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***Research Article***

# Density-based Clustered Airline Network Carriers and Efficiency Comparison with Robust DEA

**Yasin Kütük[a]**

## Abstract

**Introduction:** This research examines the concept of a network carrier, specifically its structure. In the idea of network carriers, the primary structure is constructed as a service carrier that applies a high comfort level and high ticket fares, and the secondary structure is built as a low-cost carrier that applies a low comfort level and low ticket fares for its customers. In this research, the three concepts of airline restructuring are explained in detail.

**Method:** Robust Data Envelopment Analysis (DEA) methodology is used to analyze network carriers by two outputs and four inputs. The outputs are: passengers carried (PC) and passenger kilometres flown (PKF). The inputs are: passenger tonne kilometers (PTK) performed in thousands, available seat kilometers (ASK), passenger load factor (PLF), and kilometres flown (KF) in thousands.

**Results or Findings:** These parameters are used to assess the efficiency and consistency of efficiency levels among identified airlines that employ a network carrier strategy. The results of the efficiency analyses show that the majority of airlines exhibit minor time-related drops in their efficiency while the two low-cost carriers which are the top performers keep on doing so, and the grouping of firms into three categories -better, slightly good, and worst- based on efficiency levels and stability is done using k-means clustering and the coefficient of variation.

**Discussion or Conclusion:** This research employs Data Envelopment Analysis to evaluate the efficiency and consistency of airlines operating as network carriers, offering insights into the effectiveness of this strategic approach.

*Keywords:* aviation, aircraft, network carriers, data envelopment analysis, k-means clustering, unsupervised machine learning

*JEL Codes:* L93, C44, C38, L25, M21

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# Yoğunluk Tabanlı Kümeleme ile Havayolu Ağ Taşıyıcılarının Dirençli VZA ile Etkinlik Karşılaştırması

**Yasin Kütük**[a]

## Öz

**Giriş:** Bu araştırmada, havayolu ağ taşıyıcısı (network carrier) kavramı ve yapısal özellikleri incelenmektedir. Ağ taşıyıcısı kavramı kapsamında, birincil yapı yüksek konfor seviyesi ve yüksek bilet ücretleri sunan tam hizmet taşıyıcısı (full service carrier) olarak, ikincil yapı ise düşük konfor seviyesi ve düşük bilet ücretleri sunan düşük maliyetli taşıyıcı (low cost carrier) olarak tanımlanmıştır. Bu çalışmada, havayolu yeniden yapılanmasına ilişkin üç temel kavram ayrıntılı biçimde açıklanmıştır.

**Yöntem:** Havayolu taşıyıcılarını analiz etmek amacıyla Dirençli Veri Zarflama Analizi (VZA) yöntemi kullanılmıştır. Analizde iki çıktı ve dört girdi dikkate alınmıştır. Çıktılar: taşınan yolcu sayısı (PC) ve yolcu kilometresi (PKF); girdiler ise: bin yolcu ton-kilometresi (PTK), mevcut koltuk kilometresi (ASK), yolcu doluluk oranı (PLF) ve bin kilometre uçuş mesafesi (KF) olarak belirlenmiştir.

**Sonuçlar ya da Bulgular:** Belirlenen havayolu şirketlerinin, ağ taşıyıcısı stratejisini uygulayanlar arasından seçilenlerin etkinlik düzeyleri ve bu düzeylerin tutarlılığı söz konusu parametreler aracılığıyla hesaplanmıştır. Verimlilik analizlerinin sonuçları, havayollarının çoğunun verimliliklerinde zamanla ilgili küçük düşüşler sergilediğini, en iyi performans gösteren iki düşük maliyetli havayolunun ise bu performansını sürdürdüğünü göstermektedir. Firmaların verimlilik düzeyleri ve istikrarlarına göre "daha iyi", "biraz iyi" ve "en kötü" olmak üzere üç kategoriye ayrılması, k-means kümeleme yöntemi ve değişim katsayısı kullanılarak yapılmıştır.

**Tartışma ya da Yapılan Çıkarımlar:** Bu çalışma, havayolu taşıyıcısı olarak faaliyet gösteren havayolu şirketlerinin etkinliğini ve bu etkinliğin tutarlılığını değerlendirmek amacıyla Veri Zarflama Analizi yönteminden yararlanmakta; bu stratejik yaklaşımın etkililiğine dair önemli bulgular sunmaktadır.

*Anahtar Kelimeler:* havacılık, havacılık sanayi, hava yolu şirketleri, veri zarflama analizi, k-ortalamalar kümeleme analizi, gözetimsiz yapay öğrenme

*JEL Kodlar:* L93, C44, C38, L25, M21

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## Introduction

Civil aviation meets the sole transportation needs of global business development and tourism, strengthening across the globe. It is the only and fastest transportation option between the countries and continents. Air transportation is one of the significant services that affect the social and economic status of countries. Aviation affects tourism and trade. In this way, it contributes to economic growth by providing jobs and tax revenues.

Furthermore, it is significant for the rapid movement of people and freight worldwide (Air Transport Action Group [ATAG], 2008). The airline industry holds a prominent position due to its uniqueness and fascination. It receives all attention by enhancing the number of consumers worldwide. The airline industry is also developing by attracting and reaching a high level of technological improvements (Chan, 2000). The airline industry's most important element is the selection of airlines. Airlines implement two different strategies. These are: low-cost carriers (LCCs) and full-service network carriers (FSNCs). FCNSs have two different strategies. These are legacy carriers and airline within-airline strategies.

Full-Service Network Carrier (FSNC) model is resting on the strategic base of wide connectivity, great customer service and varying fare structure. Such a case contains hub-and-spoke operations, different classes like economy, business, first of all, and in-flight and other services like meals, handling luggage, and access to lounges for the premium customers. FSNCs target to give a smooth travel experience in both domestic and international markets which is often backed up with code-sharing and global airline association such as Star Alliance, SkyTeam or Oneworld. FSNCs are, for instance, Lufthansa, famous for its world network and premium services; Singapore Airlines, which has received the Asia-Pacific region's award for service excellence; and Vietnam Airlines, which provides good service along with its extensive international routes. In Europe, Air Europa is working as a powerful FSNC under the roof of the SkyTeam alliance while in the U.S. Trans States Airlines played the role of a regional feeder, indicating the model's reach to strategic partnerships. FSNCs factor in passengers' decisions largely in terms of quality expectations, perceived quality, service value, satisfaction, and airline image factors. Customers typically expect high service from FSNCs, and through their perception and satisfaction, they become an integral part of the entire travel experience. The aim of those carriers is to give the alternatives that attract a large variety of passengers hence building up their brand. LCCs, however, have become a major challenge to FSNCs particularly in the areas of budget-conscious leisure and short-haul business as they adopt the same price, flexibility, and frequent flyer incentive approach as the FSNCs do.

With the shifting competitive landscape between FSNCs and LCCs, main question that needs further examination is: In what ways does the change of passenger preferences—especially the ones of business travelers—along with the operational strategies of LCCs, affect the long-term efficiency, market positioning, and service differentiation of FSNCs in short-haul and long-haul markets? So this paper tries to solve it using data envelopment analysis with k-means clustering.

The structure of the paper is as follows: the literature review then examines prior research on airline strategies, including post-deregulation shifts, hybrid models (e.g., airlines-within-airlines), and service quality metrics. Next, the Methodology section details the use of Data Envelopment Analysis (DEA) to assess efficiency, employing variables like passenger load factor (PLF) and seat kilometers (ASK) from 152 FSNCs (2003–2013). The Results present efficiency trends, clustering airlines into superior, moderate, and poor performers based on consistency. Finally, the conclusion highlights the success of FSNCs, such as Vietnam

Airlines, in striking a balance between efficiency and service, while also calling for future research on LCCs and dynamic market adaptations.

## Literature Review

### Airline Business Models and Strategies

The primary advantage of domestic business travel is prompt, dependable service, so additional amenities offered by FSNC airlines are deemed unnecessary by Mason (2000, 2001) and Evangelho et al. (2005). On long-haul and international flights, however, FSNC airlines offer the primary advantage of a particular comfort service. Therefore, business travelers tend to favor the FCNC model on short-haul flights, while leisure travelers prefer the LCC model. Because the LCC concept is unsuitable for long-haul flights, the FSNC model is the only option available to passengers (Acar & Karabulak, 2015).

After defining the LCC and FSNC models, the network model for scheduled airlines has gained market growth over the last few years. In this model, a flag carrier or full-service carrier airline employs the FSNC model, while its structure incorporates elements of the LCC model (Caves, 1962; Jordan, 1970). For instance, X airline is named as a network carrier. It incorporates both the FSNC model and the LCC model into its structure. The annual report of X airline is structured as an FSNC model airline, and the LCC model data of this airline are shown in this report. The network model for scheduled airlines has contributed to their year-after-year market growth. They have enhanced their profits and productivity, and they have reduced the average prices of ticket sales since the 1990s. After the 9/11 events, the civil aviation industry was increasingly questioned. During this period, the hub (or central airport used by the flag carrier airline) concept was bypassed, and point-to-point flights constituted a significant portion of the market. Thereupon, various airlines operationceased their activities, and the civil aviation industry underwent downsizing. Consumers' reliance on the civil aviation industry decreased. Alternative models have been implemented recently. At the beginning of the 1990s, the model LCC gained value in recent days because of cheap ticket prices. In the following years, with the increasing implementation of security measures in the civil aviation industry, consumers have felt confident again. The LCC model is simple to implement, and besides its simplicity, this model has helped to reduce costs by 40% - 50% of liable airline costs.

With higher load factors and labour cost benefits, a 60% decline in expenses has resulted in the establishment of new markets, and the flow of traffic has increased by 3-4 times the former levels on several routes. LCC airlines have grown and incrementally exceeded the network carrier markets. For instance, Southwest Airlines began operating transcontinental flights in the US as an enduring network carrier hub, serving as a base for development. Network Carriers have come back in two ways;

1. The foundation of low-cost and in-airline strategies.
2. Venture to lift an important amount of costs from their operations, but without changing their business passenger models.

The first mission has three feasible objectives;

1. To filter profitable tasks.
2. To observe LCC rivalry in key markets.

3. To institute a trial sample for adapting the LCC model to their central operation system.

The second goal is to reduce expenses and increase efficiency without the LCC sprout. For example, Air Canada, United Airlines, Delta Airlines, Continental Airlines (previously), and US Airways are the first strategy, as FSNC model airlines, in North America. American Airlines, Northwest Airlines, America West Airlines, and (later) Continental Airlines are LCC model airlines that use a secondary strategy. British Airways first employed this tactic in Europe, where it competed against expanding low-cost carriers such as Ryanair and EasyJet. To reduce mainline costs, British Airways assessed new procedures by lowering operating costs, improving comfort levels, and adjusting ticket prices. The hub model concept will evolve in this way. These days, LCC airlines are typically used as a nation's secondary hub, while full-service airlines are typically used as its primary hub. This tactic will become widely used in the future. Regarding the idea of network carrier airlines, there are differing views. Network carriers first determined evidence of the need for cost reduction. Second, enlarging aircraft to accommodate the heavy traffic volume, especially on short-haul routes, does not result in the expected reduction in unit costs. Thirdly, new point-to-point low-cost airlines are using secondary hubs with a new generation of small business jets, making the hub approach of today a failure (Woerth, 1995).

The concept of a hub has been argued since the fast growth of LCC point-to-point operations in North America and Europe in the mid-1990s. US big-scale airlines improved the profitability of the hub concept in the mid-1990s by closing several hubs in the US and transitioning from a directional to a continuous hubbing concept (Morrel, 2005). For instance, Northwest Airlines wanted to restructure its business model and reinforce its hubs. It has been a loyal protector of the network model since the beginning of the 1990s to the present day. One of the US's big-scale airlines, United Airlines, risked losing its brand image by dropping out of two markets (Kimes & Young, 1997). United Airlines doubted that Southwest Airlines' threats to enter long-haul markets would materialize. Another example is that American Airlines did not try the LCC model because it is difficult to prove how to behave as a group of consumers differently from others. Without important cost savings, consumers may not appreciate brand image.

Network Carriers operate primarily as full-service (legacy or traditional) and secondary as low-cost (no-frills). Their mainline fleet is equipped with large-scale aircraft for long-haul, full-service flights and smaller aircraft for short-haul, low-cost flights. They are the creation of the "carriers within carriers" (CWCs) strategy, which does not constitute an innovation because the strategic structure of network carriers is already included in their strategies. International, national, charter, and regional flights are operated either wholly owned or by leasing aircraft. Leasing aircraft is separated into two ways. These are wet leases and dry leases. Wet lease means leasing an aircraft with its crew and fuel. Dry lease refers to leasing an aircraft without any accompanying services. Furthermore, the creation of the CWC strategy is an operating system that applies lower unit costs than the leading airline. Nowadays, this system is the dynamic internal of the global airline industry.

The CWC strategy presents four potent advantages to full-service carriers. According to these are;

1. It can authorize the airline to cut down costs, especially in terms of labour, to compete with LCC airlines.

2. A CWC can be a more suitable product for leisure or hub-overcome routes, and in this way, the mission serves as an advanced form of market segmentation in network enlargement.
3. A CWC can authorize an inhibitor market entrance to stop other LCC airlines from entering the same market.
4. Alternatively, a CWC can operate as a direct competitor to an LCC already established in the market.

The quality of a commodity is of great importance in the airline industry. There are too many similar airlines. When an airline presents a distinct commodity to its passengers, this airline, in a manner of speaking, has its cake and eats it. Later, other similar airlines will adopt this strategy, but it will not be as effective as the first airline that implemented it. Due to this situation, selecting an airline individually is risky. If this airline cannot apply individual selections effectively, then it will be factored out of the purchasing determination.

To counter this possibility, airlines are seeking ways to establish their brand image, identity, and personality, aiming to implement quality strategies that foster passenger loyalty. This approach enables them to differentiate themselves from their competitors. Airlines should pay attention to the concept of the airline quality rating approach for their positive development. First of all, airlines should examine the strategies of other similar-sized competitor airlines and present arguments in support of these strategies. Secondly, airlines should also examine the traditional passenger inquiries, which accurately reflect the situation. Finally, airlines should consider expanding the number of reports about airline quality.

In the 1990s, it was unclear whether the quality ranking statistics accurately reflected the differences between airlines. Because of this, 1990s reports were not wholly accurate. For instance, the rankings of airlines in 1996 differed significantly from those in 1997. This was not possible because, in recent years, the parameters related to service quality have not been examined correctly. Also, in the last period of the 1980s and 1990s, regional carriers grew primarily in the US. Therefore, it was not easy to identify the proper service quality parameters that distinguish between airlines[1]. After the crash of Valujet Airlines, several arguments were made about the safety of regional carriers. Regional carriers (generally applying a low-cost carrier strategy) were examined regarding their safety standards. Because of this, the differences in quality related to the civil aviation industry might be more apparent among airlines that implemented different strategies.

1978 was the year of deregulation, which initiated the last stage of civil aviation history. After deregulation, safety standards and hub-and-spoke concepts were developed first in the US and subsequently adopted worldwide. During this period, full-service carrier airlines' long-haul flights were constrained by regulations regarding load factors. This situation prevented the institution of economies of scale and the setting of fares on scheduled destinations, so in many cases, these routes were 50 percent higher than nonregulated intrastate destinations. Full-service carrier airlines that could not compete on fares were expected to base their competition on the quality of service.

[1] AvStat Associates, Inc. (1998). Report for the Regional Airline Association.

## Efficiency Measurement in Aviation

The strategy of competition based on service quality rather than fares forced airlines to focus on offering cheap and below-cost air fares for passengers. To overcome this difficult status, especially US airlines launched a long and painful process of restructuring and induration. To solve this difficulty, at least for the large-scale airlines that remained viable, was a cost-competitive state that was familiar to their international competitors. This situation centres on cost-cutting regarding complaints, which increased among consumers, and an outstanding absence from the service arrangements of [2] of the top ten international airlines.

The quality of service is a significant issue for network and full-service carriers. These carriers have defined service quality as a profit strategy, which resulted in five outcomes. These are: more new passengers, more business possibilities from existing passengers, fewer lost customers, more isolation from price competition, and fewer mistakes requesting the reperformance of service level.

The service quality is separated into ten components. These are: listening to customers' complaints, listening to employees' complaints, ensuring transworthy service, taking care of the basic service standards, figure out the design of service standards, informing customers about different innovations, recovering from the problems of service standards, composing servant leaders, implementing the concept of fair play, and to foster the concept of teamwork. Four of these components are recovering: listening to customers' complaints, impressing customers with innovative solutions, addressing service standards issues, and implementing the concept of fair play. These components are involved in forming comprehension about customers' expectations, sensations, and also assembling or gathering them. All of these fields are focused on the quality of consumer surveys. There are responses related to the significance of varied views of airline service, food alternatives, comfort level, and in-flight entertainment issues, which are asked of the airlines for ranking them. All three components, fostering teamwork, listening to employees, and forming servant leaders, are activities that are indirectly monitored by customers. These activities are designed to develop employee spirit and contribute to a total quality culture. The remaining three components aim to ensure trustworthy service, maintain basic service standards, and demonstrate reliability and consistency in service judgment through the analysis of data from the Air Travel Consumer Report.

In addition to the issues identified in the 1997 Frequent Flyer Survey, the top three factors contributing to overall airline contentment were examined: on-time performance, schedule-flight accommodation, and airport check-in, which are key aspects of basic service standards and service design. [3]

## Utilized Variables

Six parameters are used in this research to calculate the efficiency and consistency of the efficiency levels of network carriers. These parameters are: the number of passengers carried (PC) and passenger kilometres flown (PKF) used as outputs to measure the performance of any network carrier. Available seat kilometers (ASK), passenger tonne kilometer performed in thousands (PTK), passenger load factor (PLF), and kilometers flown thousands (KF) are the parameters used as inputs to calculate the network carriers' efficiency and consistency of efficiency in order to contribute to the literature on network carrier airline industry related with the term of civil aviation in general.

[2] Zagat (1992). Zagat United States Travel Survey, Zagat, New York.

[3] Frequent Flyer. (1997). The people's choice, Frequent Flyer, June 24-26

## Methodology and Data

Using information from IATA and annual reports, this study evaluates the effectiveness of 152 network airlines between 2003 and 2013[4]. The analysis uses passenger load factor, available seat kilometers, and passenger tonne kilometers as inputs and passengers carried as the output. All variables were converted to their natural logarithms in order to account for significant numerical differences. Three primary steps comprised the methodology: First, a Pearson's correlation analysis is used to determine whether the variables are related; second, a Data Envelopment Analysis (DEA) with bootstrapping is used to determine input-oriented efficiency scores under different returns-to-scale assumptions; and third, a k-means clustering of the carriers' coefficient of variation in efficiency is used to classify them into three groups: low efficiency/high volatility, balanced efficiency/volatility, and high efficiency/low volatility.

This study examined data for 152 network carriers over the 11-year period from 2003 to 2013 in order to evaluate airline efficiency over time. The performance output identified by the model is passengers carried (PC). The airlines use passenger load factor (PLF), available seat kilometers (ASK), and passenger tonne-kilometers (PTK) as inputs. Natural logarithms were used to transform all four variables because of the notable scale differences.[5]

A sequential approach was taken. First, Pearson's correlation coefficients were calculated to identify and steer clear of issues with perfect collinearity between variables. Second, we used Data Envelopment Analysis (DEA) to estimate efficiency. This input-oriented DEA was enhanced by incorporating a bootstrapping algorithm to generate confidence intervals for the efficiency coefficients, under the assumptions of constant, variable, and non-decreasing returns to scale.

The stability of each carrier's efficiency over time was assessed by calculating the coefficient of variation (CV[6]) for their scores after the efficiency calculations were completed. An airline's average efficiency and performance volatility are effectively balanced by this standard deviation-to-mean ratio. Based on their CVs, the carriers were then divided into three groups using a k-means clustering algorithm, which produced clusters characterized by low efficiency/high volatility, moderate efficiency/moderate volatility, and high efficiency/low volatility.

## Robust Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric method used to measure the relative efficiency of decision-making units (DMUs). DEA is primarily aimed at quantifying the relative efficiency of DMUs -like companies, educational institutions, medical facilities, or airlines- that combine several resources to generate several outputs. DEA is one of the non-parametric methods based on linear programming that builds an efficiency boundary from the top-performing DMUs and ascertains the nearness of each unit to this boundary, not requiring any pre-specified weights or functional forms. It distinguishes between units that are efficient and inefficient, sets performance standards, and even indicates input cuts or output growth necessary to reach efficiency. However, the standard DEA models are sensitive to data uncertainty and outliers. Robust Data Envelopment Analysis (RDEA) addresses this issue by incorporating uncertainty into the model, providing more stable and reliable efficiency scores.

[4] https://www.iata.org/en/about/worldwide/europe/value-of-aviation/

[5] For intermittent missing data points, we used mean imputation based on the specific carrier's values from adjacent years to maintain the integrity of the time-series analysis.

[6] $CV_i = \sigma_i/\bar{X}_i$, the ratio of standard deviation to mean in which i={1,..,9}.

## The Standard CCR Model

The efficiency of a specific DMU, denoted as $DMU_o$, is calculated by solving the following linear programming problem. Let's assume there are $n$ DMUs, each using $m$ inputs to produce $s$ outputs.

Let:

- $x_{ij}$ be the amount of input $i$ for $DMU_j$.
- $y_{rj}$ be the amount of output $r$ for $DMU_j$.
- $u_r$ be the weight for output $r$.
- $v_i$ be the weight for input $i$.

The objective of the CCR model is to maximize the efficiency ratio of $DMU_o$:

$$\max \theta = \frac{\sum_{r=1}^{s} u_r\, y_{ro}}{\sum_{i=1}^{m} v_i\, x_{io}} (1)$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r\, y_{rj}}{\sum_{i=1}^{m} v_i\, x_{ij}} \leq 1, \quad j = 1, \dots, n(2)$$

$$u_r, v_i \geq 0$$

This fractional problem can be transformed into a linear programming problem:

$$\max \sum_{r=1}^{s} u_r\, y_{ro} (3)$$

Subject to:

$$\sum_{i=1}^{m} v_i\, x_{io} = 1(4)$$

$$\sum_{r=1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \leq 0, \quad j = 1, \dots, n(5)$$

$$u_r, v_i \geq 0$$

## Robust DEA with Interval Data

Now, let's consider the case where the input and output data are not known precisely but are assumed to lie within certain intervals. This is a common approach to robust DEA.

Let the uncertain data be represented by intervals:

- $\tilde{x}_{ij} \in \left[x_{ij}^{L}, x_{ij}^{U}\right]$
- $\tilde{y}_{rj} \in \left[y_{rj}^{L}, y_{rj}^{U}\right]$

To find a robust efficiency score $DMU_o$, we can formulate the problem from a worst-case perspective. We want to find the efficiency $DMU_o$ under the most unfavorable realization of the data for $DMU_o$ and the most favorable realization for all other DMUs.

The robust counterpart of the CCR model can be formulated as follows:

$$\max\theta$$

Subject to:

$$\sum_{r=1}^{s} u_r\, y_{ro}^{L} - \theta \sum_{i=1}^{m} v_i\, x_{io}^{U} \leq 0 (6)$$

$$\sum_{r=1}^{s} u_r\, y_{rj}^{U} - \sum_{i=1}^{m} v_i\, x_{ij}^{L} \leq 0, \quad j = 1, \dots, n, \quad j \neq o (7)$$

$$\sum_{r=1}^{s} u_r\, y_{ro}^{L} - \sum_{i=1}^{m} v_i\, x_{io}^{U} \leq 0 (8)$$

$$\sum_{r=1}^{s} u_r = 1 (9)$$

$$u_r, v_i \geq 0$$

This formulation ensures that the efficiency of $DMU_o$ is maximized while considering the worst possible values for its own data and the best possible values for all other DMUs' data within their respective uncertainty sets. This provides a lower bound on the efficiency of $DMU_o$, making the assessment more robust.

The analysis via Data Envelopment Analysis (DEA) was performed on R with the rDEA package, which is capable of performing input-oriented DEA models at constant (CRS), variable (VRS), and non-decreasing returns to scale (NDRS) for the purpose of the robustness assessment of efficiency scores and to deal with sampling variability. The decision to use k = 3 clusters was the result of a combination of quantitative validation and ease of interpretation. The elbow method (which plots the within-cluster sum of squares against k) indicated a clear inflection point at k = 3, after which the explained variance increased only marginally. This was confirmed by the silhouette analysis which showed that k = 3 had the highest average silhouette width (0.52), meaning that the clusters were quite separated from each other and also very uniform and compact. Moreover, k = 3 created clusters that were highly interpretable from the standpoint of airline performance— "Better," "Slightly good," and "Worst," which were, in turn, quite similar to the theoretical assumptions about efficiency and stability patterns. Lower k clusters were lacking in precision whereas higer values for k resulted in creating either too much fragmented or too much overlapping groups with not much of a practical distinction.

## Results

To scale the variables in a lower range and linearize them against both extreme values (outliers) and strong volatility, the variables PC, PTK, ASK, and PLF used in this study are converted into their natural logarithm. Table 1 below provides descriptive statistics for the data:

**Table 1.**

*Descriptives of the Data Set*

| Variable | Obs. | Min | P25 | Median | Max | SD |
|---|---|---|---|---|---|---|
| PC | 1,672 | 4.7100 | 15.0100 | 14.9500 | 18.6100 | 1.5710 |
| PTK | 1,672 | 1.7920 | 13.0800 | 12.9800 | 17.2300 | 1.7820 |
| ASK | 1,672 | 4.2340 | 15.7900 | 15.7100 | 19.6700 | 1.7240 |
| PLF | 1,672 | 0.0070 | 0.7141 | 0.7085 | 1.7470 | 0.0945 |
| PKF | 1,672 | 4.1430 | 15.4500 | 15.3500 | 19.4800 | 1.7960 |
| KF | 1,672 | 4.1740 | 10.8100 | 10.7700 | 14.4300 | 1.4870 |

Note. All variables are taken as natural logarithms. Created by the author using R statistical software.

It is evident that the data are somewhat normalized because the median and mean are so near to one another. To avoid the collinearity issue, pairwise correlations are calculated as shown in Table 2:

**Table 2.**

*Pearson Correlations of variables*

| | PTK | ASK | PLF | PKF | KF |
|---|---|---|---|---|---|
| PTK | 0.9059*** | | | | |
| ASK | 0.9124*** | 0.9907*** | | | |
| PLF | 0.4439*** | 0.5211*** | 0.4641*** | | |
| PKF | 0.9136*** | 0.9940*** | 0.9976*** | 0.5140*** | |
| KF | 0.9539*** | 0.9439*** | 0.9487*** | 0.4328*** | 0.9461*** |

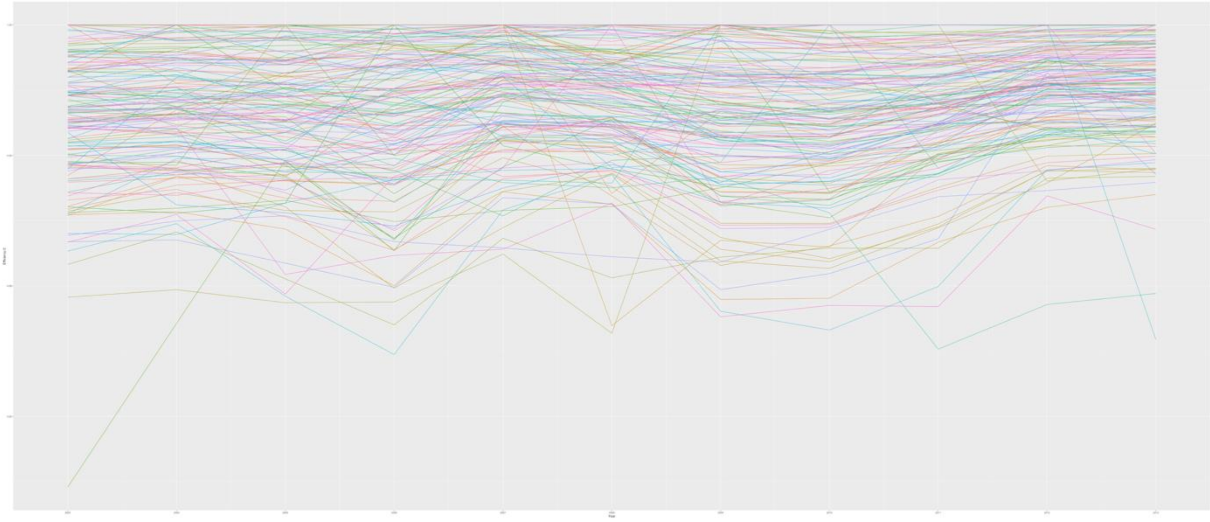
Significance levels *, ** and *** denote .10, .05, .01 respectively.
Note. Created by the author using R statistical software.

PTK and ASK have the highest correlation coefficient. Since Table 2 lacks perfect collinearity, they can be combined in the DEA to determine efficiencies. Three assumptions regarding returns to scale -constant, variable, and non-decreasing- are made when running DEA under input-oriented methodologies in order to obtain these coefficients.

Firms' efficiency scores are displayed in Figures 1, 2, and 3 based on assumptions about constant, variable, or non-decreasing returns to scale. The Appendix provides a summary of the findings.

**Figure 1**

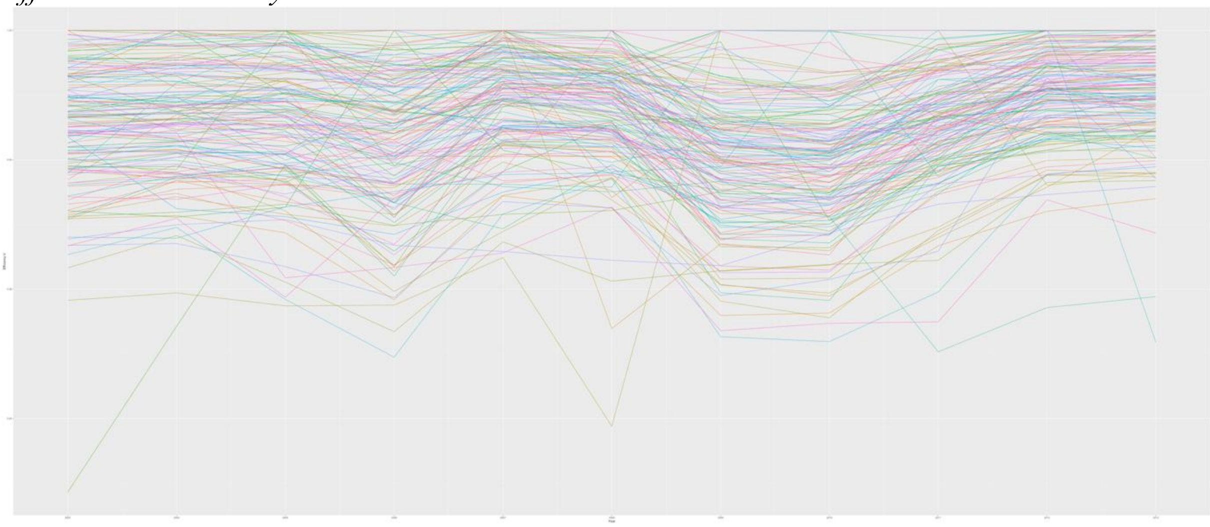
*Efficiencies over the years with Constant Returns to Scale*



Note. This figure was created via R-Studio, where Arial font customization is not supported.

**Figure 2**

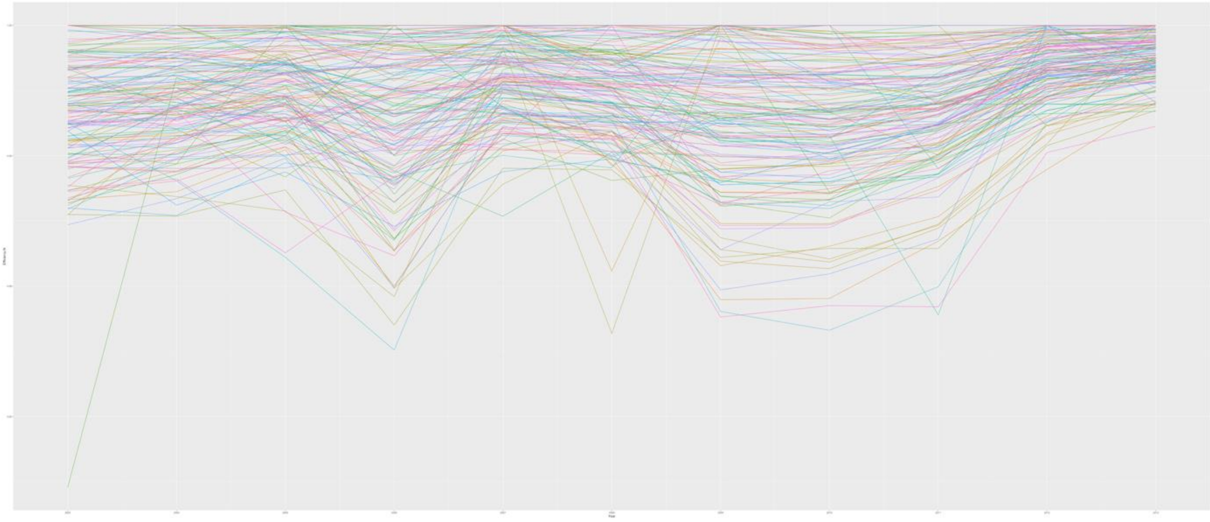
*Efficiencies over the years with Variable Returns to Scale*



Note. This figure was created via R-Studio, where Arial font customization is not supported.

**Figure 3**

*Efficiencies over the years with Non-increasing Returns to Scale*



Note. This figure was created via R-Studio, where Arial font customization is not supported.

The results clearly show that the figures showing the pattern of efficiencies over time are comparable in terms of constant and non-decreasing returns to scale (Figures 1 and 3). With the exception of seven low-cost carriers, two of them consistently perform better and earn the highest efficiency ratings. The rest show at least a slight decline in one or more years.

The mean efficiencies and changes in efficiency scores over time are also the main topics of this study. This is accomplished by calculating their means and variances over their estimated efficiency scores. Patterns are examined using the coefficient of variation formula to see if they hold true over time, change, or stay the same. CV can be used to examine stabilization because it is less susceptible to consistency issues. If the airline is less efficient, CV suffers. Once more, if the airline's efficiency score is unstable over time, CV falls because the square root of the variance falls. Their resumes are then grouped using k-means clustering, a clustering algorithm based on centroids. It is assumed that there are three clusters because any number less than or greater than three does not produce satisfactory results. Authors can give the clusters the following names:

These are the clusters;

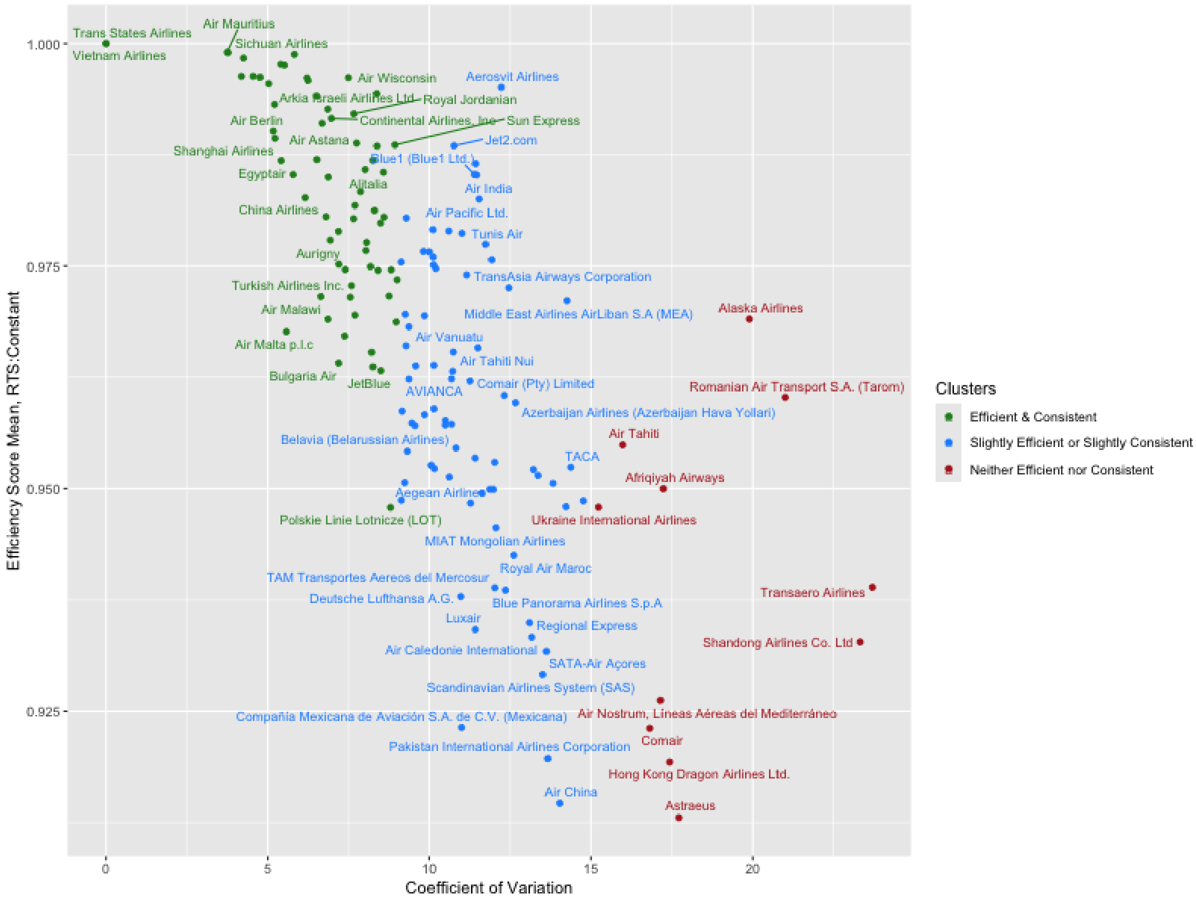
1. Better, meaning the airline is less erratic but has higher efficiency ratings.

2. Slightly good, meaning that the airline's efficiency ratings are either marginally high or somewhat erratic over time.

3. Worst, meaning that despite its extreme volatility over time, the airline has comparatively lower efficiency scores.

**Figure 4**

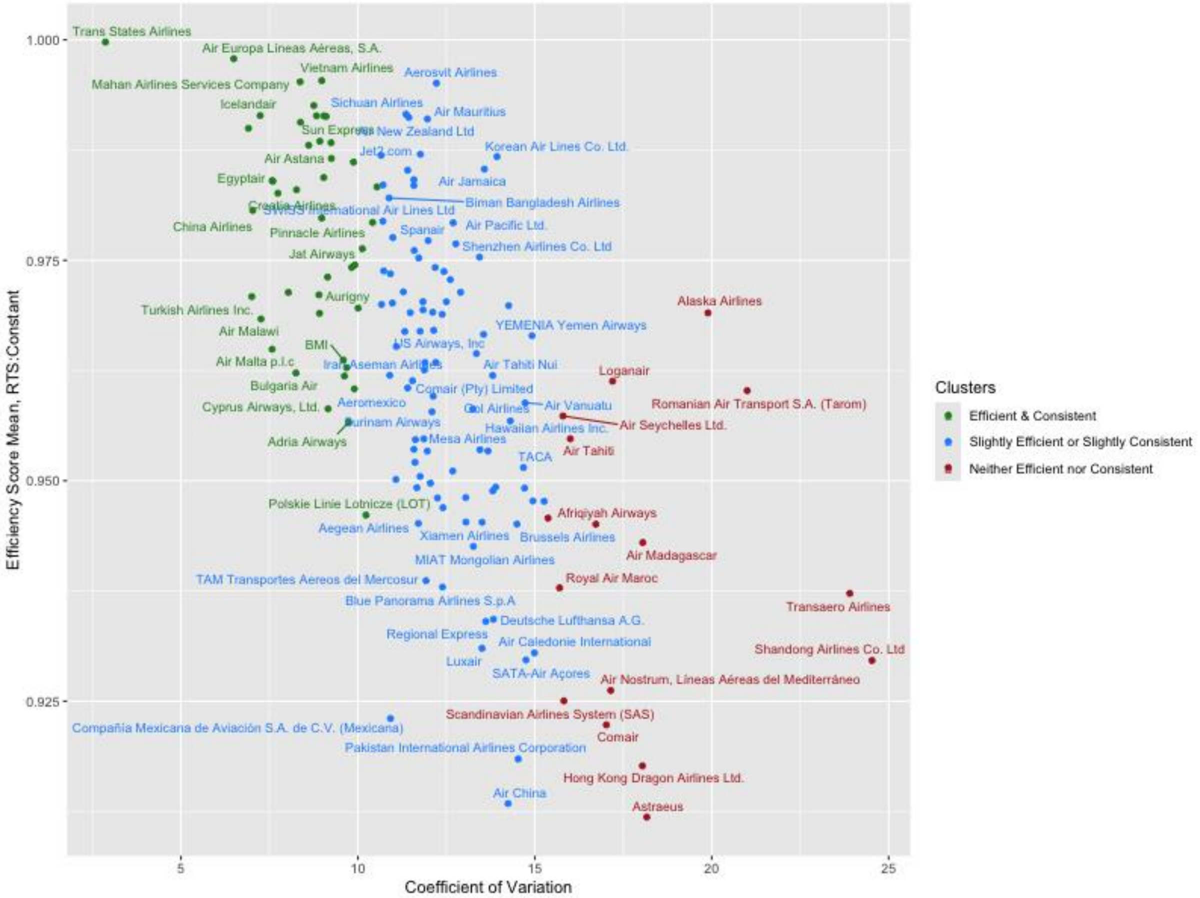
*K-means clusters of 152 FSNC with Constant Returns to Scale*




Note. This figure was created via R-Studio, where Arial font customization is not supported.

**Figure 5**

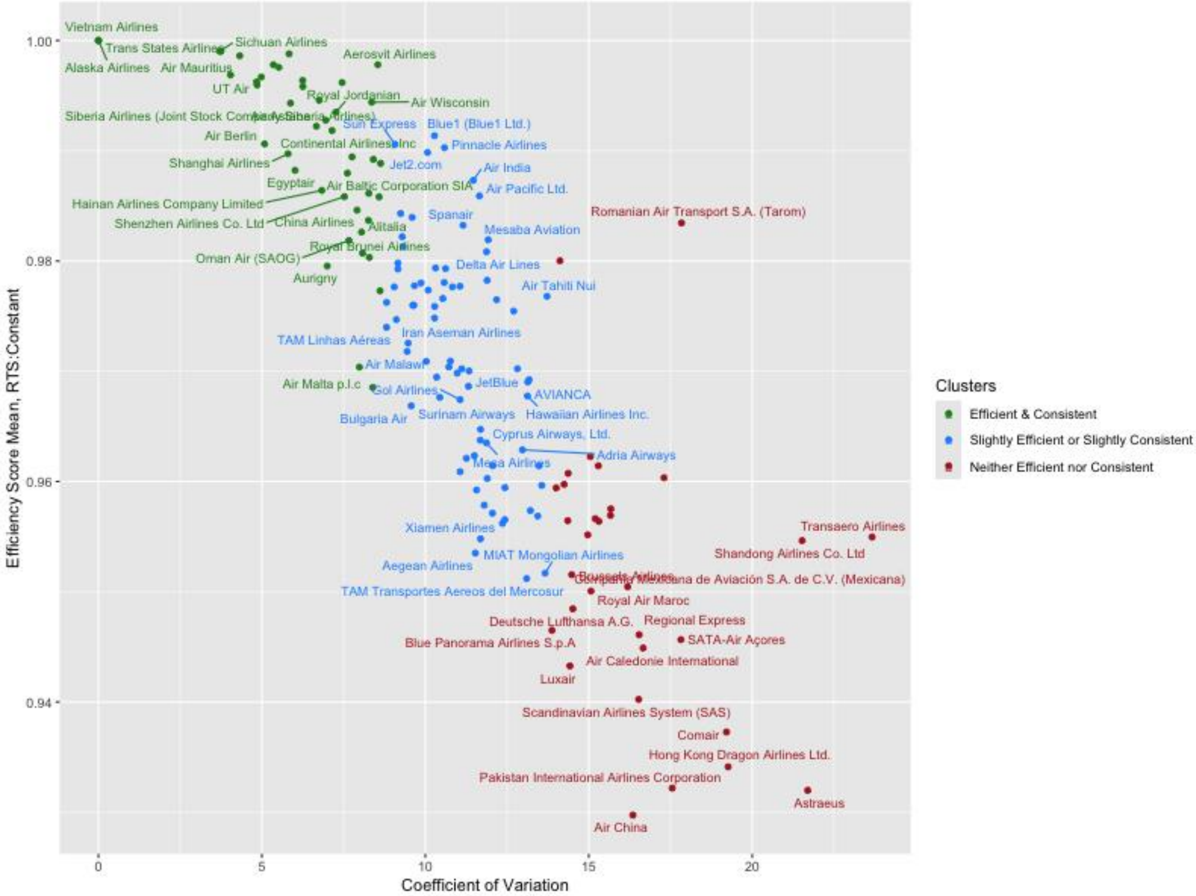
*K-means clusters of 152 FSNC with Variable Returns to Scale*




Note. This figure was created via R-Studio, where Arial font customization is not supported.

**Figure 6**

*K-means clusters of 152 FSNC with Non-increasing Returns to Scale*




Note. This figure was created via R-Studio, where Arial font customization is not supported.

## Conclusion

This study compares the efficiencies of 152 network carriers (FSNC). Efficiency can be defined as an airline's performance level. It can be claimed that this airline is successfully run if the efficiency level remains constant from year to year. The FSNC strategy is characterized by the highest level of comfort and the most efficient medium ticket prices. These airlines profit from the offtake of passengers by implementing a low fare strategy. By offering a low-cost ticketing strategy, these airlines hope to meet the demand for short-haul travel. For the past 25 years or so, the FSNC model has been in use. Trans States Airlines, Air Europa Líneas Aéreas, and Vietnam Airlines are the top FSNC airlines in terms of fleet size and strategy. This year was the cornerstone of FSNC Airlines' development. Airlines are now divided into three categories. First and foremost, the network strategy is a secondary FSNC strategy that is connected to an airline's primary mission of operating as a full-service carrier. Second, full-service carriers apply high ticket prices to their passengers by using the high comfort level method. Finally, the focus of this study is the FSNC strategy, which has to do with airlines that use a low-level comfort and low ticket fare approach. The success of an airline is defined by two broad topics. Seat spacing, seat width, the maximum baggage policy, the weight of luggage permitted in the cabin, in-flight entertainment, the number of restrooms per person, and other factors are all part of the service level. The degree of comfort in applications is gauged by these factors. For FSNC airlines, service level is not a determining measurement value. Second, the parameters of available seat kilometers (ASK), passenger load factor (PLF), passenger tonne kilometers (PTK), and number of passengers carried (PC) are all considered in the analysis of efficiency in this study. The other parameters are used as outputs, and only the PC parameter is used as an input. The PLF parameter is a percentage that ranges from 0 to 1, whereas the other parameters are large numbers that cannot be changed without the use of a transformation, such as a natural logarithm. In comparison to other airlines, Trans States Airlines, Air Europa Líneas Aéreas, and Vietnam Airlines are efficient and consistent from 2003 to 2013, according to the figures that determine the efficiency level. Trans States Airlines, Air Europa Líneas Aéreas, and Vietnam Airlines are some of the most well-known FSNC airlines. They all demonstrate the model by combining a sizable fleet with careful network planning. This timeframe was crucial to the development of FSNCs and established their fundamental position in the aviation world. These days, airlines usually fall into one of three strategic categories. The most important of these is the network strategy, in which the primary goal of an airline is to operate as a full-service carrier, a feature of the FSNC model, with supplementary tactics tailored to particular market demands or competitive positioning.

By adopting a robust quantitative methodology that incorporates Robust Data Envelopment Analysis (RDEA) and k-means clustering for airline performance assessment, this research significantly advances the aviation management field. The simultaneous application of the two methods renders the argument much stronger than the one made by the traditional models since they are capable of not only examining the actual efficiency but also checking its fluctuation over time. The study offers a precise standard for the comparison of the performance of the airlines against 152 other network carriers to the airline managers, illuminating the leading ones such as Trans States Airlines and Vietnam Airlines. Giving the "Better," "Slightly good," and "Worst" designations to airlines according to efficiency and stability, the study provides valuable information for strategic planning and operational improvement through clustering.

After analyzing these FSNC airlines, the data envelopment analysis is used in this study. To evaluate the consistency or variability of the efficiency models, CVs are calculated between years, using the efficiency coefficients from 2003 to 2013. This is in addition to the DEA. As can be seen, future research on full-service and low-cost carriers must examine their efficiency and consistency of efficiency to enlighten the literature on the airline industry, where such quantitative studies are relatively lacking compared to other disciplines.

The empirical backing for some important theoretical frameworks in aviation management is given by the results of this study and at the same time a new light is thrown on the concept of carrier stability. To be more specific, the "carriers-within-carriers" (CWC) strategy analyzed by Morrell (2005) and Graham and Vowles (2006) gets confirmed through the high efficiency and consistency scores of the Full-Service Network Carriers (FSNCs) such as Vietnam Airlines and Air Europa. While the studies of Mason (2000, 2001)and Evangelho et al. (2005) suggest that the passenger segmentation is different according to the business travelers resorting to the service on FSNCs and leisure travelers going for the lowest cost on LCCs, our Robust DEA findings imply a convergence. The most efficient FSNCs in our 'Better' cluster of efficiencies seem to be those that have been able to implement LCC-like cost savings (with increased ASK and PLF inputs) without giving up the service differentiation that is crucial for the long-haul market, a point made by Acar and Karabulak (2015). Also, if O'Connell and Williams (2005) attributed the competitive threat LCCs pose to legacy carriers, then our clustering analysis adjusts this narrative by revealing that FSNCs are not uniformly inefficient; the truth is that efficiency is highly stratified with network carriers at the top level showing a resilience that contests the idea of inevitable LCC dominance in all markets.

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## Appendix

### Appendix 1:

Average Efficiency Scores of Network Carriers over 2003-2013

| Mean.C | Mean.V | Mean.N | Firm |
|---|---|---|---|
| 0,95705575 | 0,9566409 | 0,96287064 | Adria Airways |
| 0,98696812 | 0,98403762 | 0,98797027 | Air Baltic Corporation SIA |
| 0,97673552 | 0,97015423 | 0,9776523 | Malmö Aviation Schedule A.B. |
| 0,97163218 | 0,96705873 | 0,97587599 | Meridiana S.p.A. |
| 0,95830606 | 0,95352073 | 0,96350595 | Mesa Airlines |
| 0,97867898 | 0,97536078 | 0,98192598 | Mesaba Aviation |
| 0,94560756 | 0,94255515 | 0,95168492 | MIAT Mongolian Airlines |
| 0,97109926 | 0,96985445 | 0,98002354 | Middle East Airlines AirLiban S.A (MEA) |
| 0,94990324 | 0,94804397 | 0,95686436 | Monarch Airlines |
| 0,96228729 | 0,96041367 | 0,96763442 | Myanmar Airways Int. |
| 0,98180412 | 0,96958335 | 0,98185481 | Oman Air (SAOG) |
| 0,91969541 | 0,91845138 | 0,93219029 | Pakistan International Airlines Corporation |
| 0,99014511 | 0,98332174 | 0,99062321 | Air Berlin |
| 0,97459666 | 0,96695297 | 0,97623979 | Philippine Airlines, Inc. |
| 0,98650402 | 0,97929049 | 0,99028115 | Pinnacle Airlines |
| 0,94786415 | 0,94611318 | 0,95653884 | Polskie Linie Lotnicze (LOT) |
| 0,95764245 | 0,95474483 | 0,96143516 | Qatar Airways Company (W.L.L) |
| 0,93491825 | 0,934046 | 0,9460991 | Regional Express |
| 0,96025811 | 0,96021918 | 0,98344676 | Romanian Air Transport S.A. (Tarom) |
| 0,95225291 | 0,95014962 | 0,9561999 | Rossiya - Russian Airlines |
| 0,94249395 | 0,93785645 | 0,95006353 | Royal Air Maroc |
| 0,9805363 | 0,97373326 | 0,98262375 | Royal Brunei Airlines |
| 0,99210617 | 0,99065116 | 0,99350717 | Royal Jordanian |
| 0,93331297 | 0,93047655 | 0,94490003 | Air Caledonie International |
| 0,93172694 | 0,92967885 | 0,94565735 | SATA-Air Açores |
| 0,96955916 | 0,9689855 | 0,9748196 | Saudi Arabian Airlines |
| 0,92909637 | 0,9250381 | 0,94024119 | Scandinavian Airlines System (SAS) |
| 0,93278686 | 0,92962059 | 0,95463931 | Shandong Airlines Co. Ltd |
| 0,98933107 | 0,98299567 | 0,98973347 | Shanghai Airlines |
| 0,98500332 | 0,97687177 | 0,98583566 | Shenzhen Airlines Co. Ltd |
| 0,99316458 | 0,98996477 | 0,99432084 | Siberia Airlines (Joint Stock Company Siberia Airlines) |
| 0,99897916 | 0,99156699 | 0,99902299 | Sichuan Airlines |
| 0,99765587 | 0,99255125 | 0,9977976 | Silkair (Silkair (Singapore) Private Limited) |
| 0,97892797 | 0,97758001 | 0,98324163 | Spanair |
| 0,91463958 | 0,91339944 | 0,92973988 | Air China |
| 0,99582791 | 0,98834174 | 0,99582791 | SriLankan Airlines Ltd. |
| 0,98859624 | 0,98850446 | 0,99057837 | Sun Express |
| 0,96316314 | 0,95782518 | 0,96472476 | Surinam Airways |
| 0,98554373 | 0,97943136 | 0,98581981 | SWISS International Air Lines Ltd |

| | | | |
|---|---|---|---|
| 0,95240784 | 0,95149908 | 0,95662765 | TACA |
| 0,97280235 | 0,97136322 | 0,97398557 | TAM Linhas Aéreas |
| 0,93886493 | 0,93867543 | 0,95119483 | TAM Transportes Aereos del Mercosur |
| 0,95296519 | 0,94916865 | 0,96225941 | TAP-Air Portugal |
| 1 | 0,99975229 | 1 | Trans States Airlines |
| 0,93891845 | 0,93722587 | 0,95496348 | Transaero Airlines |
| 0,998773 | 0,99785855 | 0,99878774 | Air Europa Líneas Aéreas, S.A. |
| 0,97255852 | 0,9713728 | 0,97545902 | TransAsia Airways Corporation |
| 0,97743764 | 0,97418758 | 0,97931426 | Tunis Air |
| 0,97157441 | 0,97087981 | 0,97597556 | Turkish Airlines Inc. |
| 0,94789428 | 0,94767357 | 0,95751626 | Ukraine International Airlines |
| 0,95214788 | 0,94885854 | 0,95974463 | United Airlines |
| 0,97150389 | 0,96443065 | 0,97468814 | US Airways, Inc |
| 0,99628143 | 0,99138425 | 0,99687794 | UT Air |
| 1 | 0,9953764 | 1 | Vietnam Airlines |
| 0,98879346 | 0,98354435 | 0,98944629 | Virgin Atlantic Airways |
| 0,96938969 | 0,96257432 | 0,97039425 | Vladivostok Air JSC |
| 0,98524607 | 0,98414367 | 0,98731881 | Air India |
| 0,97450845 | 0,9714126 | 0,97775452 | Wideroe Flyveselskap A/S |
| 0,95130413 | 0,94531517 | 0,95479873 | Xiamen Airlines |
| 0,97472906 | 0,96645013 | 0,97824731 | YEMENIA Yemen Airways |
| 0,99609492 | 0,98534273 | 0,99637811 | Air Jamaica |
| 0,94834599 | 0,94529356 | 0,9564479 | Air Macau Company Limited |
| 0,95058844 | 0,94299639 | 0,95638839 | Air Madagascar |
| 0,96901839 | 0,96834864 | 0,97179046 | Air Malawi |
| 0,9486663 | 0,94516465 | 0,95350535 | Aegean Airlines |
| 0,96762331 | 0,96492206 | 0,97037722 | Air Malta p.l.c |
| 0,99902633 | 0,9910335 | 0,99902633 | Air Mauritius |
| 0,99836389 | 0,99120747 | 0,99861185 | Air New Zealand Ltd |
| 0,92622886 | 0,92622886 | 0,96033804 | Air Nostrum, Líneas Aéreas del Mediterráneo |
| 0,98251459 | 0,97925764 | 0,98590557 | Air Pacific Ltd. |
| 0,96534517 | 0,95734596 | 0,97022905 | Air Seychelles Ltd. |
| 0,95489526 | 0,95475645 | 0,96142288 | Air Tahiti |
| 0,96581167 | 0,96194238 | 0,97679405 | Air Tahiti Nui |
| 0,96604155 | 0,9588299 | 0,96982907 | Air Vanuatu |
| 0,99437588 | 0,99131465 | 0,99440454 | Air Wisconsin |
| 0,96531739 | 0,96134401 | 0,96946341 | Aer Lingus p.l.c. |
| 0,96903814 | 0,96903814 | 1 | Alaska Airlines |
| 0,98334777 | 0,97525954 | 0,98368566 | Alitalia |
| 0,97662888 | 0,9688708 | 0,97804477 | American Airlines Inc. |
| 0,97764278 | 0,97347217 | 0,9798121 | American Eagle |
| 0,99262793 | 0,98654969 | 0,99276659 | Arkia Israeli Airlines Ltd |
| 0,9130368 | 0,91186492 | 0,93198534 | Astraeus |
| 0,95343398 | 0,9492854 | 0,95964761 | Atlantic Southeast |
| 0,97789971 | 0,97108558 | 0,97953963 | Aurigny |

| | | | |
|---|---|---|---|
| 0,97567967 | 0,96911097 | 0,97648972 | Austral Líneas Aéreas S.A. |
| 0,96231132 | 0,96195751 | 0,96902696 | AVIANCA |
| 0,96713706 | 0,96283298 | 0,96853263 | Aeroflot Russian Airlines |
| 0,95965409 | 0,95337133 | 0,96141944 | Azerbaijan Airlines (Azerbaijan Hava Yollari) |
| 0,98584444 | 0,97723428 | 0,9861358 | Bangkok Airways Co. Ltd |
| 0,95418757 | 0,95049001 | 0,96027601 | Belavia (Belarussian Airlines) |
| 0,98688409 | 0,98206957 | 0,98885261 | Biman Bangladesh Airlines |
| 0,9506653 | 0,94695022 | 0,95712186 | Binter Canarias, S.A. Unipersonal |
| 0,93859192 | 0,93794434 | 0,94650054 | Blue Panorama Airlines S.p.A |
| 0,97658944 | 0,97030084 | 0,97800263 | Blue Wings AG |
| 0,98528864 | 0,9852155 | 0,99136673 | Blue1 (Blue1 Ltd.) |
| 0,96376554 | 0,96369069 | 0,9700284 | BMI |
| 0,94795344 | 0,94509211 | 0,95154805 | Brussels Airlines |
| 0,98123485 | 0,97611291 | 0,98431181 | Aerolíneas Argentinas |
| 0,96408343 | 0,96222614 | 0,96686487 | Bulgaria Air |
| 0,97457185 | 0,97309875 | 0,97735995 | Caribbean Airlines |
| 0,98266515 | 0,98065848 | 0,98461114 | China Airlines |
| 0,99411539 | 0,98613986 | 0,99457973 | China Eastern Airlines |
| 0,98847379 | 0,98349047 | 0,98921738 | China Southern Airlines |
| 0,9230627 | 0,92231909 | 0,93727911 | Comair |
| 0,9604769 | 0,95959034 | 0,9692338 | Comair (Pty) Limited |
| 0,9571305 | 0,9511053 | 0,95923081 | Compagnie Aérienne Corse Méditerranée |
| 0,92316226 | 0,92303846 | 0,95045361 | Compañía Mexicana de Aviación S.A. de C.V. (Mexicana) |
| 0,95455363 | 0,95208596 | 0,95785233 | Compañía Panamena de Aviación, S.A. (Copa) |
| 0,96365536 | 0,96052383 | 0,97022097 | Aeromexico |
| 0,97519642 | 0,96938137 | 0,97927891 | Condor |
| 0,99158372 | 0,98438723 | 0,99183541 | Continental Airlines, Inc |
| 0,96817774 | 0,96340536 | 0,97091435 | Continental Micronesia, Inc. |
| 0,97401051 | 0,96659734 | 0,97771388 | Corse Air International |
| 0,98039197 | 0,97978677 | 0,98395947 | Croatia Airlines |
| 0,95870161 | 0,95816284 | 0,96374684 | Cyprus Airways, Ltd. |
| 0,95735253 | 0,95336363 | 0,96088932 | Czech Airlines - CSA |
| 0,97510645 | 0,97379499 | 0,98083694 | Delta Air Lines |
| 0,93787292 | 0,93429539 | 0,94844951 | Deutsche Lufthansa A.G. |
| 0,95263398 | 0,94973018 | 0,95944698 | Donbass Eastern Airlines |
| 0,99508376 | 0,99508376 | 0,9978066 | Aerosvit Airlines |
| 0,98685213 | 0,98396069 | 0,98822599 | Egyptair |
| 0,99628929 | 0,99137939 | 0,99669062 | El Al Israel Airlines Ltd. |
| 0,97543901 | 0,96692069 | 0,97599068 | Estonian Air |
| 0,97889067 | 0,97447624 | 0,98032901 | Ethiopian Airlines Corporation |
| 0,9790824 | 0,97030808 | 0,97936868 | Eva Airways Corporation |
| 0,96383819 | 0,95812715 | 0,96742611 | Gol Airlines |
| 0,97599896 | 0,96906608 | 0,97659956 | Gulf Air Company G.S.C. |
| 0,95721982 | 0,95356274 | 0,96233753 | Hahn Air Lines GmbH |
| 0,98528147 | 0,98261242 | 0,98640294 | Hainan Airlines Company Limited |

| | | | |
|---|---|---|---|
| 0,962069 | 0,95678179 | 0,96775628 | Hawaiian Airlines Inc. |
| 0,94998185 | 0,9450747 | 0,95692702 | Afriqiyah Airways |
| 0,91930308 | 0,91767114 | 0,93412042 | Hong Kong Dragon Airlines Ltd. |
| 0,98049918 | 0,97281224 | 0,98220236 | Horizon Air |
| 0,96870583 | 0,96341651 | 0,97089495 | Iberworld Airlines |
| 0,99546421 | 0,99141164 | 0,99596719 | Icelandair |
| 0,94859814 | 0,94770796 | 0,95515983 | Iran Air, The Airline of the Islamic Republic of Iran |
| 0,96946826 | 0,96522577 | 0,97255241 | Iran Aseman Airlines |
| 0,97983047 | 0,97631419 | 0,98129879 | Jat Airways |
| 0,95148363 | 0,94576392 | 0,96073735 | Jet Lite (India) Ltd |
| 0,98850582 | 0,98690868 | 0,98984275 | Jet2.com |
| 0,96322598 | 0,96188226 | 0,96863461 | JetBlue |
| 0,99103415 | 0,98804801 | 0,99222115 | Air Astana |
| 0,94948609 | 0,94921257 | 0,957361 | Kenya Airways Ltd. |
| 0,99756581 | 0,98676064 | 0,99756581 | Korean Air Lines Co. Ltd. |
| 0,99618244 | 0,98702885 | 0,99624718 | Kuwait Airways Corporation |
| 0,95896998 | 0,95466056 | 0,96210058 | LAM - Linhas Aéreas de Moçambique |
| 0,97492631 | 0,96999294 | 0,97729827 | Lan Airlines S.A |
| 0,97346259 | 0,96129693 | 0,97765155 | Loganair |
| 0,93415602 | 0,93100383 | 0,94326837 | Luxair |
| 0,99613525 | 0,99524314 | 0,99618653 | Mahan Airlines Services Company |
| 0,98032055 | 0,97419391 | 0,9807103 | Malaysia Airline System Berhad |
| 0,94991188 | 0,94810361 | 0,95941762 | MALEV p.l.c. - Hungarian Airline Public Ltd. Co. |

Notes.The capital letters after the variables with a“.” C, V and N indicate returns to scales which are constant, variable and non-decreasing respectively for Robust DEA.

All efficiencies are calculated with 1000 bootstrapped iterations to get robust coefficients

**Information About the Article/Makale Hakkında Bilgiler**

**The Ethical Rules for Research and Publication / Araştırma ve Yayın Etiği**

The author declared that the ethical rules for research and publication followed while preparing the article.

Yazar makale hazırlanırken araştırma ve yayın etiğine uyulduğunu beyan etmiştir.

**Conflict of Interests/ Çıkar Çatışması**

The author have no conflict of interest to declare.

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**Author Contributions/ Yazar Katkıları**

The draft process of the manuscript/ Taslağın Hazırlanma Süreci Y.K., Data Collection/Verilerin Toplanması Y.K., Writing The Manuscript/ Makalenin Yazılması Y.K., Submit, Revision and Resubmit Process/ Başvuru, Düzeltme ve Yeniden Başvuru Süreci Y.K.