Build to Order Supply Chain Efficiency Using Stochastic Frontier Analysis (SFA)

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***Abstract*--The Build-to-Order supply chain (BTO-SC) is one agile supply chain that has received great attention in research and industry. Flexibility and responsiveness in mass customization has become a major objective of many companies and this has led to the further development of BTO-SC. The main purpose of this study has been to measure, compare and analyse the impact of the BTO-SC and traditional supply chain on the company's performance and highlight the key performance measures that can influence the decision making.**

A methodology for analysing the efficiency of the BTO-SC is developed using Stochastic Frontier Analysis (SFA) which is compared to the traditional supply chain in which both are then compared to the deterministic Data Envelopment Analysis (DEA) model. The targeted population for study has been companies in the computer industry functioning in BTO-SC and/or a traditional supply chain network. Such a comparative analysis provides a more informative tool for use as part of an investment guideline for companies who wish to adopt BTO-SC principles.

I. INTRODUCTION

Companies now are competing in terms of supply chain responsiveness to variability in customer demand and market variations, and are looking for new approaches and strategies to strengthen the supply chain performance. The supply chain approach appears to be incorporating a mix of best practices from traditional supply chain and Build-to-Order supply chain (BTO-SC) methodologies [6]. Implementation of BTO-SC or traditional supply chain is a critical decision making for productive management. The capability to respond to individual customer requirements in a timely manner, with minimal inventories, suppliers and cost of logistics needs, are an essential elements of the BTO-SC that requires tight coordination using suitable performance criteria and models. Therefore, tracking the performance of the system and measuring the efficiency of the BTO environment is an essential managerial tool to sustain in such a competitive global market [20].

After the success of Dell Inc. in implementing the BTO in the early 90s, there was a considerable increased interest in BTO-SC [19]. Investigating the efficiency of the computer industry BTO-SC serves as a benchmark and provides performance evidence of the impact of the BTO transformation in the last decade [28].

Measuring efficiency has developed along two approaches: Nonparametric and parametric. Data Envelope Analysis (DEA), a mathematical programming tool, is the nonparametric method used to measure efficiency. Stochastic Frontier Analysis (SFA) is one of the parametric methods that are used to estimate efficiency [41]. Both methodologies have their individual strengths and weaknesses associated to efficiency measurement. This comparative study provides both a significant and necessary contribution to both the theoretical and empirical aspects of the efficiency measurement in the BTO-SC.

This research will focus primary on the efficiency of a company before and after transformation to BTO-SC. What factors and variables (inventory levels, revenue per unit sold, and operating cost) are related to the efficiency of the supply chain after adopting BTO strategies? How does competition and market share relate to the efficiency of the supply chain after adopting BTO strategies? And how different are the two methods SFA and DEA in measuring the efficiency?

II. LITERATURE REVIEW

A. Build -To- Order supply chain (BTO-SC)

During the last four decades, different types of the supply chain have been used and discussed in literature, starting with the traditional supply chain applying Make-to-Stock, Make-to-Forecast (MTF) or Build-to-Forecast (BTF) manufacturing strategies. Lean supply chain using mass customization was introduced in the 1980s followed by the Hybrid supply chain using Assemble-to-Order strategy in the 1990s, then in the 2000s, the agile/spontaneous/ Adaptive supply chain using Make-to Order and Engineer-to-Order strategies. The terminology of Build-to-Order was mainly used in 2005 [40][48][29][46].

Rapid development in technology, communication and the management of globalization and transportations methods; such as free trade agreements and outsourcing, were significant factors that created highly competitive environment which lead to the agile supply chain [19][49]. Many high tech companies and manufacturers of assembled products such as, Dell, BMW, Compaq and Getaway, adopted the BTO-SC [20]. Dell is generating a 160% return of investment by simply allowing customers to build their own PCs online, and deliver in a 5 days lead time [31]. Pella Corporation, a manufacturer of windows and doors, tripled the annual sales volume to over $600 million, doubled inventory turns. decreased WIP by one forth, increased on time delivery to 98.5% of its orders and reduced lead time by one fifth in less than 10 years after adapting a BTO system in 1990 [36].

BTO is designed such that there is no work in process at the end of the day, maintaining zero inventories on finished goods which lead to minimizing holding cost and inventories. The BTO-SC allows manufacturers to react on time to market demand and even shape the behaviour of the market. The productions of individual customer orders are carried out by bulling from inventories of parts instead of finished goods inventories [48].

Despite the importance of measuring the performance of the BTO-SC little research in literature could be found that dealt with finding suitable performance measures and metrics for BTO [20]. There is a considerable amount of research on traditional supply chain, supply chain networks and logistics. Yet there is limited research on BTO-SC network [19]. Research articles that address the problems of BTO-SC with modelling are limited; there is a lack of research on the suitable performance criteria and models for decision making for productive BTO-SC. [27] Reviewed selected literature on the modelling and analysing of BTO-SC management. They found that several articles reviewed the modelling and analysing of traditional SC. Meanwhile, 28% of the literature that reviewed the BTO-SC has been found to deal with the coordination level issues of the BTO-SC. Such issues include material flow decisions (i.e. inventory control, purchasing, material requirements and scheduling), performance measures, metrics and control. Gunasekaran suggested that there is a need to develop models that can evaluate the performance of BTO-SC [20].

Although the transformation to the BTO can improve efficiencies and performances in areas where traditional Build-To-Stock has its deficiencies, yet BTO is not the right strategy for every product or industry. Transitioning to a BTO requires drastic changes such as the corporate structure and organization, flow of information, decrease inventories and reduce order time [28].

Since the supply chain is a complex system with multiple inputs multiple outputs, a methodology with multiple factor performance measurement model may be applied to evaluate the supply chain efficiency. Efficiency Frontier Analysis (EFA) is a methodology that has been widely applied to performance measures for analysing productive efficiency by comparing decision making units (DMU) to an empirical production frontier constructed of a data set [47].

Farrell [31] provided the basic definition and computational framework of technical and allocative efficiency which lead to the development of measuring efficiency and estimation of frontiers. Although there have been a great progress in efficiency analysis in the past decades, yet there is no one superior method so far.

Over the past three decades DEA approach have been widely applied in measuring and analysing supply chain performance measures with more than 3200 publications including research papers, event papers and books [26] . However, the application of SFA in measuring the efficiency and productivity in the supply chain field has somewhat been prevalent. Each method has its own advantages and disadvantages with fundamental differences in there construction and underlying assumptions [43]. The main differences between the two methods are listed in table 1 [27].

TABLE 1: MAIN DIFFERENCES BETWEEN DEA AND SFA

DEA	SFA
Multiple inputs and outputs	One output multiple inputs
No assumptions needed for the production function, assign different weights for inputs and outputs	Requires assumptions of the production function and distribution of error term
No consideration for statistical error	Error term separate statistical error from technical inefficiency error
Cross-Sectional Data	Panel-Data

B. Data Envelopment Analysis (DEA)

DEA is a non- parametric linear programing technique introduced by Charnes, Cooper and Rhodes [16] to measure productivity efficiency that involves multiple inputs and multiple outputs. It calculate relative efficiencies of multiple decision making units (DMU) for multiple inputs and outputs , then DEA develops an empirical frontier and identifies the most efficient DMU and measures the efficiency of the other units based on the deviation from the efficient DMU . Due to the advantages of dealing with multiple inputs and outputs, and the unneeded of unrealistic assumptions about the data, several researchers had developed different DEA methods to measure supply chain performance, and had been claimed to be a useful technique in measuring technical efficiency and production possibilities. Seiford [11] provided a detailed literature review on DEA and its application. DEA has been widely used in measuring supply chain efficiency [24].

The basic model of DEA have been extensively used and modified in literature. DEA has been widely used for the many advantages; not only can DEA handle multiple input and outputs but it can also use real data without normalization or adjustments with outputs and inputs having different units. Also, DEA does not require any assumption of the production function relating inputs to outputs and the model can assign different weights for each input and output. DEA has been proven to be an important tool for benchmarking and determining possible sources of inefficiency [Emrouznejad, 2014]

However, DEA like any other mathematical tool has its own limitations. One of the main limitations is that DEA calculates the relative efficiency score of DMU but not the absolute, in other words it compares how well a company is doing compared to its peers but not compared to theoretical maximum. Also, DEA can create large computational intensive problems since it creates separate linear program for each DMU. Moreover, increasing the sample size will tend to reduce the average efficiency score, DEA is considered sensitive to inputs and outputs specifications and the size of the sample, because including more DMUs provides greater scope for DEA to find similar comparison partners [27].

C. Statistical Frontier Analysis (SFA)

The production efficiency is being used to find the difference of efficiencies between firms, and the factors that are contributing to the inefficiency. SFA is a stochastic frontier production model and was first developed by Aigner et al. [3] and Meeusen and Broeck [36]. SFA is a regression based approach that assumes a parametric function exists between production inputs and outputs which integrate two error terms representing effect of inefficiency relative to the stochastic frontier and random variation of the frontier, as well as measurement error and statistical noise. The main advantage of stochastic production frontier models is that it separates the impact on inputs of shocks due to random variation from the impact of variation in technical efficiency [47][12].

Meanwhile, SFA among other EFA family approaches to efficiency measurement has a disadvantage of being risky by choosing a functional form prior assumption; given that the characteristics of the production are unknown. Also, the error structure specification is considered difficult to ascertain, which leads to another potential source of error. Moreover, approximation errors are expected due to the continuity presumed in this approach [31]

Selecting a suitable production function technology is an important concern of this approach. Table 2 shows various functional forms that have been employed in analysis utilizing SFA. The model can be also the considerations of panel data and time-varying technical efficiencies and extinction the methodology for cost function. Using Panel data is one of the main advantages of using SFA allowing for measurement over a time period. For more comprehensive literature review [18][4][21][34].

A large number of model choices could be considered for any particular application. For example deciding the inefficiency distribution (i.e. half normal or general truncated normal distribution). Also, if panel data is available; considering time invariant or time varying efficiencies, Coelli recommended a number of alternative models to be estimated and that a preferred model to be selected using likelihood ratio test [12].

SFA methods to estimate efficiencies have been applied in a broad range of various industries including manufacturing, power generation, farming, and mining (Table 3). In the supply chain efficiency estimate little have been advocated to the use of SFA.

D. Build-to-Order Supply Chain in the Computer Industry

The computer manufacturers industry sells “Innovative Products “products that have short lifecycle, possible different combination of options and requires more agile manufacturing strategy. In the PC industry, 10-20% of components account for 90% of customer demand, focusing on this subset will greatly reduce the number of parts it must order. The manufacturing decision of whether to customize products and sell directly to customer eliminating retail channels is a complex decision. In the early 90’s Dell started the BTO in the PC manufacturing industry strategy selling directly to the customer through e-commerce channel where customer pays to Dell before Dell pays to the suppliers [34].

The biggest challenge in the manufacturing industry including the computer supply chain is forecasting the demand and managing inventory and orders from the supplier, due to the rapid rate of technology and short product life cycle. The BTO had been a great success in solving these problems as customer is willing to pay to the manufacturer threw e-commerce channel before the manufacturer pays to the suppliers. Now companies know the demand before they produce with no guessing [37].

TABLE 2: FUNCTIONAL FORMS USED IN SFA

Functions	Authors
Cobb-Douglas Function	Lovell and Schmidt (1977), Meeusen and van den Broeck (1997), Battese and Coelli (1995) and Mahadevan (2000)
Transcendental-Logarithmic (translog) Function	Greene (1980), Kumbhakar (1989),Lundvall and Battese (2000), and Margono and Sharma (2003)
The Fourier-Flexible Functional	Altunbus, and Chakravaty (2000), Vennet (2002), and Carbo, Gardner and Williams (2002)
Shadow Cost and Distance Functions	Atkinson and Primont (2002) and Atkinson,Fare and Primont (2003)

TABLE 3: SFA USED IN DIFFERENT INDUSTRIAL SECTORS

Sector	Authors
Agriculture sector	Liu and Zhuang (2000), Mathijs and Swinnen, (2001), Coelli, Sanzidur, and Thirtle (2003), and Latruffe, Balcombe, Davidona, and Zawalinska(2004)
Manufacturing sector	Haddad and Harrison (1993), Brada, King, and Ma (1997), Martin-Marcos and Suarez-Galvez (2000), Margono and Sharma(2003)
Underground mining industry.	Sharma et al. (2005)
Financial sector	Stiroh (2000), Berger and DeYoung (2001), Carbo, Gardner, and Williams (2003), Margono and Sharma (2007)

Although some companies had succeeded to improve its efficiency when transforming to BTO, transforming to a BTO requires a drastic changes in the corporate structure and organization, flow of information, reduce lead time and speed delivery, supplier relation and the whole operational process which may lead some companies to encounter huge problems [28].

Computer manufacturers are operating in a mix supply chain BTO and BTO, while Apple is selling directly to customer it is still also selling through its retail channel and stores. The reason we chose the computer industry BTO supply chain is because it is one of the first to use BTO triggered by Dell, and applies as benchmark for other industries and companies.

III. METHODOLOGY

The methodology used in this study is the SFA and DEA to investigate the efficiency of the BTO-SC and traditional supply chain in the computer industries.

The first step is to define the role and objective of the firm, in this research case we are focused on the supply chain of computer manufacturing companies. The next step is concerned with the number of firms to be measured. Top ten computer manufacturing companies where investigated, we identified companies that had transformed from a traditional build-to-stock (BTS) to a BTO process. The available data were not always complete which required some adjustments. Therefore, only five companies where finally selected after meeting all criteria and enough data: Lenovo, HP, Dell, Apple and Asus (Table 4).

TABLE 4: COMPUTER MANUFACTURING COMPANIES SELECTED

Company Name	Year started	Country	Products	Year Started BTO
1. Lenovo	1988	China	Computers, smartphones, tablets, smart TVs, wearables and DO it app.	2009
2. Hewlett Packard	1957	US	Computers, tablets,printers, scanners, digital cameras, calculators, PDAs and servers	2000
3. Dell	1984	US	Computers, USB keyrives, TVs, printers, and servers	1995
4. Apple	1977	US	Computers, tablets, smartphones, ipod, ipad, smartwatch, TVs, itunes and aple apps.	1997
5 .Asus	1989	Taiwan	Computers, tablets,smartphones, sound cards, digital medis and others.	2005

For accuracy and unbiased information, multiple data collection methods were used besides a broad literature review:

- Factiva: company news and announcement database. Annual reports of each company and company specific information and announcements
- Compustat North America and Compustat Global: Financial databases containing more than 300 financial variables for companies publicly traded in the US, Canada and more than 80 global countries.
- Statista.com: An online statistic portal, Provides access to data from market, opinion research institutions, business organizations, and government institutions. The plat form has statistics on over 80,000topics from more than 18,000 sources.
- Gartner.com: An American information technology research and advisory firm.
- Company annual reports and announcements.

Cross sectional and panel data were collected to serve for different purposes and models used in this research. Cross-sectional data serves for DEA model analysis, data from year 2005 and year 2014 were considered. While for the SFA models panel data were used for the purpose in which two data sets where considered. The first set of data studied the last ten years of all companies (2005- 2014). While the second set of data was constructed on the transformation timeline of each individual company. The year when a company transferred to BTO was taken as starting point (Year zero), five years before and five years after were included in the analysis to detect impact of the performance of the company due to BTO transformation [28].

An output–oriented model for DEA and SFA is developed to determine a firms potential output for a given set of inputs and measures capacity utilization as the ratio of actual to potential output. Choosing the output and input variables is very significant and should be measurable and reflects the objective of the firms. The objective of the study is to find the efficiency of the company adopting BTO strategy, and weather the transformation to a BTO has a significant impact on the company performance. The most significant factors companies are looking at when thinking about BTO transformation are [28]:

- Revenue: companies transfer to BTO to increases revenue per unit sold since customers are willing to pay more for customized products and faster delivery.
- Operating cost: Maximizing Operational efficiency is an objective of all production companies. BTO is the new strategy that companies are willing to transform to create higher profit per unit sold through fast and streamlined operations.
- Inventory: the attractiveness of reducing inventory through BTO is one of the major advantages forecasting companies are looking forward to. Carrying less inventory (Total, Row material, WIP, and Finished goods inventories) and minimizing warehouse area needed.
- Market Share: BTO increase responsiveness and decrease lead time which attracts more customers that are willing to pay extra for this service. Companies are racing for higher market share percentage of number of PC units shipped globally.

The financial measures were chosen relative to the four goals are listed in table 5. Revenue per unit sold is the output

TABLE 5: DEFINE OUTPUT AND INPUT VARIABLES

Output variable	Revenue Per Unit Sold (%)	Net sale/Unit Sale
Input variables	Profit per Unit Sold (%)	Operating Cost /Unit Sale
	Days of Inventory (Day)	Inventory*365/cost of goods sold
	Finished Inventory/Total inventory	Average Finished Inventory per year/ Total Inventory
	Market Share (%)	Company PC Units Shipped/Glopal PC Units shipped

variable. The input variables are profit per unit sold, days of inventory, finished inventory and market share percentage. Profit per unit sold is an input variable that reflects the ratio of operating cost to unit sale. Low profit margins are a major issue in the auto industry, this measure is to monitor changes in a manufactures ability to create higher profit per unit through higher operational efficiency [28]. The market share is also considered an input variable to compare between the percentages of units shipped relative to the market rather than the number of units shipped by each company.

A. DEA model

The DEA model used to calculate the technical efficiency for the supply chain performance is the CCR mode using DEA-Solver software by Cooper W. et al. [11].

The model can be represented as follows:

$$Max\ U_i = \sum_{n=1}^{N} u_n\, y_{nk} \quad (1)$$

Subject to :

$$\sum_{k=1}^{K} v_k\, x_{ki} = 1 \quad (i = 1,2,3,\dots,I) \quad (2)$$

$$\sum_{n=1}^{N} u_n\, y_{nk} \le \sum_{k=1}^{K} v_k\, x_{ki} \quad (i = 1,2,3,\dots,I) \quad (3)$$

$$u_n \ge 0 \quad (n = 1,2,\dots,N) \quad (4)$$

$$v_K \ge 0 \quad (k = 1,2,\dots,K) \quad (5)$$

Where:

U_i : is the objective function value that maximizes the ratio of DMU

(Relative Efficiency Score) of firm k.

i= 1,2,3…..5 is the number of firms.

k= 1,2,3,….4 is the number of input.

n= 1 is the number of output.

y_{ni} : is the n-th output of the i-th firm.

x_{Ki} : is the K-th input of the i-th firm.

u_n : Weight of output n

v_K: Weight of input k

B. SFA model

We decided to use the Cobb-Douglas production function since it had received more attention than other production functions for its simplicity. Thus, the relationship between inputs and outputs is assumed to be a homogeneous Cobb-Douglas.

Battese and Coelli [12] stochastic frontier production model is used with two different sets of data (2004-2014 and selected ten years period for each company) ; this model is for unbalanced panel data with the Cobb-Douglas production function and assumed truncated normal random variables to vary systematically with time. To capture the technological change the production function is allowed to vary over time. A time trend (t) is included.

Battese and Coelli [12] production model can be written as follows:

$$lnY_{it} = ln\, f(\beta_k, t, x_{it}) + v_{it} - u_{it} \quad (6)$$

Where

i= 1,2,3…..5 is the sample number (number of firms).

k= 1,2,3,4 is the number of input parameter.

t= 1,2,3,…..10 is the time period.

y_{it} is the logarithm production of the i-th sample in the t-th period.

x_{nit} is the input n-th of the i-th firm in the t-th period.

β is a vector of unknown parameters to be estimated.

v_{it} are the random variables which are assumed to be iid $N(0, \sigma_v^2)$, and independent of the u_{it}

u_{it} are non-negative random variables account for technical efficiency and are assumed to be iid as truncated at zero of the $N(m_{it}, \sigma_u^2)$ distribution. Where $m_{it} = z_{it}\delta$, z_{it} is a px1 vector of variables which may influence the efficiency of a firm

δ is an 1xp vector of parameters to be estimated.

IV. DATA ANALYSIS AND RESULTS

A. Non-parametric cross-sectional DEA model Results

Using DEA-Solver Software [11], the average efficiency estimates calculated by the DEA-CCR model (Table 6) shows that in 2005 Dell, Apple and Asus where the high efficient companies with a score of 1, while Lenovo and HP where behind with a score of 0.78 and 0.76 respectively. Lenovo was penalized for higher operating cost while HP was penalized for less market PC share (Table 7).

While in 2014 two of the five companies are efficient (Lenovo and Apple), while other are considered inefficient since their score is below 1. The two efficient companies are known to be among the best performers not only in the set of companies included in the study but also in the industry.

TABLE 6: DEA-CCR RESULTS, 2005 AND 2014

No.	DMU	2005		2014		Average	
		Score	Rank	Score	Rank	Score	Rank
1	Lenovo	0.78	4	1	1	0.89	2
2	HP	0.76	5	0.25	4	0.51	5
3	Dell	1	1	0.24	5	0.62	4
4	Apple	1	1	1	1	1	1
5	Asus	1	1	0.39	3	0.7	3

TABLE 7: INEFFICIENCY ANALYSIS THROUGH MEASURING INPUT EXCESS, 2005

No.	DMU	Score	Excess Operating Cost S-(1)	Excess Inventory Turnover S-(2)	Excess Finished Inventory S-(3)	Excess Market Share S-(4)	Shortage Revenue S+(1)
1	Lenovo	0.78	0.23	0	0	0	0
2	HP	0.76	0	0	0	6.74	0
3	Dell	1	0	0	0	0	0
4	Apple	1	0	0	0	0	0
5	Asus	1	0	0	0	0	0

TABLE 8: INEFFICIENCY ANALYSIS THROUGH MEASURING INPUT EXCESS, 2014

No.	DMU	Score	Excess Operating Cost S-(1)	Excess Inventory Turnover S-(2)	Excess Finished Inventory S-(3)	Excess Market Share S-(4)	Shortage Revenue S+(1)
1	Lenovo	1	0	0	0	0	0
2	HP	0.247	0	1.582	0	0.678	0
3	Dell	0.243	0.064	0	0	1.825	0
4	Apple	1	0	0	0	0	0
5	Asus	0.391	0.14	14.853	0	0	0

Although Dell did not make it on the CCR efficient model in 2014, it is considered by the company as “best performers” it was penalized for the high operating cost, and decreased in market PC share, while HP was penalized for high inventory turnover and decrease in market PC share. Meanwhile, Asus was penalized for High operating costs and inventory turnover (Table 8).

An improved DEA model with weighted inputs and outputs can improve the results of the model, since no restriction is placed on the weight of inputs and outputs in the DEA-CCR unrestricted model applied other than the nonnegative constraints on the components of the multiplier vectors.

B. Parametric panel data SFA model results

Using FRONTIER 4.1C software program [12], the results of the two proposed models are shown in table 9.

Using panel data over the period from 2005-2014 (Fig. 1), two of inputs coefficients are to the production function (Operating cost and Inventory turnover) are significant at the 5% level while the other two coefficients (Finished Inventory percentage and percentage of market share where not significant. This is may be related to the small sample size used in this study, also another production function such as the trans-log could be used. Moreover, three of the input coefficients display a negative sign, operating cost, inventory turnover and percentage of market share) were negative.

For the 10 years period of transformation (Fig. 2) all 5 companies showed significant efficiency increase with a mean technical efficiency of 92%. All companies recorded high technical efficiency above 92% but only Lenovo reached an efficiency of 100% in year 2014 while others remained below 100% (Fig. 2). The positive increase trend in efficiency during the BTO transformation phase indicates that the new strategy has a significant effect on the efficiency of the company, and the variables used are good indicators of the company’s performance.

Inventory turnover day, and finished goods inventory ratio had significantly decreased during the period of investigation (transforming period to BTO) (Fig. 3) except for Lenovo, although Lenovo recorded a high technical efficiency during this period 92%, inventory turnover shows 66% increase from 10 days to 30 days.

TABLE 9: SFA EFFICIENCY ESTIMATES

No.	Company	Technichal Efficiency estimates Model 1:(2005-2014)		Technichal Efficiency estimates Model 2:(Selected 10 years)*	
		Year	SFA Eff.	Year	SFA Eff.
1	Lenovo	2005	0.4536	2005	0.6921
		2006	0.8408	2006	0.8833
		2007	0.9118	2007	0.9237
		2008	0.9402	2008	0.9395
		2009	0.9680	2009	0.9471
		2010	0.7780	2010	0.9563
		2011	0.8956	2011	0.9632
		2012	0.9504	2012	0.9697
		2013	0.9601	2013	0.9745
		2014	0.9664	2014	1.0000
2	HP	2005	0.3903	1996	0.8149
		2006	0.9618	1997	0.8703
		2007	0.9614	1998	0.9038
		2008	0.9619	1999	0.9269
		2009	0.8298	2000	0.9398
		2010	0.6098	2001	0.9515
		2011	0.6798	2002	0.9618
		2012	0.7539	2003	0.9674
		2013	0.7481	2004	0.9721
		2014	0.7263	2005	0.9755
3	Dell	2005	0.5322	1992	0.7140
		2006	0.5052	1993	0.8008
		2007	0.5389	1994	0.8973
		2008	0.5805	1995	0.9147
		2009	0.6440	1996	0.9339
		2010	0.7856	1997	0.9487
		2011	0.7661	1998	0.9617
		2012	0.7757	1999	0.9669
		2013	0.4947	2000	0.9683
		2014	0.6706	2001	0.9739
4	Apple	2005	0.8469	1995	0.7129
		2006	0.9821	1996	0.8399
		2007	0.8484	1997	0.8979
		2008	0.7580	1998	0.9295
		2009	0.8161	1999	0.9442
		2010	0.9476	2000	0.9573
		2011	0.8268	2001	0.9625
		2012	0.5645	2002	0.9683
		2013	0.5925	2003	0.9743
		2014	0.6679	2004	0.9769
5	ASUS	2005	0.5361	2001	0.7618
		2006	0.6128	2002	0.8614
		2007	0.6330	2003	0.9063
		2008	0.6463	2004	0.9317
		2009	0.6586	2005	0.9419
		2010	0.7545	2006	0.9483
		2011	0.8240	2007	0.9599
		2012	0.7038	2008	0.9630
		2013	0.6631	2009	0.9685
		2014	0.5295	2010	0.9733

* Selected 10 years: 5years before transforming to BTO and 5 Years after

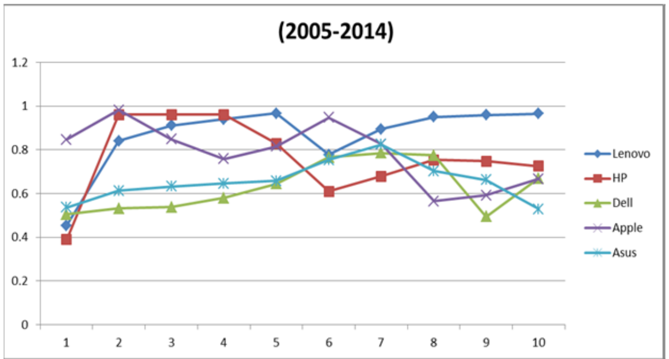


Figure 1: SFA Efficiency Estimates 2005-2014

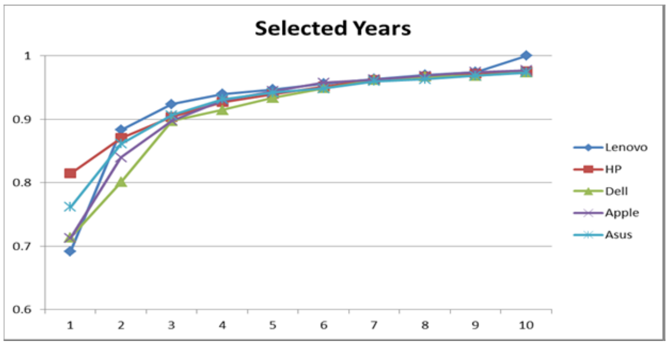


Figure 2: SFA efficiency estimates for the selected years of transformation

C. Comparison between DEA and SFA models

Comparing the results of SFA (2005-2014) model using panel-data with the DEA-2005 and DEA -2014 cross-sectional data (Table10,11) both are significantly not different with an average efficiency of 74% on both cases (Fig. 4). SFA failed to estimate a 100% efficiency for any of the companies with a maximum efficiency 87% (Lenovo), while DEA provided 3 efficient estimates with a score of 100% (Dell, Apple, and Asus) on 2005 and two efficient scores of 100% (Lenovo and Apple) in 2014.

Using DEA model for two different years we can clearly see that only two companies (Lenovo and Apple) increased efficiency during that period while the other three companies (HP, Dell and Asus) dramatically decreased its efficiency by 35%.

Using cross-sectional SFA for year 2005 and year 2014 separately (Table 10) all companies where efficient with a maximum efficiency of 99% in 2005. SFA cross sectional model also shows decrease of 30% in efficiency by the year 2014. The mean efficiency scores using SFA are higher than those of the DEA model, it is also clear that the variation of efficiency score across DMUs in SFA models (Table11) is less than the variation across the DEA models (Table 10).

D. Testing the Hypotheses

Hypothesis 1

H10: The efficiency of a company improved with time after adopting BTO strategies.

H1A: The efficiency of a company did not improved with time after adopting BTO Strategies

SFA model for the transition period from traditional to BTO strategies (Fig. 2) clearly shows that all companies included in the study show increase in efficiency over time. ANOVA results validated the result which reveals that F= 4.45, which is significant at the 95%level. However, the efficiency over the period of time 2005-2014, failed to increase over time despite adopting the BTO strategies as shown before in Fig. 1.

Hypothesis 2

H20: The efficiency of a company improve with the decrease in inventory turnover after adopting BTO strategies

H2A: The efficiency of a company did not improve with the decrease of inventory turnover after adopting BTO

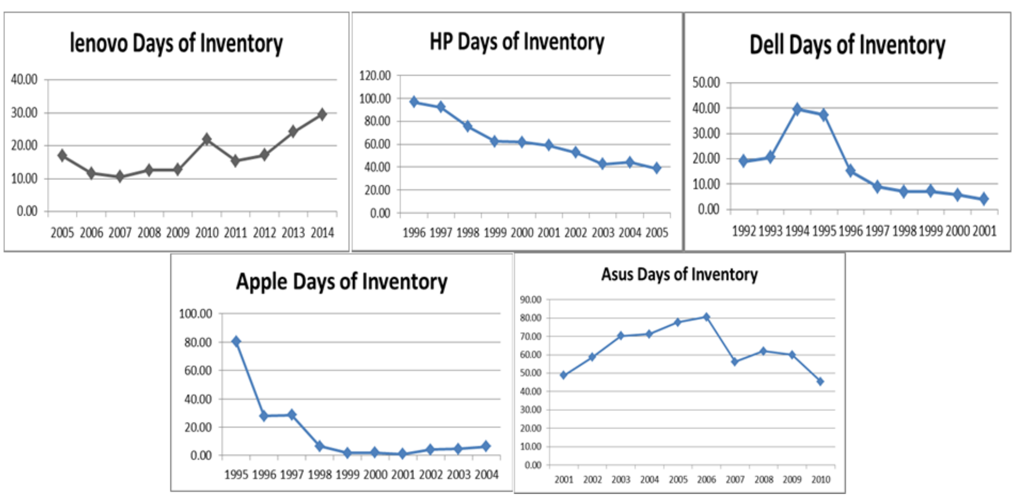


Figure 3: Days of Inventory during transformation years to BTO

TABLE 10: EFFICIENCY COMPARISON BETWEEN DEA AND SFA MODELS

Company	SFA		DEA					
	2005-2014		DEA-CCR 2005		DEA-CCR 2014		**Average DEA**	
	Mean Eff.	Rank	Eff. Score	Rank	Eff. Score	Rank	Eff. Score	Rank
Lenovo	0.87	1	0.78	4	1	1	0.89	2
HP	0.76	2	0.76	5	0.25	4	0.51	5
Dell	0.63	4	1	1	0.24	5	0.62	4
Apple	0.79	3	1	1	1	1	1	1
Asus	0.66	5	1	1	0.39	3	0.7	3
Average	0.74		0.91		0.58		0.74	

TABLE 11: COMPARISON BETWEEN DEA AND CROSS-SECTIONAL SFA MODEL

Company	SFA					
	2005 Cross-sec.		2014 Cross-sec.		Average	
	Mean Eff.	Rank	Mean Eff.	Rank	Eff. Score	Rank
Lenovo	0.99	1	0.7	1	0.845	5
HP	0.99	1	0.71	4	0.85	3
Dell	0.99	1	0.19	5	0.59	5
Apple	0.99	1	0.99	2	0.99	1
Asus	0.99	1	0.76	3	0.875	2
Average	0.99		0.67		0.83	

The t-value for the revenue turnover in the ANOVA analysis was significant T= 2.74.

The inventory turnover will contribute to the efficiency of the company. This supports the findings above in Fig. 3, as four of the companies show decrease in inventory turnover after transformation to BTO over the period of 10 years.

Hypothesis 3

H30: The efficiency of a company improved with the increase in revenue after adopting BTO strategies.

H3A: The efficiency of a company did not improved with the increase in revenue after adopting BTO strategies

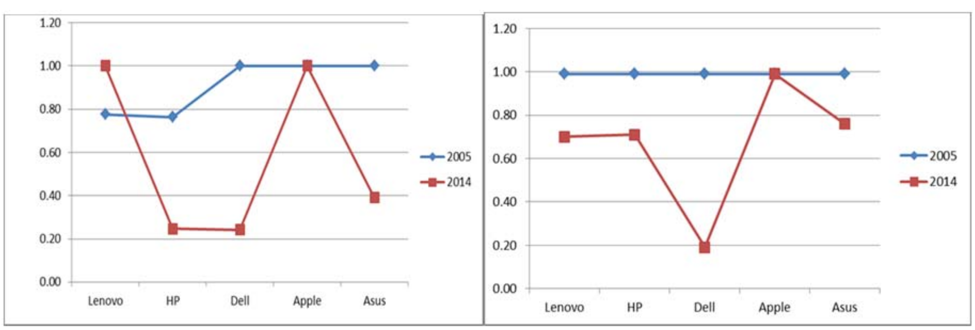
The t-value for the revenue per unit sold in the ANOVA analysis was not significant T= 1.2. Revenue per unit sold will not contribute to the efficiency of the company. This could be related to the production function used, and the small sample size.

Hypothesis 4

H40: The efficiency of a company improved with the increase of market share profit after adopting BTO strategies.

H4A: The efficiency of a company did not improved with the increase of market share after adopting BTO strategies.

The t-value for market share percentage coefficient in the ANOVA analysis was significant T= 3.09. The market share percentage will contribute to the efficiency of the company. Increasing the volume of shipped products (PC’s) to the customer will increase the efficiency of company. The more the number of customers buying the product means more customer satisfaction which goes hand in hand with the company efficiency.



DEA-CCR Results, 2005 and 2014 SFA Results, 2005 and 2014

- SFA failed to estimate a 100%
- The mean efficiency scores using SFA are higher than those of the DEA model
- The variation of efficiency score across DMUs in SFA models is less than the variation across the DEA models

Figure 4:DEA vs SFA using Cross-Sectional Data

V. CONCLUSIONS

The impact of transformation from a traditional SC to the BTO-SC on a company performance was investigated for the first time. The transformation to the BTO strategy can improve the efficiency of a company but this case was not always guaranteed.

The study has applied the two leading approaches to efficiency measurement DEA and SFA to examine the efficiency of five leading computer companies in the industry (Lenovo, HP, Dell, Apple, and Asus) that have implemented the BTO-SC strategy. Both cross-sectional and panel data were used to compare and analyze the two different approaches. Using the DEA method, the efficiency measures were estimated using DEA-CCR unrestricted model with cross-sectional data for the years 2005 and 2014. While the Cobb-Douglas production frontier was used to estimate the efficiency using the SFA method. Panel data was used in the SFA model for two different time periods, the first model examined the efficiency during the last ten years (2005-2014), while the second period examined the efficiency during the transformation period of each company to the BTO, setting the year of transformation to year zero with time frame of -5 years and +5years from year zero.

Four of the sample companies achieved significant result in reducing days of inventory level between the beginning and end of the ten year period. Only Lenovo was not able to reduce inventory level with a 0.67 mean efficiency score which proves that BTO transformation can have measurable financial impact.

All companies were significantly inefficient at the beginning of the ten year period and were significantly better at the end of the 10 years with 24% increase in mean efficiency estimate.

Despite the statistical fact that revenue and profit are significant to implementation of the BTO strategies, we cannot attribute revenue and profit improvements solely to the BTO transformation strategy. Other strategies can contribute to the success of leading pc companies and not just the implementing of the BTO. Still we can conclude that implementing the BTO strategy can be financially measured.

The financial performance of the BTO transformation has been investigated; which can provide investment guidance that can support decision making for companies as they start to transform to BTO. Benchmarking can improve their supply chain efficiency by benchmarking the managerial skills and strategies of an efficient supply chain within the same product type and environmental factors.

Despite the differences among the two methods DEA and SFA for efficiency measurement, the differences are not significant to change the statistical meaning.

VI. FUTURE RESEARCH

This work has provided the need for future research to investigate and understand other BTO characteristics and performance measures that can have an impact on the efficiency of the supply chain. The small sample size may have some limitation on the study, increasing the sample size and investigating other financial and non-financial variables such as transportation costs, outsourcing costs, product life cycle and warehouse storage area will add more insight to the study.

Using different models and techniques should also be considered. In this work only Cob-Douglas production function for SFA was applied, comparing different production functions such as the Translog production function and different distribution error term will provide new insight to the study. Also The DEA –CCR unrestricted model could be compared to other DEA models. An improved DEA model with weighted inputs and outputs can improve the results of the model, since no restriction is placed on the weight of inputs and outputs in the DEA-CCR unrestricted model applied other than the nonnegative constraints on the components of the multiplier vectors. Investigating the efficiency using DEA model with panel data will add significant results to the comparison between the two approaches.

This work focused on the strategic level of the BTO, investigating the efficiency of operational and tactical level and identifying additional performance measures (ie. non-financial measures) could also be investigated to find causes of inefficiency to the BTO supply chain.

Moreover, investigating the efficiency of other industries with other specific characteristics that differ than the computer industry such as the automobile industry, and furniture manufacturing using the computer BTO transformation as a benchmark in addition to increasing the sample size of the study.

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