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EFFICIENCY OF GLOBAL AIRLINES: AN APPLICATION OF THE METAFRONTIER DEA MODEL

Muhammad Asraf Abdullah♣
Universiti Malaysia Sarawak

Nurulhuda Mohd Satar
University of Malaya

ABSTRACT

This paper evaluates the technical efficiency of low cost and full cost carriers over the period 2002 to 2011 amid the high level of competition faced by airlines in Asia and Europe since the 2000s using the metafrontier technique based on Data Envelopment Analysis methodology. The application of this technique to airlines is interesting in order to identify the technology gap between low cost and full cost carriers. The study findings suggest that full cost carriers are technically more efficient than their low cost counterparts. The high value of TGR between the full cost carrier group and the metafrontier technical efficiencies indicates that full cost carriers have achieved the highest potential output.

Keywords: Performance, technical efficiency, metafrontier Data Envelopment Analysis, technology gap ratio, airline business model.

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1. INTRODUCTION

An estimate by the International Civil Aviation Organization (ICAO) suggests a total of 3.5 billion passengers have been transported by global air carriers in 2015 (ICAO Economic Development, nd). The fast growth of the aviation industry is inevitably contributed by the rapid growing of low cost carriers (LCC) from both European and Asian regions, where the LCC accounts for approximately one third of the total scheduled passenger traffic carried by global airlines. At regional level, statistics estimates that 43 percent and 23 percent of the total seat capacity is contributed by LCC's passenger traffics from two fast growing air transport markets namely the European Union and Asia respectively. Based on a report by ICAO (2017), there were about 131 registered LCC airline companies globally, a figure that has been growing remarkably since the opening up of the air transport markets in Europe and Asia between 1990s and 2000s. On the other hand, the full cost carriers (FCC), being one of the earliest business model introduced in the aviation industry, is catching up with the intense competition posed by the LCC through expansion of aircraft fleets and routes to high demand regions such as South America and Asia. A forecast by Pune (2019) indicates that the FCCs is expected to experience a stable growth rate exceeding 5 percent for the period 2019-2023 amidst the fast growing competition from the LCCs. As a

♣ Corresponding author: PhD, Senior Lecturer, Faculty of Economics and Business, Universiti Malaysia Sarawak, 94300 Sarawak, MALAYSIA. Tel.: +60-82584425. E-mail address: amasraf@unimas.my

dominant business model that is efficient in serving long haul routes, the FCC has an advantage over the LCC in terms of attracting long distance international passengers using its hub-and-spoke strategy and multiple wide body fleets that enable the carrier to lower its unit cost.

Rapid liberalization in the European and Asian airline industries between 2001 and 2011 inspired this study to reassess the efficiency of FCC and LCC. The 2001-2011 period is associated with a number of challenging events for the aviation business, including the sub-prime mortgage crisis sparked in the United States in 2008, followed by the Eurozone debt crisis in late 2009, which adversely affected the global economy and the performance of global airlines. Moreover, the aviation industry was hard hit by the surge in oil prices over the decade. On the other hand, the period was characterized by the influx of LCCs into the air transport markets in Europe and Asia. These two continents were among the latest to liberalize their air transport markets after the market deregulation which was initiated in the United States in the late 1970s. The entry of substantial numbers of LCCs into the global air transport market during the period has exerted an increased level of competition, particularly in these two regions, where the air transport market was liberalized much later.

Many attempts have been made to measure airlines' performance in the context of technical efficiency at both local and global levels. However, to our knowledge most studies that evaluate airlines' technical efficiency assume that all airline operates under a common or homogeneous production technology. In reality, this is not the situation as each airline in a specific group faces different resources and technological constraints. Full cost airlines, for example, are better established and receive government financial support, being regarded in some countries as a national symbol. Meanwhile, the LCCs, which were established much later than the FCCs and emerged as a result of liberalization in the air transport market, are usually private sector owned and hence subject to high capital constraints. These differences have determined the inputs and technological choices among the two groups of airlines. Therefore, treatment of all airlines as homogenous within the Data Envelopment Analysis (DEA) framework, when the samples come from different groups as discussed above, is inappropriate. It leads to comparing the technical efficiency of airlines from all groups based on a single frontier, which is misleading because it adversely affects policy implications derived from the technical efficiency estimations. This paper has two main objectives. The first is to reassess and compare the technical efficiency of two distinct airline business models, namely FCCs and LCCs, which operate under different production technologies amid increasing levels of deregulation in the air transport industry in Europe and Asia between 2001and 2011. The second is to estimate and compare the technology gap of individual airlines under FCCs and LCCs technology relative to the potential technology or the metafrontier technology. Identifying the technology gap between the group frontiers and the metafrontier is crucial in order to design performance improvement programs.

2. EVALUATION OF AIRLINES' TECHNICAL EFFICIENCY

Technical efficiency is one of the indicators of a firm's performance (Janić, 2007). Farrell (1957) defines technical efficiency as the ability of a firm to produce maximum output from a given set of inputs. Coelli, O'Donnell & Battese (2005), who referred to a production function in order to describe technical efficiency, suggest that a technically efficient firm operates on the points along the production possibility frontier. Meanwhile, Mandl, Dierx & Ilzkovitz (2008) added that technical efficiency is achieved when the highest output is obtained using available inputs or the lowest inputs are used in a production process for a given output. Technical efficiency is the focus of this study as it has an impact on the airlines' financial performance (Fried, Lovell & Schmidt, 2008).

Numerous studies have assessed the technical efficiency of airlines and its determinants over the three decades from the 1990s to the 2010s. Studies by Good, Ishaq Nadiri, Röller & Sickles (1993) and Atkinson and Cornwell (1994), suggest that input saving is important in order to ensure allocative and technical efficiencies are achieved by airlines. Another studies suggest that leading carriers from Asia have been associated with high efficiency level (Coelli, Perelman & Romano, 1999; Inglada, Rey, Rodríguez-Alvarez, & Coto-Millan, 2006; and Tavassoli, Badizadeh & Saen, 2016).

Public ownership of firm is commonly associated with inefficiency. In contrast, a privately owned firm tends to enjoy a higher degree of autonomy in terms of decision making, hence making this ownership type more successful than a publicly owned firm. Although the types of ownership may have significant impacts on the performance of airlines, most studies for example, Fethi, Jackson & Weyman-Jones (2000) and Scheraga (2004) using various DEA models reported opposite findings.

Business models play important role in shaping the operational performance of airlines. Business model may vary from LCC to FCC based on the cost structures adopted by the airline companies and reflects the degree of flexibility and independency in decision making when an airline faces turbulent periods that adversely affects its financial position. A strand of literature by Barbot, Costa & Sochirca (2008), Lu, Wang, Hung & Lu (2012), Lee and Worthington (2014), Jain and Natarajan (2015), and Duygun, Prior, Shaban & Tortosa-Ausina (2016) reveals that LCCs are efficient than other types of business models despite variety of efficiency estimation's techniques adopted by the researchers. Some of the reasons for inefficiency of FCCs are due to sub-optimal scale of operation and possession of high proportion of non- airline related assets.

Adoption of appropriate strategy is central for the success of an airline's business. Greer (2009) highlighted a negative influence of the *hub and spoke strate*gy on technical efficiency of the U.S airlines but Merkert & Hensher, (2011) stressed the importance of strategic management and fleet planning on technical and allocative efficiency of airlines. Nonetheless, Min and Joo (2016)'s study postulates no influence of alliance on airlines' operating efficiency. All the three studies calculate efficiency using different techniques. Merkert & Hensher (2011) estimates technical efficiency using bootstrap DEA, while Min and Joo (2016) adopted a contrasted DEA technique that account for categorical variables.

Airline managers are striving to ensure technical, allocative and scale efficiencies achieved simultaneously. For example, Ajayi, Mehdian & Guzhva (2010) found that large airlines from the U.S sample is allocatively more efficient than the small size air carriers. Lozano and Gutiérrez (2011) suggested that most European airlines were operating at a sub-optimal scale but Barros and Peypoch (2009) indicated a contrasted study's finding that the majority of the European airlines were technically and scale efficient. Meanwhile, Merkert & Morrell (2012) employs a DEA bootstrapping technique postulates airline scale affects mergers & acquisitions outcomes.

Studies by Zhu (2011) and Mallikarjun (2015) using a two-stage and a three-stage network DEA approaches respectively showed that major airlines are efficient where the former suggests that AMR Corp recorded the highest efficiency level, followed by Delta, United, Southwest, and Ryanair. These studies' findings indicate that the U.S major carriers are able to minimize costs in order to generate the highest possible revenues using available inputs.

Two conclusions can be drawn from the above review. Firstly, the review suggests that the metafrontier concept has not been applied in benchmarking of airline technical efficiency despite its wide application in other areas, including agriculture, banking, engineering, energy and hotels. The metafrontier concept refers to a new frontier formed by combining different group frontiers. The newly formed frontier is used as benchmarking frontier for the calculation of technical efficiency.

Secondly, the empirical findings also emphasize low cost and budget carriers as technically more efficient compared to full fare carriers, after year 2000. While benchmarking in the 1990s showed U.S. carriers to be highly efficient, recent studies have demonstrated striking findings relating to the technical efficiency of LCCs from Asia, particularly India which reported the highest efficiency score due to high economic growth in the region during the period.

3. METHODOLOGY

This study adopts the output orientation function based on DEA framework with the assumption of constant returns to scale as discussed by Charnes, Cooper & Rhodes (1978) utilizing the concept of metafrontier, as proposed by O'Donnell et al. (2008) to measure relative efficiency between firms over a specific period of time using input and output data. The study assumes output orientation DEA because some of the important inputs may be beyond the control of an airline company. For example, fuel price fluctuates and is determined by market interactions. Therefore, output is the only variable that is within the control of the firm. Furthermore, strong empirical evidences suggest that the airline industry is facing constant returns to scale, examples include Schefczyk (1993), Sickles, Good & Getachew (2002) and Greer (2009). In this context, an airline's technical efficiency is given by the distance between actual observations and the frontier constructed from observations from all the firms. Therefore, applying an output orientated CRS model, as assumed in Charnes et al. (1978), an efficiency score for the ith airline, $\emptyset_i$ in the sample of I airlines, can be estimated using the optimization equation as follows:

$$\emptyset_i = Max_{\emptyset,\lambda}\ \phi \qquad (1)$$

Subject to:
$-q_i + Q\lambda \geq 0,$
$x_i - X\lambda \geq 0,$
$\lambda \geq 0$

Where, $1 \leq \phi \leq \infty$, and $\phi - 1$ is the proportional increase in output achievable by the ith firm, holding that input quantities are constant. Meanwhile $\emptyset_i$ refers to the efficiency score for the ith airline. λ is a I x1 vector of weights.

As intuitively explained in (Coelli et al., 2005):

"The problem in LP (1) implies that ith number firms seek for a radial expansion of output vectors q_i to the maximum while still restricted within the feasible output set. The radial expansion of the output vector, qi, produces a projected point (Xλ, Qλ), on the surface of this technology. In addition, the constraints ensure that the projected point cannot lie outside the feasible set".

3.1. Metafrontier Concept Based on DEA Methodology

The idea of metafrontier originated from Hayami and Ruttan (1970) and is related to the concept of metaproduction function which is regarded as the envelope of the neoclassical production functions. This concept was later on extended by Battese and Rao (2002) and Battese, Rao & O'Donnell (2004), using the stochastic frontier approach and O'Donnell et al. (2008), who applied DEA framework to estimate the technical efficiency of firms that belong to different groups.

In the standard DEA model each firm is treated as homogenous in terms of production technology, thus making the assumption that each firm in the group is facing a similar production frontier. Hence, the firms are assumed to be operating under the same technology. This implies that measurement of a firm's technical efficiency is obtained by comparing the efficiency of a firm against a frontier for all firms, irrespective of which group they belong to. This approach in benchmarking the technical efficiency of airlines is inappropriate as FCCs and LCCs are restricted in terms of access to resources as well as the environment where they operate. For example, due to the nature of the services they render, FCCs and LCCs employ different aircraft types in their operations. LCCs, which offer point to point, short and medium haul services, usually utilize a single type of aircraft in their fleets and use secondary airports which are less busy and much cheaper. However, FCCs, which offer both domestic and international services, and serve based on 'hub and spoke' usually use different types of aircraft and large airports to meet the capacity requirements of each type of service. These factors reflect heterogeneity of technologies among the two different airline business models - FCC and LCC. Hence, each business model (group) faces a different production frontier. Therefore, comparing the technical efficiency of airlines which belong to different groups using the traditional DEA concept may provide misleading results, thus leading to wrong policy choices. Hence, this study applies the metafrontier concept in DEA framework, as developed by O'Donnell et al. (2008), to estimate the technical efficiency in a selected sample of worldwide airlines to account for the heterogeneous nature of technology of production among FCCs and LCCs.

Another approach to the heterogeneity problem in the case of two different groups of firms is to verify whether the sample variables from each group belong to identical populations by applying a non-parametric statistical test, the Mann Whitney U test as found in studies by Sala-Garrido, Molinos-Senante & Hernández-Sancho (2011) and Medal-Bartual, Garcia-Martin & Sala-Garrido (2012).

3.2. Concept of Metafrontier Technology

Assume that we have x and y non-negative real input and output vectors of dimensions Mx1 and Nx1 respectively. The metatechnology set is given as follows:

$T = \{(x, y) : x>0,\ y>0;\ x \text{ can produce } y\}$
(2)

The input and output sets associated with the metatechnology set are specified as follows:
$P(x) = \{y: (x, y) \epsilon\ T$
(3)
This output set is also called the output metafrontier. The output set is assumed to meet the standard regularity properties of Färe & Primont (1995).

Therefore, the output metadistance function is given as:

$$D(x, y) = inf_{\theta}\{\theta > 0: \frac{y}{\theta} \in P(x)\}$$
(4)

The output metadistance function above implies that a firm can radially expand its output vector given the inputs that it has. Therefore, the input and output vectors are said to be technically efficient relative to the metafrontier if $D(x, y) = 1$.

i. Concept of group frontier technology

Let us assume that firms take a number of $K(> 1)$ groups. It is also assumed that differences in access to resources, regulatory and other environmental constraints result in the firms' inability to access metatechnology production set, T. Hence the group specific technology set available to the *k-th* group of firms is given by:

$T^k = \{(x, y): x \geq 0; y \geq 0; \text{input } x \ is\ used\ to\ produce \text{ output } y\ by\ group\ k$
(5)

The output sets and output distance function with respect to group k are defined as:

$P^k(x) = \{y: (x, y) \in T^k\}, where\ k = 1,2, \dots, K;\ and$
(6)
$D^k(x, y) = inf_{\theta} \left\{\theta > 0: \left(\frac{y}{\theta}\right) \in P^k(x)\right\}, k = 1,2 \dots\dots, K$
(7)

The boundaries of the group specific output set are also called the group frontiers. If the output set $P^k(x), k = 1,2 \dots, K$ satisfies the standard properties, then the distance functions, $D^k(x, y), k = 1,2 \dots. K$, also satisfy the standard properties. These properties are defined as:

1. If $(x, y) \in T^k$ for any k, then $(x, y) \in T$;
2. If $(x, y) \in T$ then $(x, y) \in T^k$ for some k;
3. If $T = \{T^1 \cup T^2 \cup \dots \cup T^k\}$; and
4. If $D^k(x, y) \geq D(x, y)$ for all k = 1, 2…., K.
5. Convex in unrestricted output set $P(x)$ is not necessarily followed by convex group output set, $P^k(x), k = 1, 2 \dots,\ K$

From these rules, it is concluded that the group specific output sets $P^k(x), k = 1, 2 \dots, K$ are subsets of the unrestricted output set $P(x)$.

ii. Technical efficiency and technology gap ratio

This sub-section provides the definitions for technical efficiencies with respect to group frontier, its metafrontier, and the technology gap ratio (TGR).

An output orientated estimate of the technical efficiency with respect to group k technology for a pair of input x and output y is defined as:

$$TE^k(x, y) = D(x, y) \quad (8)$$

Meanwhile, an output orientated estimate of the technical efficiency with respect to the metafrontier is defined as:

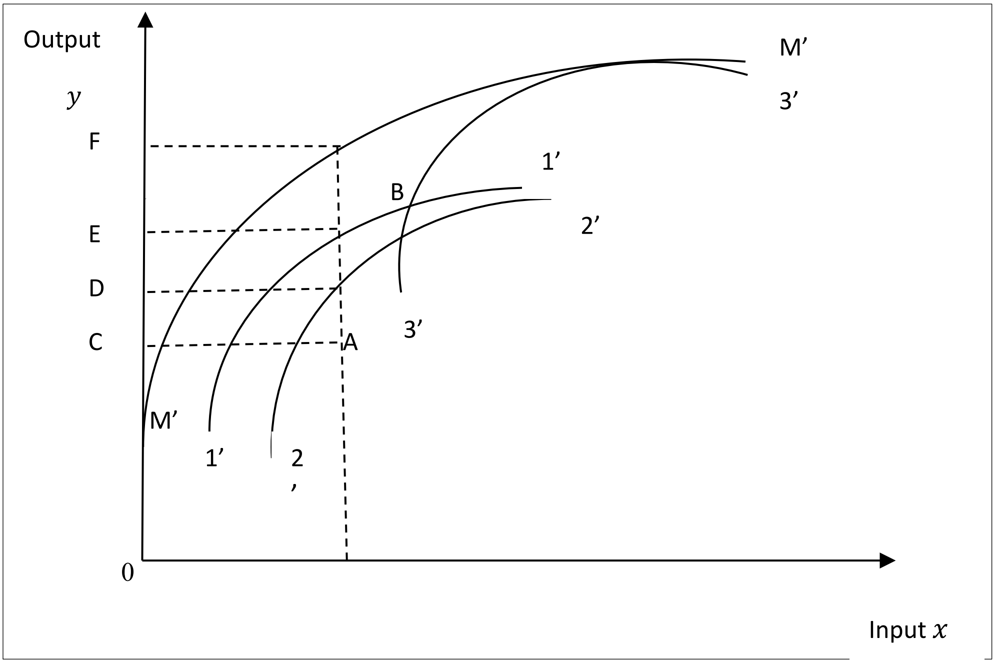
$$TE(x, y) = D(x, y) \quad (9)$$

Hence, the output orientated TGR for group k firms is defined as:

$$TGR^k(x, y) = \frac{D(x,y)}{D^K(x,y)} = \frac{TE\ (x,y)}{TE^k(x,y)} \quad (10)$$

Figure 1 shows the concept of metafrontier in diagrammatic form. The curves labeled 11', 22' and 33' refer to frontiers with respect to three different groups, 1, 2, and 3. Meanwhile, the wider frontier labeled MM' refers to the metafrontier. In this case, the metafrontier MM' enveloped all three different groups of firms (Figure 1).

Figure 1: Group Frontiers and Metafrontier Technologies



Source: O'Donnell et al. (2008)

Assuming a convex metafrontier, as labeled by MM', the technical efficiency for the group 1 (TE^1) frontier, using input and output combination at point A, is calculated as:

$$TE^1(A) = OC/OE \tag{11}$$

Meanwhile, the metafrontier technical efficiency, TE(A) for group 1 using input and output mix at point A when benchmarked upon the metafrontier MM' is given by:

$$TE(A) = OC/OF \tag{12}$$

Hence, the TGR for group 1 at point of input and output labeled A is measured by:

$$TGR^1 = \frac{TE(A)}{TE^1} = \frac{OC/OF}{OC/OE} \tag{13}$$

Intuitively the TGR value in equation 13 implies that the larger the TGR value, the closer the group towards the optimal production technology. Meanwhile, a value of TGR approaching zero indicates that the group lags far behind the optimal technology frontier, thus is inefficient in using present resources and technology to generate the most output relative to the other groups.

The technical efficiency for each individual airline relative to groups of FCCs, LCCs and the metafrontier is calculated by solving equation 1 separately for all three frontiers using the 1-Stage DEA model as applied in O'Donnell et al. (2008) seminal paper on the DEA metafrontier model. The 1-Stage DEA technique enables the slacks in the DEA model to be calculated using the 1-Stage approach. Next, pooling the sample airlines from both groups yields the metafrontier technical efficiency scores for each group of airlines. The group technical efficiency scores for FCCs are calculated by solving the DEA mathematical programming as stated in equation (1) 43 times, i.e. for each of the FCCs in the group. The same applies to LCCs which comprise 13 samples. The metafrontier technical efficiency scores are obtained by pooling observations for all airlines in both groups, i.e. solving the LP in equation 1 by 56 times for each of the airline in the observations. The analysis is made simple by employing MaxDEA Pro 6.6 developed by Cheng & Qian (2014).

3.3. Data Descriptions

The selection of appropriate input and output which closely characterizes the actual operation of the firm is central in DEA. The production theory classifies factors of production as land (natural resources), labor and capital (Heathfield, 1971). Input variables consist of total operating costs and size of operating fleet. Total operating cost is given by the sum of labor and fuel costs as these inputs form the largest portion of costs incurred in an airline operation. Meanwhile output variables for this study are proxy by total operating revenues; for examples see Assaf and Josiassen (2011), Min and Joo (2016) and revenue passenger kilometers as applied by Assaf and Josiassen (2012), and Tavassoli et al. (2016). Due to inconsistency in reporting revenues between FCCs and LCCs, total operating revenue is used as an alternative measure to specific outputs related to passenger and freight operations. Total operating revenue captures revenues for both passengers and cargo carried by each individual airline. Meanwhile, revenue passenger kilometer reflects the revenue generated by transporting passengers. Measurements of input and output variables in this study follow the standard formulation as specified by the International Civil Aviation Organization (ICAO). For more details of definitions with respect to each input and output variable for DEA estimation of technical efficiency, please see *"Reporting Instructions in Form EF of the ICAO Digest of Statistics"* (various issues).

The technical efficiency of airlines in the study is estimated using two inputs and two outputs. The total sample size of airlines in this study is 56 which is more than sufficient for the DEA methodology to provide a high degree of discretionary power in the efficiency score when using a combination of two input and two output variables, and the sample comprises airlines from two business models, namely FCCs and LCCs. The study covers a 10 year time period, from 2002 to 2011. The FCCs in the sample numbered 43 airlines whilst there were 13 LCCs in the sample. The sample size is sufficient for the DEA estimator to perform efficiently because it meets the requirement stated by a common DEA convention which argues that the minimum number of decision making units shall be three times the total input and output (Dyson, Allen, Camanho, Podinovski, Sarrico, & Shale, 2001). The total observations for FCCs are 430 > 3(2+2), and low cost airlines are 130 >3(2+2) respectively, which meet the standard convention requirement. Major sources of input and output variables for the study were obtained from annual reports of various years from 2002 to 2011for each individual airline, ICAO Digest of Statistics (printed and online version), and Air Transport World (ATW) reports of various years. The list of inputs and outputs used for the DEA estimations of technical efficiency are presented in (Table 1).

Table 1: List of Inputs and Outputs, Unit Measurements and Symbols for DEA Technical Efficiency and Productivity Change Analyses

Variable	Unit of measurement	Symbol
Operating cost	million USD	OPCOST
Operating fleets	Number of fleets	OPFLEET
Operating revenues	million USD	OPEREV
Revenue passenger kilometer	‘000 RPK	RPK

Table 2 depicts the characteristics of input and output variables for FCCs and LCCs in the study sample throughout the period 2002 to 2011. Most of the financial data for individual airlines could be obtained from the ICAO Digest of Statistics and are reported in USD. Some airlines do not consistently report their financial statistics data to ICAO, (for example labor cost, fuel cost and total operating revenues) thus leading to missing data for certain years. Such missing data were supplemented by data extracted from annual reports. Financial data from annual reports for individual airlines are presented in the national currency and thus require standardization by conversion to USD. Local currency is converted to USD using the purchasing power parity (PPP) index obtained from the Penn World table, as applied by Assaf and Josiassen (2012) to overcome the problem associated with changes in exchange rate and real price level (Oum & Yu, 1995). The table shows that, on average, FCCs consumed considerable inputs which transform into larger outputs compared to LCCs, which utilized much lower inputs hence producing lower levels of outputs as well.

Table 2: Descriptive Statistics for a Sample of 56 of World Airlines, 2002-2011

Group	No. of airlines		OPCOST (million USD)	OPFLEETS	OPEREV (million USD)	RPK
Full Cost Carrier	43	Mean	2876.8	143	6158.1	58119
		Minimum	30.7	7	74.6	794
		Maximum	22135.0	806	35230.0	425640
		Standard Deviation	3166.9	145.3	6068.9	67708
Low Cost Carrier	13	Mean	1059.3	106	2148.6	25341
		Minimum	9.1	3	22.2	130
		Maximum	10015.0	564	15658.0	157040
		Standard Deviation	1536.8	123.1	2542.0	29594

FCCs in the study sample carry mostly passengers and a certain portion of freight, whereas LCCs carry mostly passengers. Another characteristic of the airlines in the sample included their operating both domestic and international business segments. The sample of airlines in the study is reasonable as it included multiple scales of operation ranging from an airline with operating revenue as low as USD222.4 million to an airline with operating revenues as large as USD 35.2 billion in 2011.

3.4. Non-Parametric Test for Suitability of the Metafrontier Approach

Since input and output variables in this study are not normally distributed, a non-parametric statistical test, the Mann-Whitney U test, was applied in order to verify whether the two groups belong to the same or different populations and to support our argument that FCCs and LCCs are indeed do not belong to the same population. The null hypothesis for the Mann-Whitney U test states that the two groups of airlines come from the same population while the alternative hypothesis states that the two groups come from different populations. The results in Table 3 show that across all the variables tested, the FCCs recorded the higher mean rank values compared to the LCCs. This indicates that the two groups of airlines are operating at different levels of operating revenues, revenue passenger kilometers, operating costs, and size of operating fleet.

Table 3: Rank Results of Mann-Whitney U Test

Variable	Type of Airline	N	Mean Rank	Sum of Ranks
OPEREV	Full Cost Carriers	430	318.9	137157
	Low Cost Carriers	130	153.2	19923
	Total	560		
RPK	Full Cost Carriers	430	304.3	130847
	Low Cost Carriers	130	201.7	26233
	Total	560		
OPCOST	Full Cost Carriers	430	316.9	136303
	Low Cost Carriers	130	159.8	20777
	Total	560		
OPFLEET	Full Cost Carriers	430	294.1	126479
	Low Cost Carriers	130	235.3	30600
	Total	560		

Table 4: Test Statistics Results of Mann-Whitney U Test

	OPEREV	RPK	OPCOST	OPFLEET
Mann-Whitney U	11408	17718	12262	22085.50
Wilcoxon W	19923	26233	20777	30600.50
Z	-10.23	-6.32	-9.70	-3.62
Asym.sig (2-tailed)	.000	.000	.000	.000

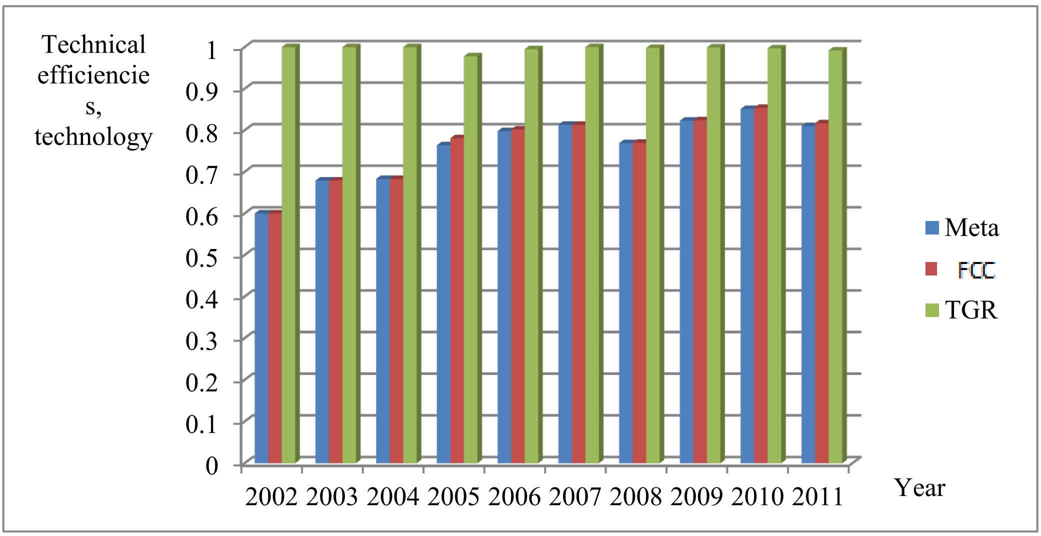
The results of the analysis in Table 4 confirmed our prior expectation that the two groups are different, hence confirming that the groups are heterogeneous as suggested by Barney (1991) and Rumelt (1991), which strongly supports our proposal to use the metafrontier DEA approach to benchmark the efficiency levels of the two different airline business models. Both U-values and p-values for all variables presented in Table 4 confirm the suitability of the application of the metafrontier concept based on the DEA technique in the context of airlines.

4. RESULTS

4.1. Technical Efficiency Results

Figure 2 shows the FCC technical efficiency scores relative to the group frontier and the metafrontier technologies respectively, over the period 2002 to 2011. Both the group and the metafrontier technical efficiencies are estimated using equations 8 and 9 respectively. The results demonstrate a trend of increasing FCC technical efficiency when benchmarked against both the group technology and the metafrontier technology. Additionally, the findings indicate that the scores for individual airlines' technical efficiency relative to the group frontier and the metafrontier technologies showed similarity over 50% of the period observed. During 2005, 2006, 2008, 2010 and 2011 the values of the group and the metafrontier technical efficiencies varied with the group technical efficiency score much higher than the metafrontier technical efficiency score. In fact, the TGR scores for the FCC group were exceptionally high and approached 1 in all the years observed.

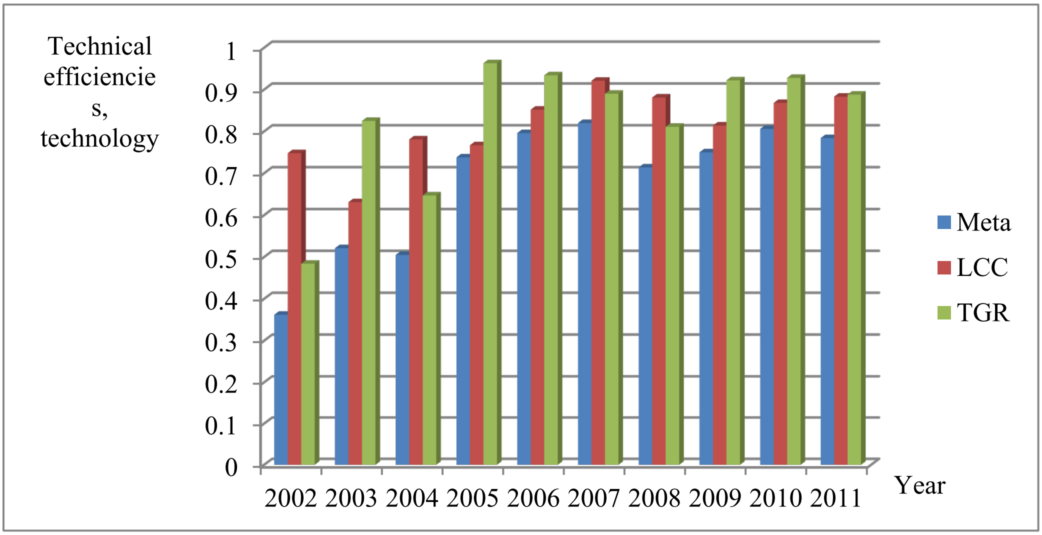
Figure 2: Trend of Geomean Technical Efficiency of FCC Relative to Group Frontier, Metafrontier and Technological Gap, 2002-2011



The improvement in the metafrontier technical efficiency score for FCC is compensated by a narrowing technology gap with respect to the metafrontier technology, as depicted in (Figure 2). In addition, the findings suggest that the technical efficiency of FCC with respect to the group frontier and the metafrontier converge over the study period from 2002 to 2011. This indicates the high level of technical efficiency associated with FCC. Additionally, empirical studies by Ramsay et al. (2013), and Bitzan and Peoples (2016) confirmed the pattern of convergence of the operational costs in both FCCs and LCCs. Furthermore, labor cost and stage length have been improved for legacy carriers in the United States as the airlines streamlined their business by engaging in downsizing and cost cutting measures in their efforts to regain profitability (Tsoukalas, Belobaba, & Swelbar, 2008). Arjomandi and Seufert's (2014) recent findings confirmed that in their study from 2007 to 2010 FCCs were the most efficient airlines owing to the stiff competition from LCCs since the beginning of the millennium which have forced FCCs to adopt best practice management including aggressively seeking to upgrade their technological capabilities by selling air tickets through direct distribution channels from the airline company's website, which results in substantial distributional costs savings as compared to the former practice of selling air tickets through the Global Distribution System and travel agents.

Figure 3 portrays the LCC technical efficiency score relative to the group frontier and the metafrontier respectively over the period 2002 to 2011. On average, LCCs show trends of increase in both the group frontier and the metafrontier technical efficiency scores. The technical efficiency estimates for LCC when benchmarked against the group frontier demonstrate high scores over the period 2002 to 2011. Meanwhile, the technical efficiency of LCC relative to the metafrontier estimates are relatively low compared to the technical efficiency scores when benchmarked against the group frontier technology. This suggests that there is a large technological gap between the group frontier and the metafrontier technologies among LCCs. Closing the gap is important to LCC airlines in order to raise their technical efficiency.

Figure 3: Trend of Geomean Technical Efficiency between LCC-Metafrontier, LCC-Group Frontier and Technological Gap, 2002-2011



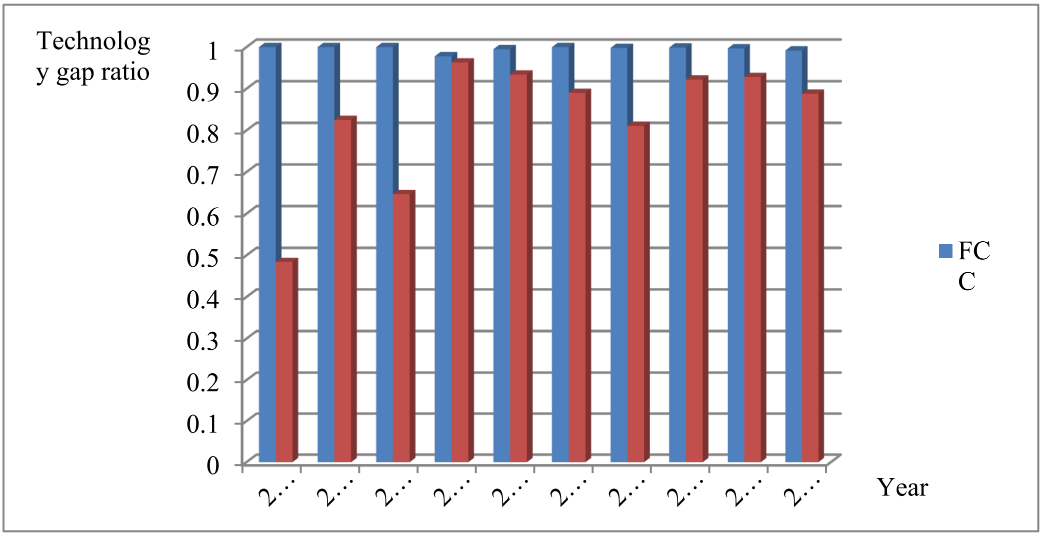
In general, throughout the period 2002 to 2011, most LCCs displayed high efficiency scores when benchmarked against the group frontier. However, the technical efficiency scores fell short when compared against the metafrontier technology. The discrepancy in the metafrontier-group technical efficiency scores left the LCCs in a large technology gap with the metafrontier technology, which indicates that LCC technology is lagging far behind the optimal frontier technology, as demonstrated in Figure 3.

This finding challenges the traditional view that LCCs are relatively more technically efficient than FCCs, as evidenced in past studies, for instance those of Barbot et al. (2008), and Assaf and Josiassen (2011). Meanwhile, LCCs are experiencing increasing operational costs attributed to the maturity of the business model as shown by an increase in the fleet age and employees' seniority (Arjomandi and Seufert, 2014). These factors add to the rise in fuel consumption and labor costs in LCCs.

4.2. Results of Technological Gap Ratios for Full Cost Carriers and Low Cost Carriers

The TGR values in Figure 4 are computed using the formula expressed in equation 13. Initially, in 2002, there was a large gap in the TGR between the FCCs and LCCs. The gap in the technology between FCCs and LCCs, however, narrowed from 2002 to record the highest TGR, approaching unity, in 2010. It is also worth noting a spectacular fall in the TGR value for LCCs during the 2007 and 2008 global economic crisis. The sluggish global economic performance negatively affected the demand for air transport in the LCC segment. Adding to this problem was the high cost of fuel, which was expected to increase by USD40 billion in 2007 (ATW Report, 2008).

Figure 4: Geomean Technology Gap for Full Cost and Low Cost Carriers, 2002 -2011



This finding suggests that FCCs form the best practice frontier in the airline industry. The exceptionally high TGR values recorded by FCCs throughout the period indicate that the optimal technology frontier is determined by airlines from the FCC group. Furthermore, the average technical efficiencies with respect to the FCC group frontier coincides with the metafrontier technical efficiency. An examination of the efficiency scores for individual airlines suggests that the FCC group from the Asia Pacific region recorded the highest level of technical efficiency when measured with respect to the metafrontier technology throughout the period of study (2002 to 2011) which is consistent with the study findings of Inglada et al. (2006) and Rey, Inglada, Quirós, Rodríguez-Álvarez, & Coto-Millán (2009).

Table 5 presents a summary of the technical efficiency scores for individual airlines relative to group technology frontiers for LCCs, FCCs and the metafrontier. The findings indicate that LCCs are technically more efficient when benchmarked against the frontier from a similar group. This is evidenced by the mean technical efficiency score (81%) being higher than that of the FCC group (75.8%). This indicates that if the efficiency increases by 19%, the production of the LCC group can be maximized and become efficient using the present level of technology. On the other hand, FCCs can maximize their operational efficiency using the FCC technology through a 24.2% increase in their technical efficiency. In addition, low variation in the technical efficiency scores of the FCC group indicates that this group has the higher degree of homogeneity (Table 5).

Table 5: Summary Statistics for Group Technical Efficiencies (TEK), Metafrontier Technical Efficiencies (TE) and Technological Gap (TGR) for Global Airlines, 2002-2011

Group Carrier	Observation	Efficiency Score	Geomean	SD	Minimum	Maximum	% of efficient firms
FCC	43 firms /430 obs.	TE^K	0.758	0.169	0.195	1.000	16
		TE	0.755	0.168	0.195	1.000	15
		TGR	**0.996**				
LCC	13 firms /130 obs.	TE^K	0.810	0.172	0.380	1.000	30
		TE	0.659	0.205	0.189	1.000	8
		TGR	**0.814**				

In contrast, when the technical efficiency is benchmarked relative to the metafrontier technology, the results are the opposite, with FCCs seen to be the more efficient group, with an average technical efficiency score of 75.5% compared to that of the LCCs (65.9%). The results reveal that the average efficiency of FCCs is 75.5% based on the benchmarking result using the metafrontier technology as the basis for the technical efficiency calculation. In a way, the findings imply that FCC can achieve fully efficient status with a 25.5% improvement in operations using the common frontier technology. Meanwhile, LCCs can achieve a potential saving of 34.1% by improving their technical efficiency performance. In addition, the figures in Table show a relatively larger degree of dispersion in the average technical efficiency score for LCCs as compared to those for FCCs, which suggests a high degree of heterogeneity in the group. This result is as expected because airlines in the LCC sample represented those from variable scales of operation.

The TGR values across the two groups of carriers vary from 81.4% to 99.6%. The FCC group shows a higher TGR value with a score of 99.6%, which implies that the group produces 99.6% of the potential outputs (operating revenue and revenue passenger kilometer) using the FCC technology, given the same input vectors (number of operating aircraft, jet fuel, and employees). This notion suggests that the FCC group is technically efficient and thus represents the best practice frontier. In addition, the high average TGR indicates that there is a large capacity for FCCs to absorb new technology in the future. The LCC group TGR value is 81.4%, which suggests that the LCC group produces 81.4% of the potential output using the LCC technology; hence implying that LCCs have room to improve in the future. This suggests that the LCC group is technically less efficient than the FCC group. However, the LCC group may increase its output level compared to that of the FCC through a 18.6% increase in its potential output. The findings also suggest that the LCC group is operating in an increasing cost environment (Tsoukalas et al., 2008; Bitzan & Peoples, 2016).

Overall, the TGR findings suggest that the FCC group has more efficient airlines from the techno-economic perspective, as reflected by the high TGR value. It is reasonable to claim that the FCC group, having been in the market for a relatively longer period than the LCC, which only recorded a massive influx into the market after the air transport market deregulation in the United States in 1978, has invested a lot in technology in order to improve the technical efficiency of its operation (Barros & Couto, 2013; and Arjomandi and Seufert, 2014). This finding conflicts with opinions expressed in earlier literature (Barbot et al., 2008; Lee & Worthington, 2010; Assaf & Josiassen, 2011), which supported the notion that FCCs are relatively less efficient than LCCs. One possible explanation for the contrast between the result of our study and those of previous studies is that previous studies assumed that the LCCs and FCCs belonged to a homogeneous group. They therefore compared the technical efficiency of each airline in both groups against a single frontier, which is inappropriate as in reality each airline is heterogeneous at least in the technology that it embraces.

No doubt the FCC group is the more efficient carrier based on the analysis above. However, the LCC group has displayed an impressive improvement in narrowing the technology gap with world technology, as shown by a significant increase (about 50%) in the growth of TGR between 2002 and 2011 compared to the FCC group, which recorded almost zero growth during the same period. Looking at various innovations carried out by the LCC, including aggressive selling of air tickets via online platforms, replacement of printed ticket itineraries by electronic ones via smartphones, self-service baggage tagging, innovative, economical self-service check-in kiosks[1]and the use of modern yet fuel saving aircraft such as Airbus A320 for domestic and short haul routes, as found in Air Asia fleets, we can infer that there is a tendency for LCCs to improve further and move closer to the metafrontier technology, hence forming the best practice frontier of the future. Another feasible strategy is to save large costs by outsourcing some of the more expensive in-house activities, for instance leasing aircraft to fulfill temporary high surges in demand during peak seasons instead of purchasing new ones, as commonly practiced by newly established LCCs and using highly capable third parties to take care of aircraft maintenance, catering, cleaning and other such high cost services.

5. CONCLUSIONS

This paper assesses and compares the technical efficiency of LCCs and FCCs for the period 2002 to 2011, when airlines faced high levels of competition due to rapid liberalization in the airline industry. This study contributes to the literature on airline technical efficiency by adopting the metafrontier technique based on the DEA methodology, which is an extended DEA technique, in order to reconfirm the efficiency levels of LCCs and FCCs. The metafrontier DEA technique examines the technology gap between the metafrontier technology and the group frontier

[1] The kiosk, which is largely composed of cardboard, is said able to save up to 80% of the cost of using a traditional kiosk machine (http://www.airlinetrends.com/category/low-cost-airlines/).

technology. The findings suggest that FCCs are technically more efficient than their LCCs counterparts. Additionally, the TGR between the FCCs group technical efficiency and the metafrontier technical efficiency indicates that FCCs attained the highest potential output of 99.6 percent. The results reconfirm that of the two groups of airline carriers, the FCCs are the more efficient. Their favorable performance is due to intense competition resulting from rapid liberalization of the air transport markets in Europe and Asia during the late 2000s. Nevertheless, findings from this study conflict with outcomes highlighted in most previous studies, which were conducted prior to the rapid liberalization of the air transport market. In conclusion, high levels of competition faced by legacy carriers have motivated the airlines to adopt best management practices in order to further slash their operational costs. Future researchers who are interested in assessing the performance of airlines using the metafrontier approach may divide the airlines' sample into three regions namely North America, Europe and Asia to check for possibility of technical efficiency differences due to different approach used in clustering the airlines' samples.

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