuits, semiconductors, compressors and equipment of the mobile phones as finished products. It also creates related local productions of assembly and testing of HDDs, ICs, and other electronic components meant for export. The export of electrical appliances in Thailand in 2014 was USD 32.3 billion. The local supply chain is quite competitive but has faced rising labor costs recently. The manufacturer may consider investing in automation and machine tools for metalwork, seeking energy-efficient equipment and robots and adopting advanced R&D.

We can explain sources of a declining-rising share of the manufacture sub-sector by translating the share to compare with their 1990's position. It should be noted here that the epochal of periods using 'crisis break' *may and may not* give rise to the 'rising or declining' share of manufacture sub-sector. It is basically for explanatory convenience. It has to be tested by a solid econometric process. The results can be analyzed as follows:

We have pegged our value-added deflator of the manufacture sub-sector with the assumed *numeraire* namely the *GDP deflator of 'food and beverage product'*. The value-added price by definition is cost GDP production from primary factors inputs of 'capital' and 'labor' inclusive of indirect taxes as we have used value-added price at market price instead of at factor cost. To be comparable to one another, we have used the value-added price of food and beverage as a medium of comparison (Figure 3).

1) Manufacture sub-sectors with *the declining* **share** over the period 1990-2016 comprise paper and printing products; food and beverage products; textiles and wearing apparel; wood and furniture respectively. These sub-sectors more or less rely on traditional resource base for their production.

2) Some sub-sectors have shown *rising trend* before AFC and have surpassed the AFC but showing declining share thereafter. They are non-metallic mineral product; paper and printing products; the chemical process products respectively

3) Some have expanded until the GFC and declining thereafter. These are Basic metal and fabricated metal products and electrical machinery and electrical appliances respectively.

4) Only the sub-sector likes the motor vehicle and transport equipments which have exposed to the modern technology and having strong markets bases have shown a rising share over the whole period.

The interpretation is simply that if the food and beverage is representative of a 'wage good', this would imply that the primary cost of production of most of the sub-sectors are equivalently cheaper than food production in relative terms, especially after the AFC for most of the sub-sector and after GFC for the others. This may also mean that food and beverages which are basically labor-intensive, small and medium enterprise have faced *rising wages* during the study period, especially after the GFC. On the other hand, may it mean that most of the manufacture sub-sector other than food and beverages has shifted to capital investment and relying higher capital intensity?

5) It is found that most of value added price of manufacture sub-sector in Thailand 1990-2016 have shown a declining trend except those of chemical process product and manufacture services (Figure 4).

We have selected manufacture sub-sectors and rank them according to their domestic intermediate input ratios. The processed food and beverage and rubber and plastic manufacture production had high domestic intermediate input higher than 50 percent of percentage of gross output during 2000, 2005 and 2010 respectively. In other words, they had low foreign intermediate input content of less than 20 percent of gross output during the periods. The foreign input content of transport equipments and motor vehicles sub-sector was approximately 40 percent as compared to domestic input content of 37.4 percent of gross output in 2010. The electronics and electrical machinery had its foreign input content of 37.7 percent in 2010 as compared with 55.3 percent in 2005. It is noted that the value added over gross output in processed food and beverage sub-sector was declining during 2000, 2005, and 2010. It was 23.1 percent in 2000, 19.5 percent in 2005 and 2010. In contrast, the foreign input content has increased from 13.7 in 2000 to 16.6 percent of gross output in 2010 respectively (See Table 2).

The brief scenario mentioned above has implied that the role of foreign input or import content has shifted in processed food and rubber and plastic products sub-sector while the foreign input content in the case of iron and steel, electronics and electrical machinery, as well as motor vehicle and transport equipments, have shown a stable and declining trend instead. The cost of value-added in gross output production has been quite stable and even declining trend. These may be an impressive indication firstly; production cost in Thailand was quite stable and still competitive as far as the cost of value added is concerned at least until 2010. Secondly, foreign input content has increased in Thai gross output production of food and rubber and plastic products. Thirdly, the manufacturing industry which has strong linkage to global value chains like electronics and electrical machinery, as well as automobile and transport equipment has turned *backward linkage* to domestic intermediate inputs more while toning down the linkage to foreign intermediate inputs market. Nevertheless, there is a limitation in this interpretation for an open economy. The direct coefficients of the Thai I-O 2000, 2005

2010 may not be able to indicate how deep the Thai manufacture sub-sector link with the global value chains.

Table 2: Structure of Domestic and Foreign Inputs in Gross Output Production

	2000					
	Gross Output	Value Added	VA ratio,	Intermediate ratio, %	Domestic	Import
	(1)	(2)	(3)=(2)/(1)%	(4) = (5) +(6)	(5) % of (1)	(6) % of (1)
Processed food	354,989	81,966	23.1	76.9	63.2	13.7
Rubber products	139,146	39,436	28.3	71.7	57.5	14.1
Iron and Steel Products	99,904	35,359	35.4	64.6	35.8	28.8
Electronics and Electrical Machinery	1,166,785	205,714	17.6	82.4	23.5	58.8
Motor vehicles and transport equipment	454,898	119,064	26.2	73.8	34.6	39.2
	2005					
	(1)	(2)	(3)=(2)/(1)%	(4) = (5) +(6)	(5) %	(6) %
Processed food	423,692	82,692	19.5	80.5	60.9	19.6
Rubber products	240,793	49,820	20.7	79.3	64.4	14.9
Iron and Steel Products	286,867	61,979	21.6	78.4	48	30.4
Electronics and Electrical Machinery	1,742,738	326,161	18.7	81.3	25.9	55.3
Motor vehicles and transport equipment	1,001,786	229,397	22.9	77.1	35.6	41.5
	2010					
	(1)	(2)	(3)=(2)/(1)%	(4) = (5) +(6)	(5) %	(6) %
Processed food	548,771	106,813	19.5	80.5	63.9	16.6
Rubber products	363,678	63,295	17.4	82.6	63.1	19.5
Iron and Steel Products	200,182	37,621	18.8	81.2	48.5	32.7
Electronics and Electrical Machinery	3,352,430	586,824	17.5	82.5	45.1	37.3
Motor vehicles and transport equipment	1,379,300	312,975	22.7	77.3	37.4	39.9
Source: Thai Input-Output Tables 200,2005 and 2010 by the National Economic and Social Development Board						

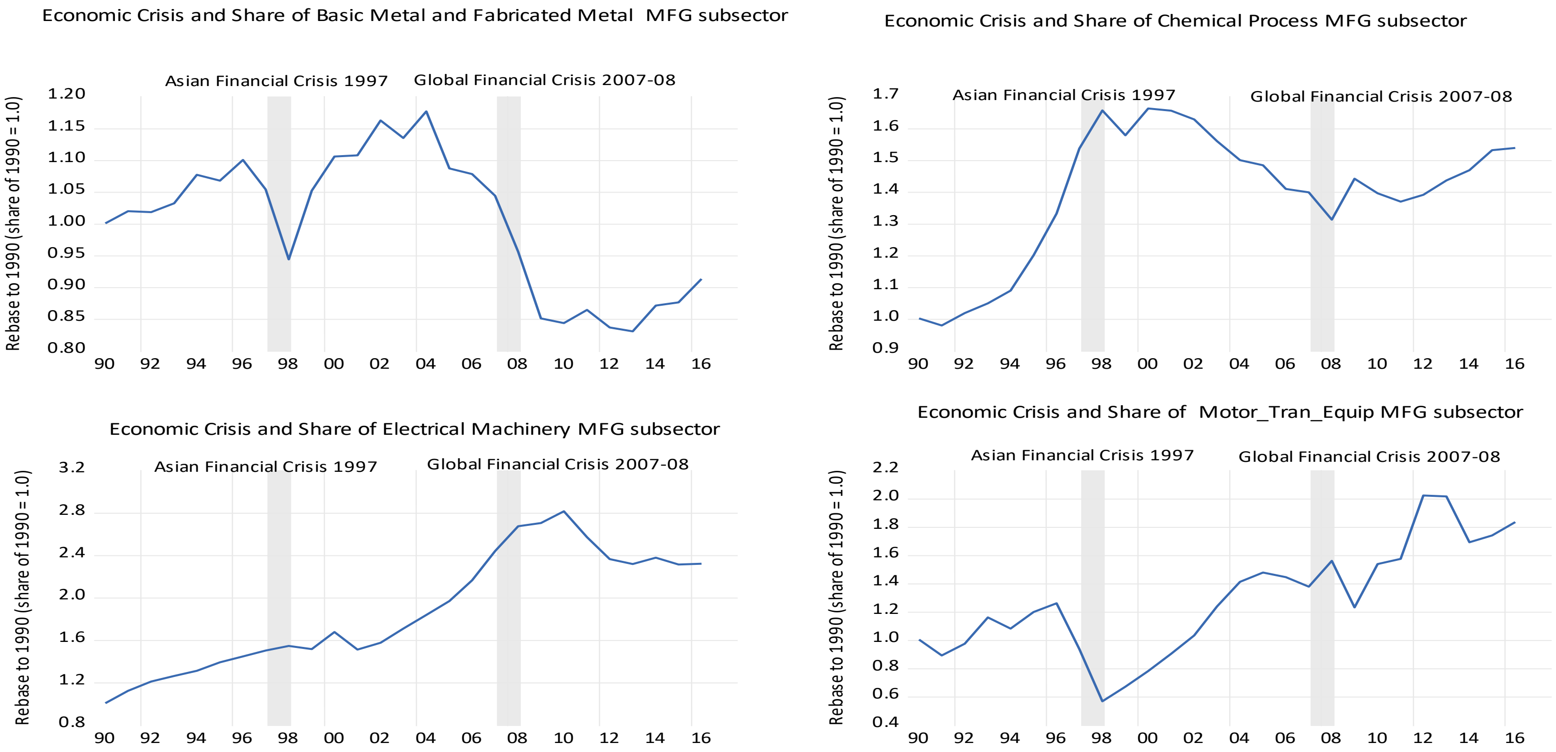


Figure 3: Share of Manufacture Sub-sector 1990-2016 (Rebase to 1990)

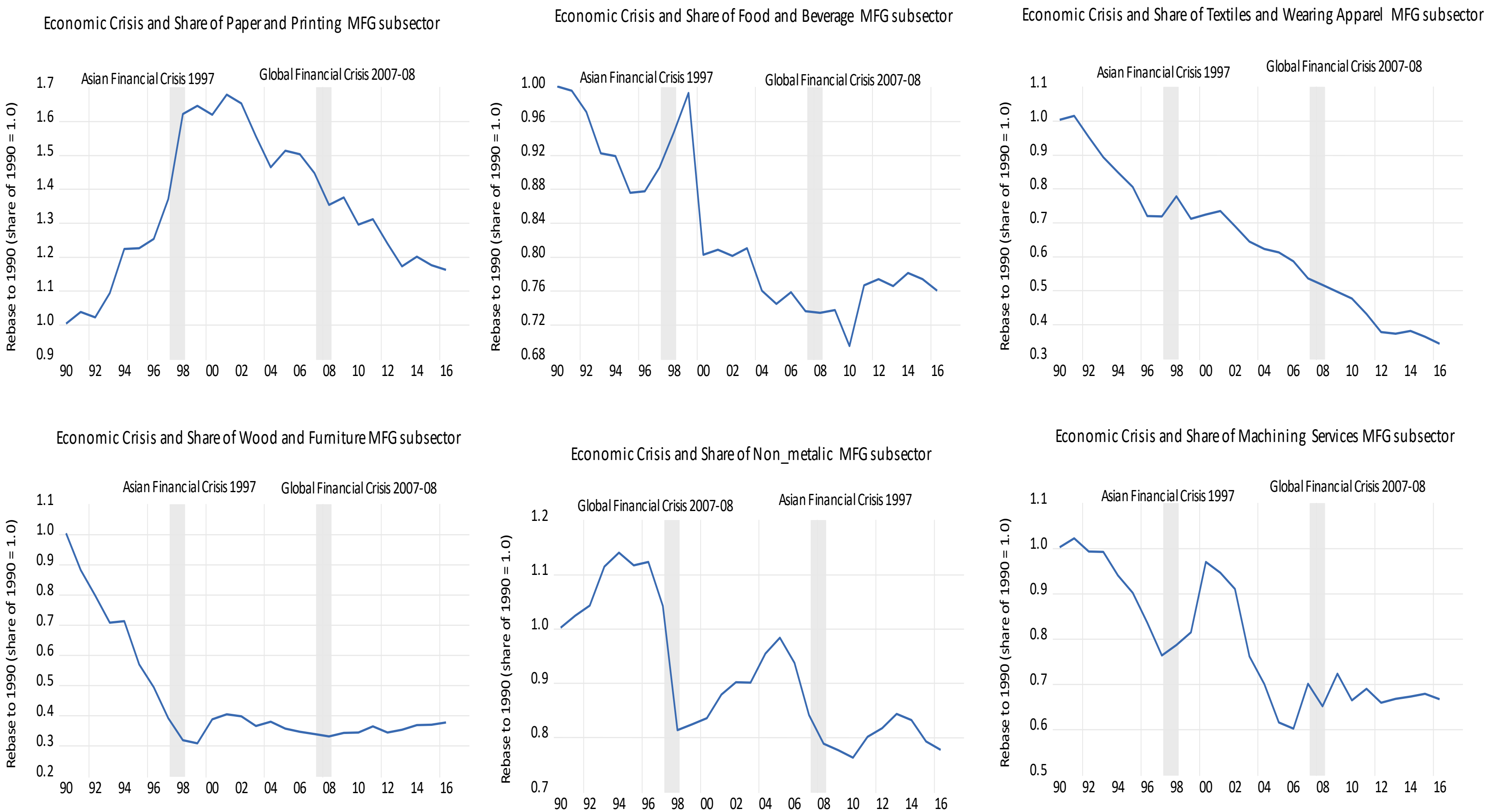


Figure 3: Share of Manufacture Sub-sector 1990-2016 (Rebase to 1990), continued

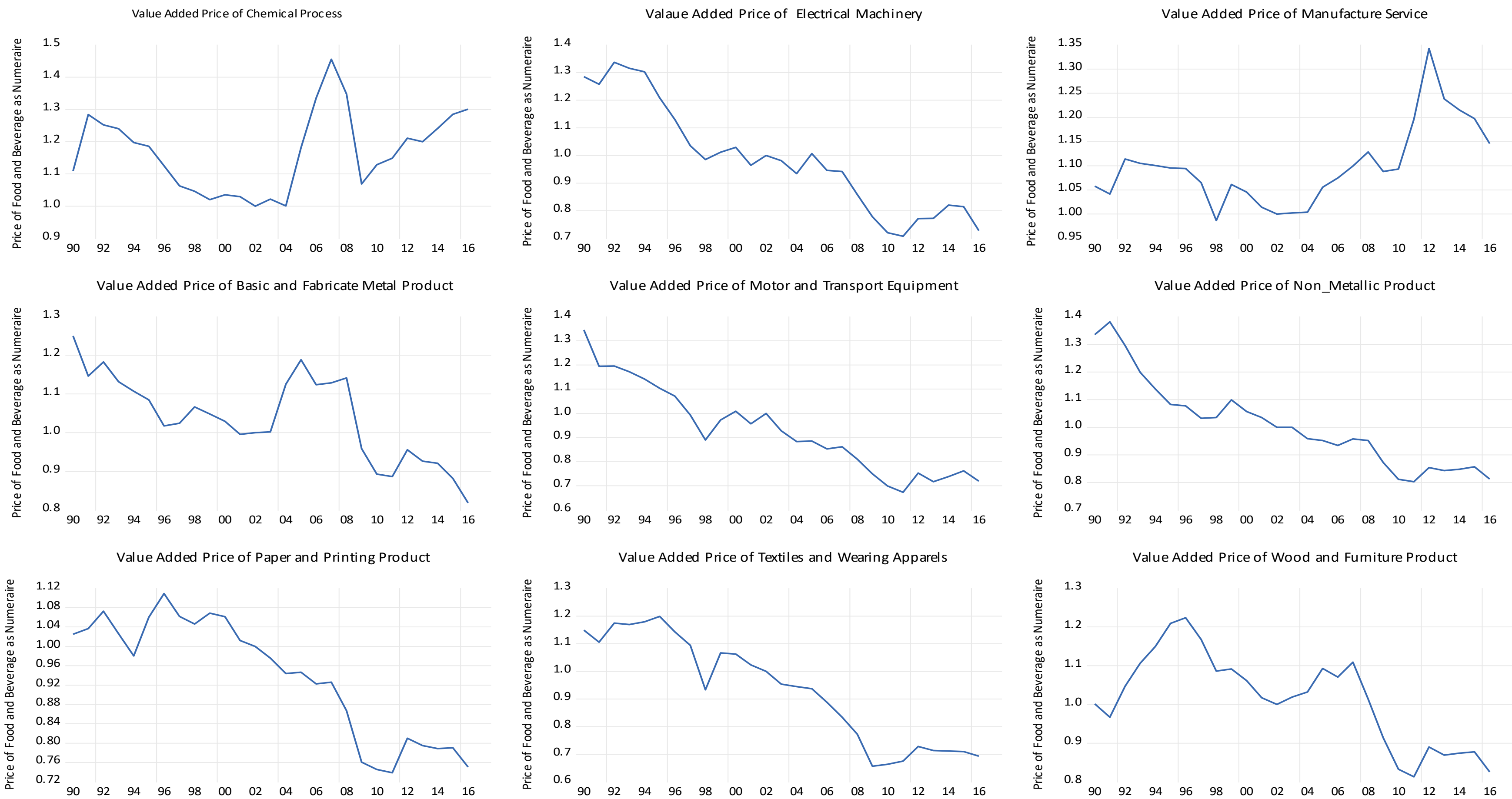


Figure 4: Value added price of Manufacture Sub-sector GDP, 1990-2016 (price of 'food and beverage' as *numeraire)*.

Table 3: Export of Manufacture Products, 2005-2016, In Percentage

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total Export (Millions USD)	110,110	130,580	153,571	175,908	152,497	195,312	228,824	229,545	228,527	227,573	210,883	213,593
Manufacture Export	101,400	119,167	141,890	163,757	143,814	182,455	209,185	213,851	213,558	214,962	200,257	203,517
Percentage Share	100	100	100	100	100	100	100	100	100	100	100	100
Intermediate goods	46.9	47.2	47.9	43.6	43.2	44.2	46.9	43.8	45.4	45.4	44.2	44
Household consumption	25.9	23.9	23.3	24.4	25.7	23.4	23.6	22.7	22.6	22.9	23	23
Capital goods	12.9	12.6	11.8	12.1	11.2	12.8	12.3	14.9	15	15.6	15.4	14.5
Mixed end-use	11.7	12.9	13.5	14.4	15.5	15.5	12.3	13.3	11.6	11.5	14	16.2
of which Personal computers	8.2	9.1	8.8	8.2	7.8	7.1	5.4	6.4	5.7	5.7	5.7	5.2
Passenger cars	2.1	2.5	2.7	3.2	2.8	3.9	3	2.7	3.1	3	4.7	5.7
Personal phones	0.2	0.1	0	0	0	0.1	0.1	0	0.1	0.2	0.3	0.3
Precious goods	1.1	1.2	1.8	2.9	4.7	4.3	3.7	4	2.6	2.5	3.2	4.9
Packed medicines	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Miscellaneous	2.6	3.4	3.5	5.5	4.4	4.3	4.9	5.3	5.4	4.6	3.4	2.4

Note: Mixed end-used comprises personal computers, passenger cars, personal phones, precious goods, and paced medicines

Source: https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

Table 4: Import of Manufacture Products, 2005-2016, In Percentage

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total Import (US Dollar, Thousands)	118,164	128,584	143,761	178,613	133,770	182,393	228,483	247,576	250,708	227,932	202,019	195,714
Manufacture Import	94,016	100,675	113,113	135,618	105,498	147,758	181,661	197,414	197,831	180,611	168,157	167,340
In Percentage	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	100	100
of which, Intermediate goods	67.7	69	70.9	67.3	66.4	67.4	60.9	60.5	59.2	61.2	60.6	60.5
Household consumption	6	6.3	6.4	7	7.7	6.9	6.9	7.3	7.7	8.1	9	9.5
Capital goods	16.8	15.2	14.9	15.5	16.3	14.9	16.3	19.3	17.8	17.7	17.9	18
Mixed end-use	7.5	7.1	5.9	9	8.5	9.7	14.1	11.2	13.3	9.8	10.7	9.7
of which Personal computers	2	1.9	1.6	1.6	1.8	1.7	1.8	2.3	2	2	2.1	1.9
Passenger cars	0.4	0.2	0.2	0.3	0.4	0.5	0.5	0.7	0.7	0.7	0.6	0.6
Personal phones	1.6	1.5	1	0.9	0.9	0.8	1	1.4	1.6	2.1	2.3	2.3
Precious goods	3	2.8	2.4	5.5	4.4	5.9	10	6	8.3	4.2	4.8	4.1
Packed medicines	0.6	0.7	0.7	0.7	1	0.8	0.7	0.7	0.7	0.8	0.9	0.9
Miscellaneous	2	2.3	1.9	1.2	1.1	1.2	1.8	1.8	1.9	3.1	1.8	2.3

Note: Mixed end-used comprises personal computers, passenger cars, personal phones, precious goods, and paced medicines

Source: https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

2.2 Structure of Demand for Manufacture Products and the Global Value Chains

The demand prospect of selected sub-sector can be summarized in short as follows: The structure of Thai manufacture via the demand for export may be analyzed in-depth further through the international comparison of the indicators called the ‘Global Value Chains, or the GVC’. It is indicators based on the global input-output model for the year 1995, 2000, 2005, 2008 and 2009 respectively. The international I-O was harmonized by the OECD[4] covering 58 economies (34 OECD and 23 non-OECD, plus rest of the world economy) and 37 industries[5] and representing 95 percent of world trade. Given the Inter-Country Input-Output (ICIO) where the coefficients are values of all inputs used by one industry in a given country. The ICIO has coefficients of *domestic and foreign inputs* which we can construct indices that can be decomposed according to *domestic* production stages and *foreign* production stages.

In 2016, the Thai manufacture has its export share of the intermediate goods of 44 percent, the household consumption goods of 23 percent and the export of capital goods 14.5 percent respectively. The trend of export share by component has not been changing much during 2005-2016. The import share of intermediate and capital goods has overwhelmed the import of manufactured goods to Thailand during the same period.

The domestic value-added of the Thai industry has a significant contribution to gross exports during 1995-2011 as reported by the OECD in the GVC calculation. The declining trend has been observed and replaced by the rising trend of the foreign value-added contribution to gross exports of Thailand during the same period. The domestic value-added contribution to final goods export has declined and may imply the *cost inefficiency* as far as domestic factor inputs are concerned. Instead, the re-exported of the intermediate imports as a percentage of the total intermediate imports has risen significantly during the period. By construction, the *foreign value-added* embodied in Thai *exports* measured as a percent of the total gross exports is defined as the *‘Backward participation in the GVCs’*. It has been rising significantly. On the other hand, the *domestic value-added* embodied in *foreign exports*, measured as the percent of

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[4] De Backer, K. and S. Miroudot (2013), • Annex1: Indicators on global value chains, page 44, Mapping Global Value Chains, *OECD Trade Policy Papers*, No. 159, OECD Publishing, Paris. http://dx.doi.org/10.1787/5k3v1trgnbr4-en.

[5] See www.oecd.org/sti/inputoutput/

the total gross exports is nominated as the '*Forward participation in the GVCs'*. (Refer to Table 3-5)

Table 5: Joining the Global Value-Added Chain of Thai Manufacture, in Percentage

	1995	2000	2005	2008	2009	2010	2011
Industry domestic value-added contribution to gross exports	42.27	39.96	38.08	35.07	38.62	37.71	34.4
Industry foreign value-added contribution to gross exports	19.68	26.25	30.51	32.23	28.62	30.65	32.19
Domestic value added in exports of final products as a share of total gross exports	34.07	27.58	23.91	22.69	24.24	22.78	21.39
Re-exported intermediate imports as % of intermediate imports	38.25	59.21	55.5	57.92	58.61	58.05	58.2
Foreign VA embodied in exports, as % of total gross exports (Backward participation in GVCs)	19.7	26.3	30.5	32.2	28.6	30.7	32.2
Domestic VA embodied in foreign exports, as % of total gross exports (Forward participation in GVCs)	9.6	12.1	13.2	12.4	12.8	13.6	12.4
Source: https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm							

3. Stochastic Frontier Models Applied in Current Study

3.1 Basic Concept of the Cross-sectional Production Frontier Model

In our study, we have followed Kumbhakar and Lovell (2003) and Kumbhakar, Wang and Horncastle (2015). Kumbhakar and Lovel (chapter 3, p 63-) has described in detail of the estimation of technical efficiency with the 'output-oriented measure of technical efficiency'.

Firstly, each firm as subset of I producers (i=1, 2,3,….I), uses cross-sectional quantities x_i of N inputs to produce single output y_i. The *production frontier* $f(x_i\ ;\ \beta)$ where β is a vector of technology parameters to be estimated, can be written as

$$y_i = f(x_i\ ;\ \beta) * TE_i \qquad (1)$$

In case producer may face *random shocks* that are not under the control of a producer. Thus, the equation (1) can be written as a *stochastic frontier* model

$$y_i = f(x_i\ ;\ \beta) * \exp\{\upsilon_i\} * TE_i \quad , \qquad (2)$$

The technical efficiency of producer *i-th,* facing the stochastic situation is defined as

$$TE_i = \frac{y_i}{f(x_i\ ;\beta)*\exp\{\upsilon_i\}} \quad , \qquad (3)$$

where $[y_i = f(x_i\ ;\ \beta) * \exp\{\upsilon_i\}]$ is the stochastic production function frontier which comprises deterministic and stochastic parts, $\exp\{\upsilon_i\}$. Here, y_i achieves its maximum feasible value if and only if, TE_i=1. Otherwise, TE_i<1, the technical efficiency is lower than its maximal feasible output value at the frontier. The stochastic component $\exp\{\upsilon_i\}$, is allowed to vary across producers.

The nonstochastic model (1) can be estimated applying the 'goal and quadratic programming'. This is to *minimize the sum of squared proportionate deviations of the observed output of each producer beneath maximum feasible output*[6]. The estimation of the parameter β of the production frontier, assuming the log-linear Cobb-Douglas uses mathematical programming. Further, given $u \geq 0$ of the exponential distribution

$$f(u) = \frac{1}{\sigma_u} * \exp\{-\frac{u}{\sigma_u}\}, \qquad (4)$$

of the log-likelihood function and the half-normal distribution function

$$f(u) = \frac{1}{\sqrt{2\pi}\sigma_u} * \exp\{-\frac{u^2}{2\sigma^2{}_u}\} , \qquad (5)$$

The log-likelihood function is

$$\ln L = constant - \frac{1}{2} ln2\sigma^2{}_u - \frac{\sum_i u_i^2}{2\sigma^2{}_u} \qquad (6)$$

We derive the parameters of the deterministic production frontier.

It has been known that the application of a cross-sectional data may result in the downward or/and upward biased. It is caused by the 'heteroskedasticity' appears in the symmetric noise error component. Even though, the all parameters of the production frontier can be estimated with unbiased (except for the intercept, since $E(u) \neq 0$). This is called 'ν **Is Heteroschedastic**'. See Kumbhakar and Lovell (2003, p. 116). The similar econometric problem can occurred when using cross-sectional data. The producer specific factors have influenced on the technical efficiency through distribution of 'u' called **' u Is Heteroskedastic'** . Neglecting to take into account of the heteroskedasticity in 'ν' and 'u' that may appear in the symmetric noise error component may adversely affect the result further. This will produce upward (downward) bias of technical efficiency for relatively small (large) producers when there is 'ν Is Heteroschedastic' in the systematic noise error component. However, the estimation can obtain unbiased parameter estimate describing the structure of production frontier. The effect of neglected 'u Is Heteroskedastic' has both effects. These are the opposite direction with the former effect in terms of the technical

[6]. See p. 67- of Kumbahaka and Lovel (2003).

efficiency and biased parameter estimate as well. There may be the case that our estimated model will have both described effects. The effect may be reduced but not certain.

3.2 Basic Concept of the Cross-sectional Cost Frontier Model

In our analysis, we are interested in the 'input-oriented approach' applying the cross-sectional data inputs to estimate the cost efficiency model. It is noted in brief as follows: (1) the estimation of cost efficiency requires information on input prices, output quantities, and total expenditure on the inputs used and input cost shares. The cross-sectional data of the Thai industrial census 2012 has the foregoing characteristics more or less. (2) The database has information on the share of the multiple outputs. We may rely on the input distance function which is dual to cost frontier and can be used to estimate input-oriented technical efficiency respectively. (3) We may treat some inputs differently between variables and quasi-fixed inputs (some inputs are not variable during the cross-sectional period). In the data, we have labor inputs, material inputs as well as a fixed assets which can be treated differently respectively. (4) We think that in the competitive environment, input prices can be treated as exogenous while input quantities are endogenous to a production decision. The output is demand-driven thus can be treated as exogenous to the behavior of cost minimization. (5) The cost-efficiency can be decomposed whereas technical efficiency cannot be so. Any departure from *cost-efficiency* can be decomposed as *input-oriented technical inefficiency* and *input allocation inefficiency* respectively.

Given prices of inputs employed, the quantities of outputs produced, and the total expenditure of each producer *I*, the single-equation cost frontier model can be expressed as follows:

$$E_i \geq c(y_i, w_i \; ; \beta), \qquad i=1,\ldots\ldots, I, \tag{7}$$

where $E_i = w_i^T x_i = \sum_n w_{ni} x_{ni}$ is expenditure in production of producer *i*, $y_i = (y_{1i}, \ldots\ldots, y_{Mi}) \geq 0$ is a vector of outputs produced and $w_i = (w_{1i}, \ldots\ldots, w_{Mi}) > 0$ is vector of input prices faced by producer i., $c(y_i, w_i \; ; \beta)$ is the cost frontier common to all producers, and β is vector of technology parameters to be estimated. The *cost efficiency* CE_i is determined as

$$CE_i = \frac{c(y_i, w_i \; ; \beta)}{E_i} \tag{8}$$

Since $E_i \geq c(y_i, w_i \; ; \beta)$, it follows that $CE_i \leq 1$ which is the ratio of minimum cost to observed expenditure. When expenditure may be affected by *random shocks* which is not under the control of producers, we can estimate the *Stochastic Cost Frontier* instead of the deterministic formula above as

$$E_i \geq c(y_i, w_i \; ; \beta)\text{*exp}\{v_i\}, \qquad (9)$$

Here,$[c(y_i, w_i \; ; \beta)\text{*exp}\{v\}]$ is the stochastic cost frontier (hereafter called the *SCF*). It composed of two parts: a deterministic part $c(y_i, w_i \; ; \beta)$ common to all producers and a producer-specific random part $\exp\{v_i\}$ which captures the effects of random shocks on each producer. Now, the measure of cost efficiency (8) becomes

$$CE_i = \frac{c(y_i, w_i \; ; \beta) * \exp\{v_i\},}{E_i} \qquad (10)$$

In our study, we will attempt to estimate a *SCF* with special feature with a *'Single-Output Translog Variable Cost Frontier'*. (See Kumbhakar and Lovell 2003), p. 145).

3.3 Econometric Model

In our study, we have followed Kumbhakar, Wan and Horncastle (2015, Chaper 6, pp. 149-72) for our empirical model. Here we have applied a translog specification of cost function to Thai manufacture Census data by the National Statistical Office (2012). For the input-oriented technical inefficiency, producer will minimize the cost of production as

$$\frac{min}{x} \quad w'x \qquad s.t. \quad y = f\,(xe^{-\eta}),$$ which gives the first-order condition (FOCs)?

FOCs: $$y = \frac{f_j\,(xe^{-\eta})}{f_1\,(xe^{-\eta})} = \frac{w_i}{w_1} \qquad , j = 2, \ldots .J \qquad (11)$$

where $\eta \geq 0$ is input-oriented technical efficiency, and $f_j(\cdot)$ is partial derivative of $f(\cdot)$ with respect to x_j. Using the *J*-1 FOCs above and solve for *J* input demand functions in the form $x_j e^{-\eta} = \varphi_j(\mathbf{w}, \mathrm{y})$, for *j=1,….,J*. Define the pseudo cost function as

$$\boldsymbol{C}^*(\mathbf{w}, \mathrm{y}) = \sum_{\mathrm{j}} \mathrm{w_j x_j}\, e^{-\eta} \qquad , \qquad (12)$$

which is the minimum cost function of the program?

$$\frac{min}{xe^{-\eta}} \quad \boldsymbol{w}'xe^{-\eta} \qquad s.t. \quad y = f\,(xe^{-\eta}), \qquad (13)$$

The $\boldsymbol{C}^*(\cdot)$ is *frontier cost function* which gives the minimum cost to produce the observed level of output, y, given the input prices **w.** If there is technical inefficiency in the production system, it means the observed input use x is too high for same output as compared with the fully efficient input use of $xe^{-\eta}$ which is less than the input x since $0 \leq xe^{-\eta} \leq 1$ and the efficient minimum cost would be $\boldsymbol{w}'xe^{-\eta}$ which is less than the actual cost of $\boldsymbol{w}'x$. We apply Shepherd's lemma (1970, Chapter 7, p.147) to (12), that is

$$\frac{\partial C^*}{\partial w_j} = x_j e^{-\eta} \Rightarrow \frac{\partial \ln C^*}{\partial \ln w_j} = \frac{w_j x_j e^{-\eta}}{C^*} \quad (14)$$

The actual cost is defined as $\boldsymbol{C^a} = \sum_j w_j x_j = e^{\eta} \sum_j w_j x_j e^{-\eta} = \boldsymbol{C}^* e^{\eta}$ which can be written as $\ln \boldsymbol{C}^*(\mathbf{w}, \mathrm{y}, \eta) = \ln \boldsymbol{C}^*(\mathbf{w}, \mathrm{y}) + \eta$, (15)
the actual cost share equation j-th, is

$$S_j = \frac{w_j x_j}{\boldsymbol{C^a}} = \frac{w_j x_j}{\boldsymbol{C}^* e^{\eta}} = \frac{\partial \ln C^*}{\partial \ln w_j} + \zeta_j , \quad j=1,\ldots.J \quad (16)$$

The estimated model comprises system of equations (15), and *J-1* equation (16) with random error ζ_j as shown. It is interpret as function of allocative inefficiency as well. Finally, we arrive at the translog specification of cost system model with quasi-fixed inputs (q) is shown as follows:

$$\begin{aligned} \ln C^a &= \ln C^*(\mathrm{w}, \mathrm{q}, y) + \eta \\ &= \beta_0 + \sum_j \beta_j \ln w_j + \sum_r \gamma_r \ln q_r + \beta_y \ln y \\ &\quad + \frac{1}{2} [\sum_j \sum_k \beta_k \ln w_j \ ln w_k + \sum_r \sum_s \gamma_{rs} \ln q_r \ln q_s + \beta_{yy} \ln y ln y] \\ &\quad + [\sum_j \sum_r \delta_{jr} \ln w_j \ ln w q_r + \sum_j \beta_{jy} \ln w_j \ln y + \sum_r \gamma_{ry} \ln q_r \ln y + \eta \quad (15.1) \end{aligned}$$

$$S_j = \beta_j + \sum_k \beta_{jk} \ln w_k + \sum_r \delta_{jr} \ln q_r + \beta_{jy} \ln y + \square_j , \ j=2,\ldots.J \quad (16.1)$$

The symmetry between $\beta_{jk} = \beta_{kj}$ and $\gamma_{rs} = \gamma_{sr}$ is assumed. The cost function is homogenous of degree 1 in input prices (i.e., $w_1, \ldots, w_J$). Thus, the restrictions will be applied:

$$\sum_j \beta_j = 1, \quad \sum_j \beta_{jk} = 0 , \quad \forall \mathrm{k}, \quad \sum_j \beta_{jy} = 0$$

One of the input prices is chosen to normalize cost and other input prices.

4. Data and Econometric Estimation Results

In our study, we have used data from the "Business and Industrial Census 2012", by the National Statistical Office, Thailand. The establishments of manufacturing sub-sector with at least 11 employees[7] are selected in this study. Some features of the data are as follows:

In 2012, the manufacturing industry gross output was 7.08 trillion baht. It employed 3.7 million persons with a net fixed asset of 3.8 trillion baht. The average productivity per person was 1.91 million baht and the asset per labor ratio was 1.03 million baht per person respectively. The labor productivity was high in the Petroleum and coke, Basic metal and steel products, and Motor vehicle and transportation equipment sub-sector respectively. The labor productivity was quite low in the Textiles and apparels, and the Furniture sub-sector.

Definitions:

[7] This is not inclusive of construction, transportation, banking and finance and agriculture sector.

The size of firms defined in this study as follows: (1) Small Enterprise (SE) is firms with employment size 51-250 persons (exclusive of very small of less than 51 persons). (2) Medium Enterprise (ME) is firm with employment size 251-500 persons. (3) Large Enterprise (LE) is a firm with an employment size of over 500 persons. The following variables are used in the estimations.

Table 6: Description of Production Structure of Thai Manufacture Sub-sector 2012

Manufacturers	Gross Output (Million Baht per year)	Total Labor (Persons)	Net Fixed Asset (Million Baht)	Average Productivity (Million Baht /person)	Asset-Labor Ratio (Million Baht per person)	Number of Sample firms
Overall	7,081,791	3,705,442	3,829,122	1.91	1.03	80,720
Processed Food, drinks	1,665,616	979,560	1,327,629	1.70	1.36	20,329
Textiles and apparels	483,159	885,962	266,187	0.55	0.30	14,408
Paper and printing	196,144	98,962	104,063	1.98	1.05	1,368
Petroleum and coke	202,875	21,980	154,122	9.23	7.01	128
Chemical product	496,924	174,876	403,070	2.84	2.30	2,623
Rubber and plastic	778,154	294,655	233,889	2.64	0.79	2,990
Non-metallic mineral	321,133	199,540	293,964	1.61	1.47	5,449
Basic metal and steel	457,035	96,630	228,774	4.73	2.37	1,354
Fabricated metal	386,176	301,333	181,802	1.28	0.60	7,878
Transport equipment	1,639,431	385,943	487,635	4.25	1.26	3,620
Electronics, Electrical	369,151	137,448	105,922	2.69	0.77	1,071
Furniture	85,992	128,553	42,064	0.67	0.33	2,620

Source: Industrial Census 2012, National Statistical Office, Thailand

Table 7: Inputs' Structure in Percentage Measure at mean (Overall Size) in Percentage Share (x100%)

Cost component	Mean	Std. Dev.	Sample size
Total Expenditure or Cost	1.00		80,000
(1) production and administration (stco) |	.4583992	.2583465	
-share of production & admin. cost (sct)	.2706584	.226911	
-share of Labor cost (swl)	.1877407	.2230575	
(2) share of raw material (smat)	.5416008	.2583465	

Source: Manufacture Census of Thailand, 2012 by NSO

In our model, we treat the short-run capital as a fixed input. It is the average beginning and end year of a fixed asset of firms' balance sheet. In short-run, the rental rate of return to fixed capital is assumed to be exogenously given. In other words, firms face a uniform rate of return to the use of capital inputs. The cost component of firms in our database comprises (1) cost of production or cost in the production process, (2) cost of raw materials and other expenses. Here, the raw material is treated as a quasi-fixed variable in our study and (3) administration cost of the enterprise to reach the maximum profit respectively.

The administration cost of firm comprises (3.1) cost of sale which is inclusive of advertisement, shipment of products, trade margin and others ; (3.2) cost of petrol used, utility (electricity and water supply) and cost of waste garden and environment management: (3.3) cost of RD and training; (3.4) cost of finance which is inclusive of the cost of insurance, interest payment, write-off the debt overdue and exchange loss incurred, consulting fees, attorney fees, accounting fees; (3.5) the cost of communication like telecommunication charges, and logistics like building rent, vehicle rental, and stationery supply.

Defining total cost or total expenditure of firm as the summation of cost in the production process plus the cost of raw materials and the primary factor cost of labor plus administration cost (3.1-3.5) respectively.

Table 8: List of Variables in the Model

Variables	Description	Notes
lncap	log (fixed capital inputs)	Average of beginning and end of a period fixed asset
lnmaterial	log(raw material inputs)	used in production
lntco	log(production and administrative cost)	See definition admin. cost
lnc	log(administrative cost)	see definition above
lct	log(production cost)	in the production process
lwl	log(primary inputs labor cost)	both skill and unskilled
lrt	log(total revenue)	all revenue of firms
lytotal	log(gross output)	gross output of all products

Note data manipulations and for translog function transformation, etc. They will be described subsequently

4.1 Stochastic Production Frontier Estimation

The stochastic production frontier estimation for small, medium and large firms with the translog function has shown robust results for all three sizes. (Refer to Table 9). The skewness for SE is greater than those for ME and LE respectively. The skewness indicates the existence of the inefficiency in the production structure of firms in manufacture in Thailand in 2012. Efficiency for SE<ME<LE by the size of firms is in ascending order as expected when firms sizes are larger. After taking into account the correction of inefficiency estimate for the OLS (COLS) and for the Mean Absolute Deviation (CMAD), it is found that the efficiency indicator has increased by the size of firms but the absolute scalar values are somewhat lower, even though we have applied large enough of sample firms. It might be the case that the cross-sectional data have systematic 'heteroscedastic' errors in the sample data as generally understood. We have tried to introduce estimation procedure with correction for this problem i.e., using the 'Half-normal Model with heterogeneity'. It was found that efficiency indices have increased substantially for all sizes of firms approaching unity or the maximal value. This may be biased upward owing to the correction of the heteroscedasticity problem.

We now turn to an alternative estimation procedure of SCF for the Production system with the 'Output Distance Function' (ODF) and the 'Input Distance Function' (IDF) for all sizes of firms. Even though the coefficients of the model can achieve the significance level of 95% confidence, however, we did not get the statistical significance of the disturbance term for inefficiency (usigma). *However, we have* *obtained an assertion of the Efficiency index closed to unity from the output distance function,* ***ODF*** *while the efficiency index from the result of the assumed Half-normal distribution for the data samples, the input distance function, (****IDF****) index is of 1.17 respectively*. (Refer to Table 10).

At this point, we can summarize that the manufacture in Thailand in 2012 has shown efficiency than the opposite. The efficiency has increased with the size of firms. It should be noted that in our model we have excluded the very small firm size up to the 50 employed persons. The number of small and very small (mostly informal activities) are numerous among the total sample sizes of 80,000. We have done data clean up to exclude the incomplete information in the sample as well. Thus, if small firms are inclusive of our analysis, the inefficiency will be more realistic. But, as we would like to recommend for policymaker that is why we have concentrated only on well-established firms.

Table 9: Estimations Result of Stochastic Production Frontier by Size of Firms

Equations	SE (51-250)	ME(251-500)	LE(>500)
lnytotal			
_cons	2.35808*	3.041771*	2.276078*
lnltotal	.0695789*	.0331751 (t=0.62)	.0737216*
lncap	.0633669*	.0580682*	.0404024*
lnmaterial	.622737*	.6520261*	.7169823*
lnc	.2343103*	.1793629*	.1572968*
*=significant CI 95%; p-value=0.0			
Adj R-squared	0.9291	0.9133	0.9214
Number of obs (excl. missing sample)	6,668	1,388	1,259
Schmidt&Lin (1984) Skewness test *=reject Normality,	2.318431*	1.941247*	1.998069
Coelli (1995) test shown by MT3T	77.288764	29.525687	28.943273
Model Corrected OLS (COLS) and Corrected Mean Absolute Deviation (CMAD)			
Efficiency index shown by ‘**eff_cols = exp(-u_star)**’ where ‘u_star = -(e - r(max)) <=> inefficiencies	***.0163701***	***.0594033***	***.059317***
Efficiency index is shown by ‘eff_cmad=exp(-eta_star_q)’ where	***.0101761***	***.0323587***	***.041767***

eta_star_q = -(e_cmad - r(max)) <=> inefficiencies			
Half-normal Model with heterogeneity			
inefficiency u, usigmas	-14.28828	-14.88937	-12.95004
random error v, vsigmas significant at CI95%, p_val=0.0	-1.520497	-1.838164*	-1.790814
variance u, sigma_u_sqr= exp(usigmas)	6.23e-07	3.10e-06	5.37e-07
variance v, sigma_v_sqr= exp(vsigmas)	.2186032	.1591093	.166825*
Efficiency index, bc_h,	*.9993344*	*.999423*	*.9987713*
Inefficiency index, jlms_h	*.000666*	*.0005773*	*.0012299*

Table 10: Production Frontier with Output Distance Function (ODF) and Input Distance Function (IDF) with All Size firms	
Input demand: nlnltotal	ALL SIZE
frontier: lnytotal	-.8547353*
nlncap	.0651255*
nlnmaterial	.4680442*
nlnc	.2185962*
_cons	1.983178*
usigmas (z_val=-0.22l; p_val=0.82), ***inefficiency parameter*** *=significant, CI 95%; p-value=0.0	-14.42443
return to scale RTS r_idf (***input distance scalar***) = - 1/[frontier]_b[lnytotal]= 1.1699528	*.92263233*
bc_h, *efficiency index*	***.999423***
bc_h_odf , *efficiency index (output distance function,* ***ODF****)*	***.9997545***
jlms_h , estimated values of *inefficiency measures at CI95%*	.0005773
jlms_h_idf = jlms_star * r_idf	.0006885
bc_h_idf *efficiency (Half-normal, input distance function,* ***IDF****)*	***1.169265***
Note: Normalized variables for the input distance function is as follows: nlnltotal=-lnltotal; nlnk=lnk- lnltotal; nlnmaterial= lnmaterial –lnltotal. Here, we choose labor as the numeraire.	

In order to get insight into the analysis, we have shown the graph system of the Production frontier for clarity below.

Figure 5: Histogram of OLS Residual and COLS Efficiency (Production System SCF)

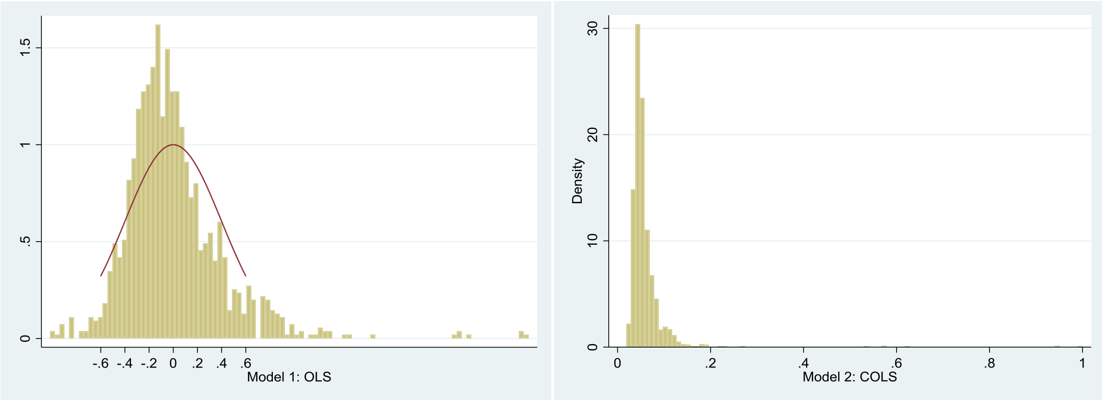


Figure 6: Histogram of CMAD Efficiency and Half-Normal Showing Efficiency Index (Production System SCF)

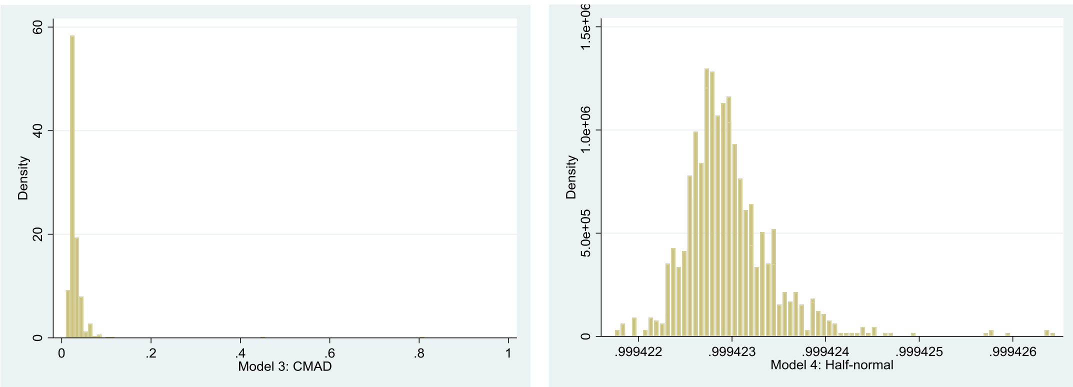


Figure 7: Histogram of Half-Normal Model Showing Inefficiency and Half Normal Input Distance Function Model (Production System SCF)

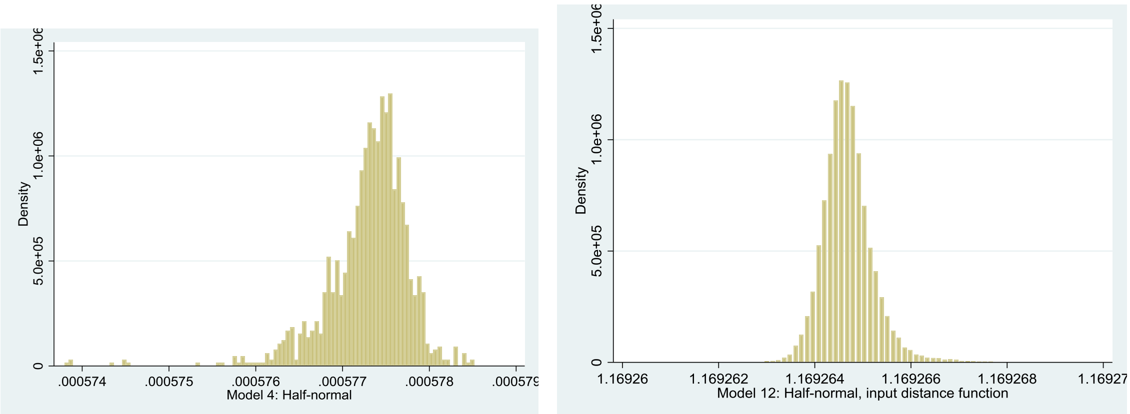
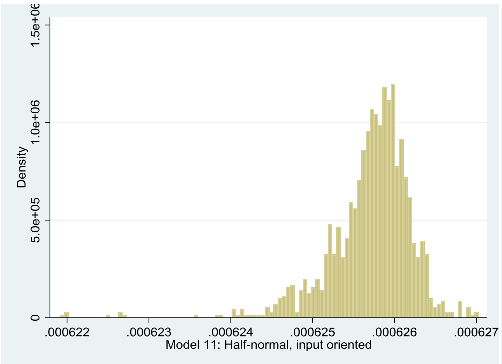


Figure 8: Histogram of Input-Oriented Half-Normal Model Showing Inefficiency



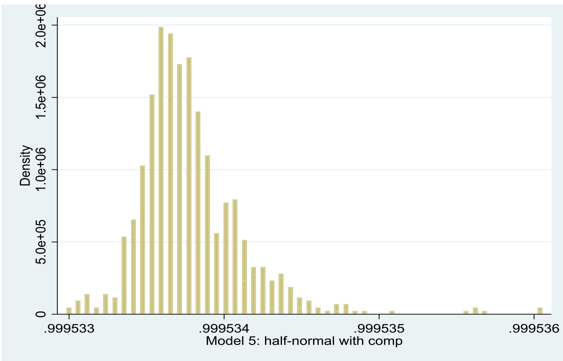
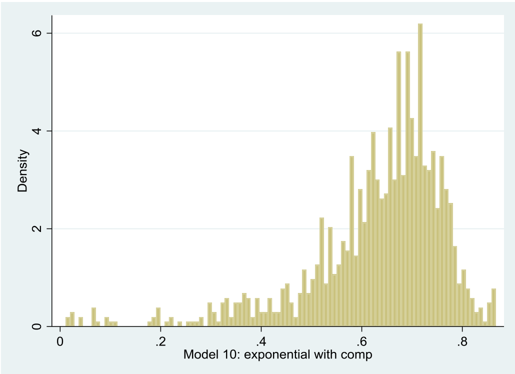


Figure 9: Histogram of Exponential Model with Heterscedasticity (Production System SCF)



4.2 Stochastic Cost Frontier Estimation

Firstly, we transform variables to be consistent with 'Translog function' for our estimation: lct2 = 0.5*(lct)^2 ; lrt2 = 0.5*(lrt)^2; lcD2 = 0.5*(lcD)^2 ; lc6D2 = 0.5*(lc6D)^2; lclc6D = lcD* lc6D; lrtlcD = lrtD* lcD; lrtlc6D = lrtD* lc6D; lctlrtD = lctD*lrtD.

Note that ct=total cost of firms in production and administration inclusive of the primary cost of inputs; rt=total revenue; c6=cost of raw materials and others; c=cost administrative of the establishment; D=operator indicates division by average wage rate. l=logarithmic respectively.

The estimation result has indicated that firms with *low* efficiency with high total cost measured in terms of average wage rate (quintile division of sample estimation using Thick Frontier Approach, TFA) have *negative* cost elasticity of revenue. This implies that low-efficiency firm still has more rooms to improve its efficiency. Its production system is still sub-optimal. Thus, it can either increases its revenue until reaching the cost frontier where cost started increased with increased revenue at the margin. On the contrary, firms with high efficiency (low cost), the increase in marginal revenue cannot be easily achieved since the cost will increase with rising revenue or scale of production, given input prices near the cost frontier. The COLS has assumed fixed prices for all firms or prices are exogenous to the decision in production, thus, they have reached cost frontier constraints like the high-efficiency firms. Interestingly, the OLS case has its feature of cost frontier relationship similar to the TFA with low-efficiency firms.

We have tested the monotonicity of cost components. It is found that the cost of raw materials and others (c6) has a negative sign unlike their counterpart of total revenue (rt), wage cost, and administrative cost (c) respectively. The OLS has shown a little skewness (1.024) in the residual of inefficiency. The efficiency index (eff_cols) is 0.0075 for 53,000 sample firms. These are inclusive of small and very small activities that have a *downward* bias of inefficiency in the case of the OLS model.

We have estimated the TFA and found that the average ***inefficiency*** of high cost (low efficiency) firms are higher than found from the OLS model. The inefficiency of cost estimates can be summarized that high-cost firms with inefficiency have their average cost 35.2 % higher than the low-cost firms with high efficiency. The TFA may have some drawbacks as firms are sub-grouped at arbitrary to be what efficiency as a criterion is high and low (see Table 11).

A further effort is to estimate the SCF by the 'Quantile Regression' in addition to the Thick Frontier Approach (TFA)'. All samples are used in the Quantile regression. This is different from the 'TFA' where the sub-group of samples is divided into 'low' and 'high' cost group. In TFA the econometric estimation is independently for each sub-group

In Quantile regression, we normalized average cost over total revenue, lavgctD = ln(ct/(wage*rt)), and create an index to identify *quintile* which each observation belongs. The estimation will select data samples according to a group in which they belong. The flag is indexed by {gindex2 = lavgctD and nquantile(4)} which is the first quartile - the average cost of the firm at the 12.5% Quantile and 87.5 Quantile respectively.

The total cost ratio is computed i.e., cost of the first Quantile compares to cost of the fourth Quantile {ct_ratio = CC_best/CC_q4 if gindex2 == 4}.This is to take into account the different sizes of firms biased against the cost-efficiency frontier using the overall sample in estimation. The Quantile Regression Approach has firms with low cost has an average cost of 26.49 percent of the high cost, inefficient firm (see Table 11).

5. Conclusion and Policy Recommendations

The manufacturing industry in Thailand has played an important role in the country's economic development during 1960-2015. The sources of Thai manufacturing growth were mainly from capital deepening rather than total factor productivity growth's contribution. The Global Value Chain of Thai manufacture has risen during 2005-2012. Recently in 2017, the government has expressed willingness to improve the efficiency and performance of the Thai manufacturing sector. In this study, we have applied a *Stochastic Frontier Analysis* to explore the technical efficiency in their production and cost system applying a cross-section data of the Manufacture Census 2012.

Thai manufacturing has consistent efficiency in ascending order of firm sizes. The larger firms have efficiency than the medium and small enterprises respectively. The overall efficiency of firms has reduced significantly when the firm employs less than 51 persons.

The Thick Frontier Approach (TFA) has found that the cost of inefficiency firms is 35.2 percent higher than the efficient firms. The Quantile Regression Approach, firms with low cost has the average cost of 26.49 percent of the inefficient firm. Finally, firms that are located around the capital city BMR have superiority of efficiency at the margin.

In summary, the Thai manufacture is widely efficient. This is the reason to explain the power of penetration to the GVC. The firms' spatial has a marginal effect on the firm's efficiency when they are located in the Bangkok Metropolitan Region.

Thai manufacture’s efficiency can be improved by (1) promote the enlargement of small enterprises to reach the optimal size. (2) Establishment of Industrial Development Zone that can be accessed from the BMR’s vicinity. (3) The *allocative efficiency* has not been addressed in this study and needs further study to explain the decomposition of a firm's efficiency. (4) the marginal effect of the firm's investment in Research and Development, as well as skills development and training, will be another study agenda.

Table 11: Stochastic Frontier Cost Estimation

Translog, Cost Equation	OLS	COLS	Thick frontier Approach (TFA)	
			Firms with High-Efficiency	Firms with low Efficiency
lctD				
lrt	-0.814 (43.55)**	1.252 (107.80)**	0.206 (4.74)**	-1.344 (33.06)**
lcD	0.243 (41.42)**		0.140 (8.98)**	0.104 (10.24)**
lc6D	0.285 (54.41)**		0.258 (17.07)**	0.261 (29.83)**
lrt2	0.066 (50.85)**	-0.019 (24.54)**	0.004 (1.42)	0.116 (38.30)**
lcD2	0.057 (43.71)**		0.038 (15.90)**	0.026 (12.00)**
lc6D2	0.054 (69.39)**		0.047 (27.37)**	0.041 (31.07)**
lclc6D	-0.000 (0.25)		-0.028 (16.56)**	0.004 (2.56)*
lrtlcD	-0.019 (13.59)**		0.018 (6.69)**	-0.001 (0.50)
lrtlc6D	-0.026 (21.30)**		-0.010 (3.78)**	-0.045 (19.31)**
_cons	7.278 (53.90)**	-2.871 (33.62)**	-1.517 (4.31)**	10.184 (37.23)**
R2	0.89	0.87	0.95	0.82
N	53,600	82,095	7,777	18,666
Ratio of Exponential of average **cost** over mean of revenue cL= exp(AC1)/M1rt;			.01240951	
average ***inefficiency*** of high cost (low efficiency) firms = cH_star/cH				. 35246511

Cost Inefficiency over average cost of low cost firms = (cH - cH_star)/cL				.35246511 or 35.2 % higher
* p<0.05; ** p<0.01				
mono_c	.0528506			
mono_c6	-.0455209			
mono_wage	.9926703			
mono_rt	.1270335			
monotonicity violation if <0				
Skewness	1.024707			
Efficiency Index=eff_cols = exp(-eta_star), where eta_star = (epsilon - r(min)) = inefficiency	.0075435			

Table 11: Stochastic Frontier Cost Estimation (continued)

	Quantile Regression Based TFA		Half-normal Model with Heteroscedasticity
Translog, Cost Equation	12.5% Quantile of sample	87.5% Quantile	
lavgctD as a translog function of			
lrt	-1.119 (69.71)**	-2.033 (52.65)**	-0.382 (23.71)**
lcD	0.371 (73.53)**	0.053 (4.34)**	0.318 (68.26)**
lc6D	0.253 (56.19)**	0.279 (25.81)**	0.274 (65.36)**
lrt2	0.017 (15.52)**	0.079 (29.55)**	0.036 (32.67)**
lcD2	0.071 (62.91)**	0.099 (36.61)**	0.053 (59.21)**
lc6D2	0.052 (77.90)**	0.071 (44.17)**	0.050 (94.32)**

lclc6D	-0.014 (17.83)**	-0.032 (17.04)**	-0.003 (3.98)**
lrtlcD	-0.027 (22.80)**	-0.001 (0.52)	-0.020 (19.54)**
lrtlc6D	-0.002 (1.87)	-0.023 (9.24)**	-0.014 (14.90)**
_cons	1.697 (14.64)**	9.735 (34.90)**	3.464 (29.40)**
usigmas with dummy 'D_Vinicity'			***-0.585*** (41.14)*
_cons			-0.207 (20.01)**
vsigmas _cons			-3.073 (164.36)**
Wald chi2(9) with Prob > chi2=0.0			
Kodde-and-Palm (1986, Econometrica).critical values of the mixed chi-square distribution			9.634 at sig. level 0.05
average marginal effect of D_Vinicity on uncond itional E(u)			***-.19195196***
average marginal effect of D_Vinicity on uncond V(u)			***-.14635961***
Pseudo R2	0.6974	0.6974	
N	53,600	53,600	
First quantile compared to fourth quantile ct_ratio = CC_best/CC_q4 if gindex2 == 4 in terms of cost. (This is to take into account different size of firm's biased against the cost efficiency frontier)	.2649724 or first 12.5% of firms belong to Quantile1 (low cost) has total cost = 26.49% of 87.5% of firms belong to Quantile4 (high cost)		
Skewness (Residual Skew to the right)	1.024707		

References

(1) Cooer William W., Seiford Lawrence M., and Tone Kaoru (2007), Data Envelopment Analysis, Second Edition, Springer.

(2) Coelli, T. (1995), "Estimators and Hypothesis Tests for a Stochastic Frontier Function: A Monte Carlo Analysis," Econometric, **39**,255-6

(3) Kumbhakar Subal C. and Lovell Knox, C.A. (2003), Stochastic Frontier Analysis, Cambridge University Press.

(4) Kumbhakar Subal C., Wan Hung-Jen, and Horncastle Alan P. (2005), Stochastic Frontier Analysis Using STATA, Cambridge University Press.

(5) Kodde, D.A., and Palm, F.C. (1986), "Wald Criteria for Jointly Testing Equality and Inequality Restrictions," Econometrica, 54, 1243-8.

(6) Office of Industrial Economics (2011), National Industrial Development Plan 2012 -2031, The Ministry of Industry, Thai Government

(7) Punyawich Sessomboon (2017), Decomposition Analysis of Global Value Chain Impact on Thai Economy, Faculty of Economics, Thammasat University. https://www.bot.or.th/Thai/.../Student/.../M_Doc_Prize3_2559.pdf

(8) Schmidt, P., and Lin, T.-F (1984), "Simple Test of Alternative Specifications in Stochastic Frontier Models," Journal of Econometrics, **24**, 349-61 Skewness test

(9) Shepherd Ronal William (1970), Theory of Cost and Production Functions, Princeton Legacy Library.

(10) Chambers, R. G.(1988), Applied Production Analysis: A Dual Approach, Cambridge University Press1988, reprint 1989,1991,1994.