Journal of Air Transport Management 93 (2021) 102059

Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: http://www.elsevier.com/locate/jairtraman

An empirical investigation of European airline business models: Classification and hybridisation

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ARTICLE INFO

Keywords:
Airline business models
LCCs
FSCs
Hybrid airlines
Clustering
k-modes

ABSTRACT

Airline business models are evolving and what was once a clear distinction between low-cost carriers (LCCs) and full-service carriers (FSCs) is now less apparent. LCCs and FSCs are merging into new hybrid carrier business models, a convergence accomplished in different ways by various airlines. This paper aims to establish how many types of business models exist and to examine the defining characteristics of the various levels of hybridisation. This is an empirical study based on a sample of 49 European airlines. Data are collected in a categorical format, where appropriate, or transformed into categorical variables if numerical. The methodology employed for analysis is the well-established *k*-modes technique. The clustering process indicates that there are four observable airline categories: FSCs, LCCs, and two hybrid types in between.

1. Introduction

The impact of the COVID-19 pandemic on the global airline industry surpassed any previous disruptive events, such as the 9/11 terrorist attacks, the Severe Acute Respiratory Syndrome in 2003 and the 2008 global financial crisis (Gudmundsson et al., 2021). Most airlines experienced an unprecedented drop in demand due to lockdown measures, borders closing, quarantine restrictions and airports closure. Some financially distressed airlines ceased operations, while others were pushed into administration or partial government ownership (Bauer et al., 2020). While recovery is in sight, with recovery paths on average expected to take 2.4 years from 2020 (Gudmundsson et al., 2021), most airlines are having to rethink their operations and financing and, in some cases, even the overall business model to avoid bankruptcies and secure survival. Albers and Rundshagen (2020) observe that strategic priorities and decision-making of airlines will change significantly, which will impact the business models, particularly given the increasing role of governments following the state bailouts of certain carriers.

While the pandemic appears to have accelerated change, the airline industry was already experiencing transformation when COVID-19 arrived. Airlines were going through consolidation processes and considerable internal transformations. The industry was seeing signs of disruption e.g., by the long-haul low-cost airlines (Albers et al., 2020) and the re-emergence of ultra long-haul operations (Bauer et al., 2020). This paper is looking at the airline industry amid transformation, as it was just prior to the pandemic. The aspect of change covered in this paper is the hybridisation of airlines and the convergence of business models.

Airlines have a diversity of business models and do not act as a monolithic group. Each airline has a unique combination of business characteristics that helps to differentiate it from its competitors. However, airlines are not entirely unique and share overlapping characteristics that allow us to classify them into larger groups, usually centred around the concepts of low-cost carrier (LCC) and full-service carrier (FSC). Initially, the established national carriers exemplified the FSC model. The deregulation process, which started in the US but expanded globally, encouraged the launch of new airlines. Among the new entrants were several airlines pursuing the LCC model and competing directly with the legacy carriers (Doganis, 2010). The difference between these two business models is straightforward.

Traditionally, LCCs operated point-to-point network models, and the uniformity of the fleet has often been highlighted as one of their critical cost-saving tools (Mason and Morrison, 2008). Key drivers of the economics of LCCs are younger fleets, denser seating capacity, higher aircraft utilisation and greater labour productivity (Doganis, 2010). Their pricing strategies focus on unbundled fares, with ancillary services available for additional fees (Fageda et al., 2015). LCCs concentrate on selling tickets through direct sales on their websites and rarely collaborate with other airlines through alliances or codesharing (Iatrou and Oretti, 2007).

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https://doi.org/10.1016/j.jairtraman.2021.102059
Received 25 February 2020; Received in revised form 9 March 2021; Accepted 9 March 2021
Available online 21 March 2021
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Airlines in the FSC spectrum traditionally operate hub-and-spoke network models (Doganis, 2010), with high-frequency routes (Wojahn, 2002), and fly both short- and long-haul routes with diverse fleets (Iatrou and Oretti, 2007). FSC pricing strategies are complex and often involve bundled fares and a wide range of services, such as complimentary meals on board (Fageda et al., 2015). They usually offer frequent flyer programs (Tomová and Ramajová, 2014). For FSCs, an extensive network is an important competitive tool, achieved via codesharing with many partners and global alliances (Burghouwt et al., 2015). The offering of corporate discounts is another FSC feature (Pachon et al., 2007).

However, as observed in Mason et al. (2013), a dominant characteristic of the commercial air travel industry is its dynamic nature. Business models change over time in order to adapt to changing markets. Some carriers evolve by embracing both FSC and LCC characteristics, and a new, hybrid type has emerged, alongside the already established LCC and FSC business models.

As a result of these developments, airlines at the opposite ends of the business model spectrum are becoming increasingly similar. LCCs are targeting business travellers, flying longer routes, or subscribing to global distribution systems. At the same time, FSCs are pursuing LCC-like strategies such as cabin densification and fleet standardisation. This behaviour suggests that a shift from conventional LCC and FSC models to hybrid models is taking place. The literature is not entirely clear on what constitutes a hybrid model. In broad terms, we have certain expectations about the characteristics of the LCC and FSC models, but the middle ground of the hybrid model is still opaque (Klophaus et al., 2012).

The European airline market is crowded, and it is characterised by low concentration and high competition (Corbo, 2017). There are many airlines operating in Europe, and it is not easy to distinguish their business models between LCC and the hybrid model, or FSC and the hybrid model. Certain airlines are routinely recognised as LCCs (e.g. Ryanair) or as FSCs (e.g. Air France). While Aer Lingus (O'Connell and Connolly, 2017; Renehan and Efthymiou, 2020) and the now-defunct Air Berlin (Corbo, 2017) are, for example, often recognised as hybrid carriers, for most airlines, the classification is not immediately apparent.

There is plenty of evidence from the scholarly research (Mason et al., 2013; Daft and Albers, 2015; Jean and Lohmann, 2016) to suggest that the aviation industry has been experiencing a trend to convergence in the business model that leads more airlines towards a commoditised middle ground. According to Porter's theory (Porter, 1985), airlines at the traditional extremes of the business model concept, which follow either a differentiation or a cost leadership strategy, are more likely to achieve superior returns. At the same time, hybrid types in the middle are at risk of diminished profitability.

The classification of airlines can reveal where an airline is positioned on the business model spectrum. The managers who share Porter's view and whose airlines are in the mainstream middle may benefit from the awareness of "new challenges that might be caused by the growing similarity of airlines" (Daft and Albers, 2013). As a result of this awareness, the airline executives may feel they need to decide if the carriers' competencies should be re-oriented towards differentiation or low cost, as it is "extremely difficult to integrate both elements successfully – being 'stuck in the middle' positions the carrier towards mediocracy and structural weakness" (Lohmann and Spasojevic, 2018).

There is also an alternative view that the positive relationship between strategic purity and profitability may differ by industry. Given the growing move towards the middle of the business model spectrum, it is plausible that the aviation industry is one of the sectors in which hybrid strategies, under the right circumstances, may be successful. It is argued that a hybrid model may require management to remain vigilant to maintain the delicate balance between competitive strategies (Thornhill and White, 2007).

Besides the profitability aspect, which can make airline executives reassess their company's programs and services, this research can be helpful from a practitioner's standpoint, for example, when parties with a commercial or regulatory interest in the industry seek to identify suitable peer groups or to understand the positioning of an individual airline against the spectrum of all airlines.

In this study, we explore the classification of business models in order to extract information not only on the extremities of the business model spectrum (LCC and FSC) but also on the somewhat hazy middle ground of the hybrid model. We hypothesise that there is an unknown number of business models, of which at least three are widely accepted: true FSCs, true LCCs, and hybrid, with a mixture of FSC and LCC features. The first goal of this paper is to estimate the number of business models; the grouping between subtypes of business models is based entirely on a quantitative analysis of data, and the focus is on European airlines that fly scheduled flights. The second goal is to identify the grouping characteristics of the business models of airlines and to understand which features consolidate and nuance the different types of models.

The approach proposed in this paper and the results of the analysis will contribute to the ongoing conversation of both academics and practitioners on the topic of airline business models. The extant literature has already identified changes to these models, with convergence from the extremities of the business model range towards a more central position. We contribute by taking stock of the current positioning of a considerable number of airlines, thus obtaining a more nuanced image of their business models and where convergence has driven them.

2. Airline business models

The topic of airline business models and the differences between them has been widely researched, but only a few studies have approached the comparison quantitatively. As noted by Mason and Morrison (2008), there is a lack of a "consistent and standardised approach to analysing airline business models". Today this observation remains as relevant as ever.

The first framework for quantifying the distinctions between airline business models was the work of Mason and Morrison (2008). The authors used a product and organisational architecture (POA) model to analyse the differences between six European LCCs (easyJet, Ryanair, Norwegian, FlyBe, SkyEurope, and Air Berlin). The classification is based on 37 operational and managerial variables, grouped into ten indices created by benchmarking airlines against each other using "best in class" performance. Based on the combination of indices, the paper concludes that there are substantial differences between the six airlines considered in the study, even if they were all previously classified as LCCs. The authors observe that constrictions (the study was conducted in two years, 2005–2006) imposed limitations on their conclusions about the evolvement of the POA of airlines over time and repeat the analysis in Mason et al. (2013), using the same structure of indices and the same six airlines. Revisiting the analysis while covering a more extended period of six years (2005–2010), they conclude that there are at least two discernible types of LCCs: the "truly low cost" and the "full-service airline competitor". The truly low-cost type has deviated very little from the original strategy between 2005 and 2010, while the full-service airline competitor has shown a convergence towards the FSC model of legacy competitors.

Lohmann and Koo (2013) also use the index-based approach described in Mason and Morrison (2008) in their study. They consider nine US airlines, which are then ranked to create a spectrum of different business models. The lists of variables and indices are derived from Mason and Morrison (2008) and based on operational data from the 2008–2009 period. The business model spectrum is re-examined by Jean and Lohmann (2016) for the 2011–2013 period; they conclude that US airlines which merged moved closer to the FSC spectrum, while those which did not merge moved closer to the LCC spectrum post-2009.

Moir and Lohmann (2018) revisit the POA model. Their variables are grouped into seven indices representing measures of revenue, connectivity, convenience, comfort, unit cost, aircraft, and labour, over the 2011–2013 period. Their approach shows that competitive heterogeneity exists among US airlines and that hybrid business models can achieve both cost leadership and success in their differentiation strategy. The authors' conclusion is a departure from the competitive advantage theory described in Porter (1985), which indicates that companies can compete on cost or differentiation, but not on both.

Daft and Albers (2013) introduce a new framework to assess airline business models and their convergences over time. The layout of their framework consists of three components (corporate core logic, configuration of the value chain activities and assets). The framework is illustrated in practice by five German airlines (Lufthansa, Germanwings, Air Berlin, Condor, and Germania), and the business model convergence is assessed between 2003 and 2010. They find that by 2010, the non-FSC airlines in the sample had started to adopt certain practices which, in 2003, had been used only by the FSC Lufthansa. Lufthansa remained fundamentally unchanged.

Building further on the framework in their earlier (2013) study, Daft and Albers (2015) conduct a longitudinal study to compare the positioning of 26 European airline business models across four points in time: 2004, 2007, 2010 and 2012. The results present a picture of business models changing from their original positions in 2004 and converging towards a middle ground represented, by 2012, by less-differentiated business models. Their study shows a reduction in the differentiation of airline business models across all the framework components. Moreover, the reduction in differentiation is consistent across all three periods, suggesting a real impact resulting from the strategic experiments by airline management, rather than a random effect.

The indices approach taken by several authors is useful in defining the cost and product data structure but demanding in terms of data collection, especially with regard to the availability of cost and revenue information. It has, therefore, been applied mostly to small numbers of airlines. The most extensive study to date, in terms of the number of airlines, is that of Daft and Albers (2015). In contrast, our analysis covers almost twice as many airlines as their 2015 study and is the most exhaustive coverage available of airlines in a single geographical area. The airlines included in our study operate a fleet representing 80% of the total European fleet size (excluding Russia and Turkey).

Previous studies have already established the temporal element of convergence, and there is evidence that airline business models have changed over time. In view of the existing research, we believe that the next pivotal undertaking is to take stock of the current status of airlines in order to investigate the effects of convergence and the resulting nuances in the airline business models. We research the business characteristics across an exhaustive number of airlines and record data as being available at a point in time, rather than monitoring it across an extended period. We restrict the study to European airlines, as they share some commonality in the legal framework, customer travel behaviour and, of course, geography. Also, the many European airlines in operation allow us access to a large sample size.

Our approach has similarities with that adopted by Klophaus et al. (2012), who examine the blend of low-cost characteristics between 20 of the largest European LCCs and, as a control group, four major European FSCs. Klophaus et al. (2012) assess airlines based on whether or not they have conventional LCC characteristics. In their approach, they classify airlines by creating an LCC index that counts how many of the variables meet the LCC criteria. The LCC characteristics are counted, summed, and ranked. The airlines ranked towards the top are nearer to the typical LCC model, as they score highest for fulfilled LCC criteria. Conversely, the airlines ranked towards the bottom are nearer to the FSC standard model, as they have the lowest scores for LCC characteristics. Their study concludes that most European LCCs adopt hybrid features and that carriers either have dominating FSC or LCC characteristics. In contrast with the study of Klophaus et al. (2012), ours does not merely count the LCC characteristics. Rather, it uses a classification algorithm that clusters similar airlines together, thus not only obtaining a ranking of the clusters by the total number of LCC features, but also a grouping together of comparable airlines.

3. Data and methodology

3.1. Data

Our data consists of a series of categorical variables that represent conscious business decisions such as network configuration, pricing policy, membership of international alliances, and lease versus own decisions in aircraft procurement. Most of the information is in the public domain and was collected in 2019.

The study uses a selection of 20 variables that are extracted either from the websites or the annual reports of the airlines, or from subscription-based platforms. We believe this type of data is easily replicable and could be regularly reviewed in the future. This section presents a list of the 20 variables accompanied by a description of specific data selection and transformation details. A series of points outlining these variables are included in Appendix 1.

Appendix 2 contains the list of variables, stating their name, a short description of how they are derived or measured, their original scale (continuous interval, categorical, percentage), the median, if they are numeric or the number of counts if they are categorical, and how they are coded. If the variable is categorical from the start, its coding is "0" if the answer to the statement is "No" and "1" for "Yes". If the variable is numerical, then its values are mapped into "0" or "1" depending on the position relative to the median.

As in any empirical study, particular consideration was given to the sample composition. Our aim is to include all major European commercial airlines, which brings with it the challenge of the treatment of airlines-within-airlines (AWA). These are subsidiary carriers designed to complement the parent services and to follow a more focused business model than the parent airlines. The degree of horizontal integration may vary; the two airlines may be linked by agreements like partnerships and alliances or independent except for equity interest (Lindstädt and Fauser, 2004). It has been argued that the parent airline may exert prohibitive control over the AWA entity (Pearson and Merkert, 2014). Ideally, regardless of "hidden scale economies and cross-subsidization", the two airlines should operate as independent and separate brands (Graham and Vowels, 2006). With limited visibility on the level of control exercised by the parent entity, the AWA in the sample are treated as the stand-alone brands they are supposed to be. For example, Lufthansa and Eurowings, Iberia and Iberia Express, and Air France, KLM and Transavia are considered as separate entities in the paper.

3.2. The k-modes method

We propose the *k*-modes clustering technique instead of the ranking approach prevalent in the literature. Clustering creates homogenous groups of airlines by allocating together the airlines that share many characteristics. The *k*-modes method developed by Huang (1998) is commonly used in clustering categorical data. The more commonly used *k*-means method, from the same family of clustering techniques as the *k*-modes, has already been used for clustering data in the aviation industry in previous studies, but in a different context. The *k*-means approach was used to classify the profiles of the LCC travellers and their preference for various flight characteristics (Martinez-Garcia and Royo-Vela, 2010), airport typology (Madas and Zografos, 2008; Adikariwattage et al., 2012) or the relationship between air traffic volumes and macroeconomic factors (Chen et al., 2020). However, to the best of the authors' knowledge, the present study is the first to use *k*-modes for clustering airline business models.

The data set covers $n = 49$ airlines. Each airline can be thought of as an object $X_i = [x_{i1}, x_{i2}, \dots x_{im}]$ with $m = 20$ components, one for each of the 20 measured variables, and $i \in [1, n]$. The variables that are perceived to be more characteristic of an LCC airline are coded as 0, while those that have more FSC attributes are coded as 1:

$$x_{il} = \begin{cases} 0 \text{ if variable } l \text{ is an LCC characteristic for airline } i \\ 1 \text{ if variable } l \text{ is an FSC characteristic for airline } i \end{cases}$$

We can say that two airlines, X_i and X_j, have identical attributes if for any $i, j \in [1, n]$ $x_{il} = x_{jl}$ for $l \in [1, m]$, and are dissimilar if there is at least one variable $l \in [1, m]$, such that $x_{il} \neq x_{jl}$. We measure the dissimilarity between two airlines as the sum of all discrepancies across each of the $l \in [1, m]$ variables:

$$d(X_i, X_j) = \sum_{l=1}^{m} \delta(x_{il}, x_{jl}) \text{ where } \delta(x_{il}, x_{jl}) = \begin{cases} 0 \text{ if } x_{il} = x_{jl} \\ 1 \text{ if } x_{il} \neq x_{jl} \end{cases}$$

The aim is to cluster the objects (airlines) by the similarity of the sequence of “0” s and “1” s. The *k*-modes analysis is done in *R* (R Core Team, 2019) using the *kmodes* function in the *klaR* package by Weihs et al. (2005). The algorithm requires prior knowledge of *k*, the number of clusters.

The true value of *k* is unknown to us but can be estimated using one of the many analytical techniques available in the literature. There is no single method superior to all the others. Most approaches repeat the clustering algorithm for $k = 1, 2, 3, \ldots$, and select the best resulting partition according to a criterion, which optimises an objective function of the data. In our case, we combine two metrics, one to minimise the within-cluster dissimilarity and the other to maximise the between-clusters dissimilarity. In this way, we aspire to choose a *k* value for which the clusters are homogenous internally and heterogenous externally. In theory, *k* can be any number between 1 and 49; in reality, we are interested in partitioning the data in at least $k = 3$ clusters, as common knowledge already supports the existence of three airline business models: the LCC, the FSC, and the hybrid.

One of the main outputs of the *kmodes* function consists of *k* final modes, one for each cluster; all modes are a sequence of “0” s and “1” s, similar to the input data. Formally, a mode, similar to an airline X_i, can be described as an object with $m = 20$ components $Mode_p = [\hat{x}_{p1}, \hat{x}_{p2}, \ldots \hat{x}_{pm}]$ where

$$\hat{x}_{pl} = \begin{cases} 0 \text{ if } \max\left(\sum_{i_p=1}^{n_p} x_{i_p l}, n_p - \sum_{i_p=1}^{n_p} x_{i_p l}\right) = n_p - \sum_{i_p=1}^{n_p} x_{i_p l} \\ 1 \text{ if } \max\left(\sum_{i_p=1}^{n_p} x_{i_p l}, n_p - \sum_{i_p=1}^{n_p} x_{i_p l}\right) = \sum_{i_p=1}^{n_p} x_{i_p l} \end{cases}$$

for any known $k, p \in [1, k], l \in [1, m]$, where n_p is the size of cluster *p* and $i_p \in [1, n_p]$ is the index of an airline in cluster *p*. Essentially, $\hat{x}_{pl}$ is “0” if the majority of components $x_{i_p l}$ in cluster *p* are “0” s, and “1” if the majority of $x_{i_p l}$ in cluster *p* are “1” s.

The algorithm uses modes to calculate the most frequent categorical attributes of a cluster and to represent the centres of the clusters. In the initial step of the algorithm, *k* airlines are randomly assigned to the *k* clusters. The rest of the airlines are assigned to the clusters by minimising D_p, the within-cluster differences, that is, minimising the sum of mismatches between airlines and the cluster modes.

$$D_p = \sum_{i_p=1}^{n_p} d(X_{i_p}, Mode_p)$$

The final clusters have characteristics dictated by the most common features of their components. This means that the cluster characteristics may or may not match an actual data point, that is, an airline. Each cluster corresponds to a business model and is likely that it does not describe an existing airline.

3.3. Simulation study

The initial random allocation may impact the classification obtained at the end of the algorithm, and therefore, the final clustering may vary. Some classifications are better than others, which is why we conduct a simulation study. We explore the space of solutions by generating a wide range of initial random allocations and investigating the resulting cluster patterns in search of the best solution. The frequency distribution of the resulting partitions frequency is illustrated in Fig. 1 for $k = 2, 3, \ldots 7$. The case of $k = 1$ is skipped as all simulations lead to the same partition, which makes the result redundant.

For each $k = 1, 2, 3 \ldots$, we generate 10,000 data partitions from which we chose the partition generated most often. The clusters that form this partition represent our solution. We extract one such partition for each *k* and then select, as the number of clusters, the *k* that provides the optimal solution. We define as an optimal solution a cluster for which W, the sum across all clusters of the within-cluster distances, is minimum, where W is defined as

$$W = \sum_{p=1}^{k} D_p$$

The smaller the W, the more similar the elements inside clusters. This metric alone does not reveal the extent to which the clusters are dissimilar from one another. Another desirable quality of an optimal solution is to have a high degree of separation between clusters. We measure the distance between clusters as the sum of mismatches between the modes of each pair of clusters:

$$B = \sum_{i=1, j>i}^{k} d(Mode_i, Mode_j)$$

The *k* value for which a partition minimises W and maximises B is the optimal number of clusters. We can find the optimal number of clusters by using an index that combines both the within-clusters and the between-clusters distance, such as $H = \log\left(\frac{B}{W}\right)$ proposed by Hartigan (1975). The index values are plotted against the number of clusters in the elbow plot, in the left panel of Fig. 2. As there is no apparent change in the curvature of the plot, we chose to objectively investigate the elbow location using the approach described in Dimitriadou et al. (2002). For each *k*, we derive the differences to the right of *k* as H_{k+1}-H_k and the left of *k* as H_k-H_{k-1}. The difference between the right and left differences, also referenced as the “second differences”, calculates how the elbow curve grows at *k* relative to its neighbours. The *k* value for which the second differences index reaches its minimum is the “elbow” value and the optimal number of clusters. The H index, the differences to the right and the left for index H, and the second differences are displayed in Appendix 3. The second differences index reaches its minimum for $k = 4$, and we conclude that four is the optimal number of clusters in the data. Four clusters in the data are equivalent to identifying four airline business models. This is an interesting result as it suggests that, in addition to LCC and FSC groups, there are two levels of the hybrid model. For the rest of the paper, we refer to the two business models identified along with the LCC and FSC, as Hybrid 1 and Hybrid 2. In the following section, we describe the results of dividing the 49 airlines into the four clusters and the overall features of each cluster.

4. Results

This section outlines the main findings of the *k*-modes output based on the optimisation of the H index which leads to the conclusion the optimal number of clusters is $k = 4$ and on the following simulation study which, for $k = 4$, identified one particular partition as the most frequent one (794 out of 10,000 simulations). Fig. 3 summarises the results of the *k*-modes method by illustrating the modes of the resulting clusters. The modes are dichotomous variables, which, in common with the data from which they were calculated, take values of 0 or 1. A value of 0 illustrates an LCC characteristic, and a value of 1 represents an FSC

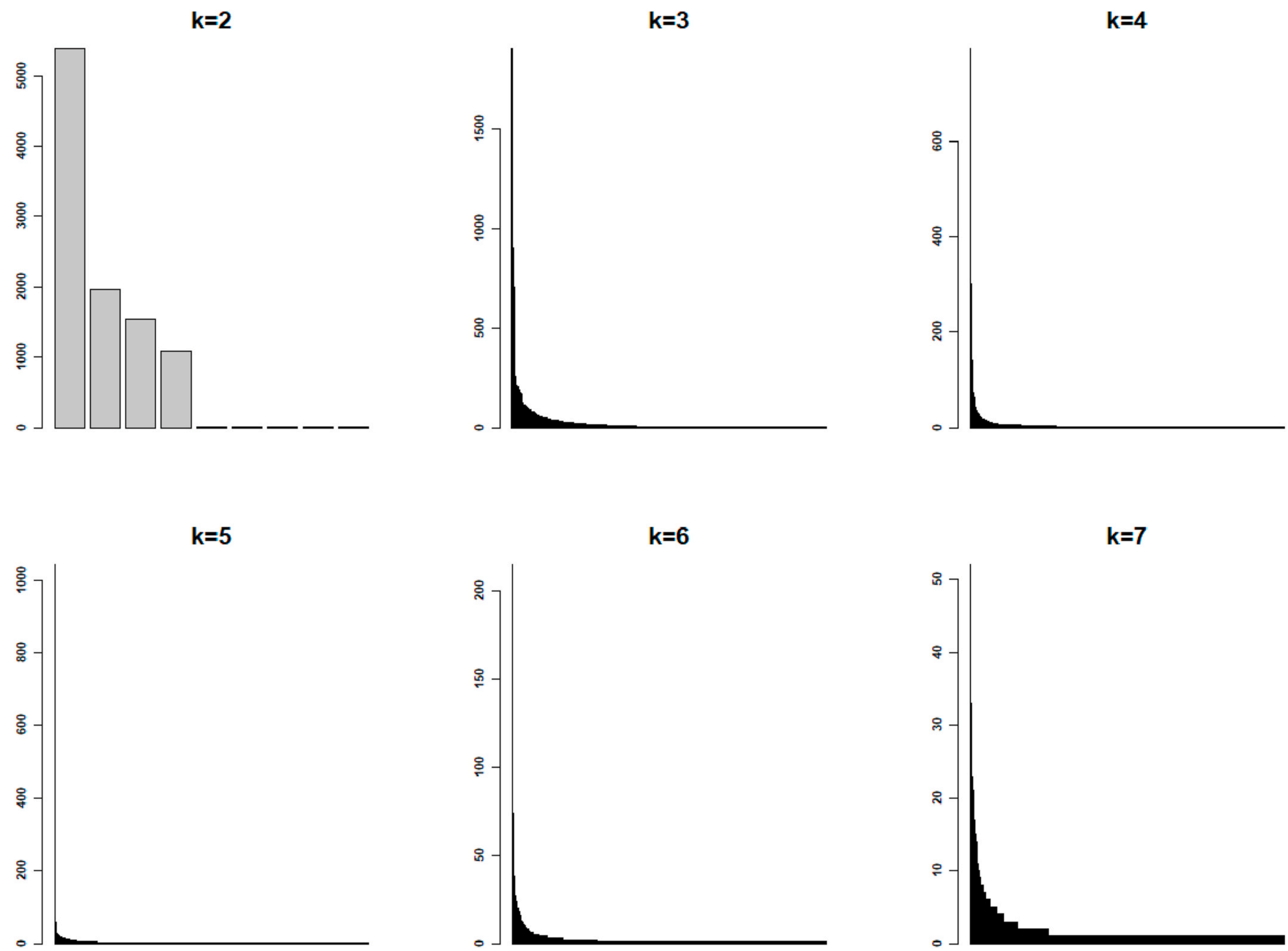

Fig. 1. Results of the simulation study: the frequency of each unique partition generated for $k = 2, 3 \ldots 7$. In each case, one partition appears to dominate the space of solutions.

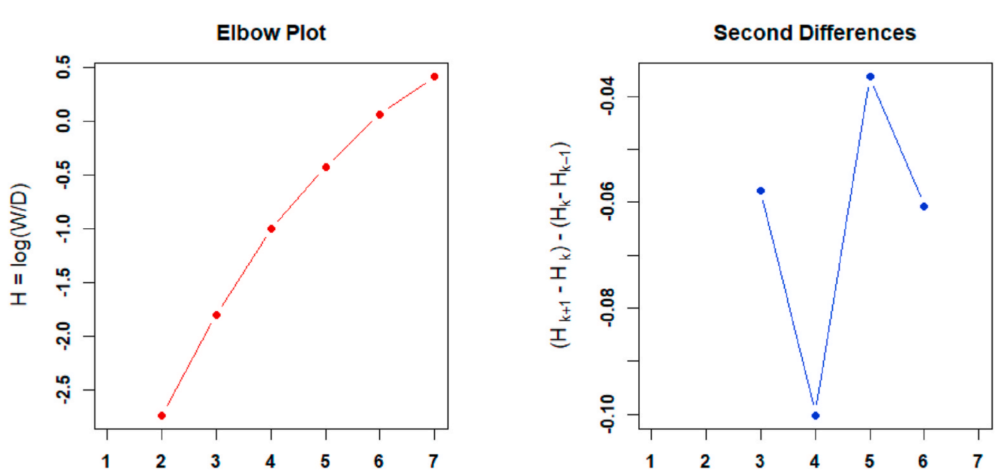

Fig. 2. The elbow plot in the left panel and the index optimisation in the right panel.

characteristic. At this stage, it is still understood that the LCC and FSC attributes in the modes are labels of what we perceive *a priori* as having LCC and FSC characteristics. We interpret the general features of the four clusters by observing the variables for which they are best represented by LCC (0) or FSC (1) values. Two variables ("Bag" and "Unions") do not differentiate between clusters, and score as an FSC feature even for the LCC model category. All the other variables contribute to differentiating between the four clusters.

4.1. FSC cluster

In theory, pure FSC should be represented by a flat line represented

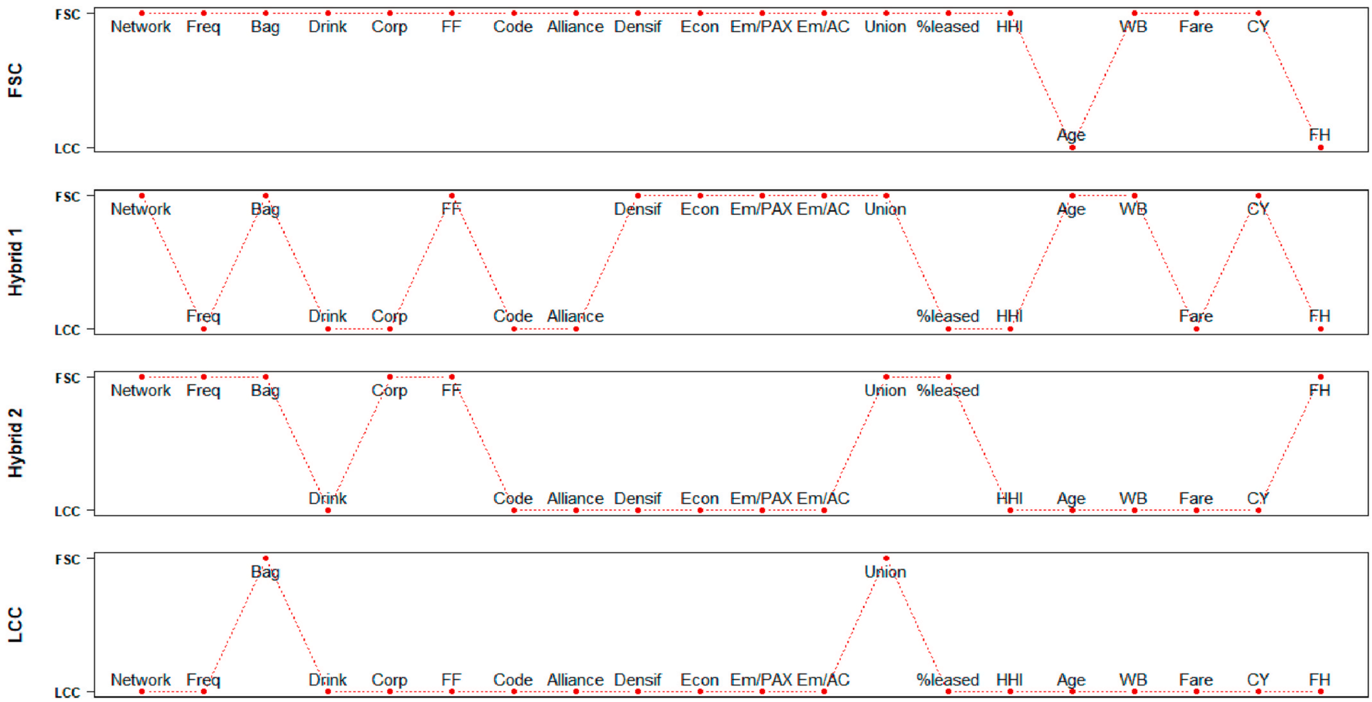

Fig. 3. Summary of the modes for the four business models. Each business model is represented by its mode.

by a sequence of points, all equal to 1. However, our data indicate that the FSC model departed slightly from the theoretical expectation and embraced LCC characteristics related to efficiency. More than 50% of the airlines associated with the FSC model operate young fleets with a high level of utilisation as measured by flight hours. All the other FSC characteristics remain in place; airlines aligned with the FSC model offer complimentary beverages, codeshare with other airlines, participate in international alliances, and offer a wide range of fares. The FSC model is the only business model with these four attributes. While a small number of individual airlines aligned with the other business models may offer complimentary beverages, codeshare with other airlines, participate in international alliances, and have high fare segmentation, these are not dominant features in any of the other business models. The airlines most representative of this type, whose characteristics precisely match the theoretical model, are Lufthansa, KLM, and SWISS.

It is essential to highlight the fact that the departure from the FSC model towards the LCC model is a dominant characteristic of the airlines included in this group but not a comprehensive one. Only 56% of the airlines in the group operate young fleets and only 63% of them operate hight flight hours, in line with the LCC expectations. However, this evidence is sufficient to cast a new light on the shift in the behaviour of the FSC model.

4.2. Hybrid 1 cluster

While Hybrid 1 preserves some of the FSC features, it also borrows some of the LCC characteristics. The gap between the number of FSC and LCC attributes is small; there are 11 attributes, previously perceived as FSC, and nine attributes, previously perceived as LCC. The FSC retained features are the hub-and-spoke network structure, the free carry-on bag allowance, subject to certain limitations, and access to frequent flyer programs. It also preserves lower densification of the aircraft layout and offers non-economy seats. In terms of the labour metrics, it scores highly, with above-median ratios of employees to the number of aircraft and of employees to the number of passengers. These ratios suggest that the size of the workforce is relaxed relative to the size of the fleet and to the number of flying passengers, which may be linked to the efficiency of core airline operations or the presence of ancillary activities that inflate the workforce. Other features are the presence of older aircraft and twin-aisle aircraft in their fleet composition, with a low flight-cycle utilisation. Airlines in this group also recognise trade unions. This variable, along with the aforementioned free carry-on bag allowance variable, are of less interest as they are labelled as FSC characteristics for all groups; thus, they do not contribute to the differentiation between any of the business models.

In a departure from the FSC model, airlines in the Hybrid 1 model operate a low level of flight frequency, do not offer complimentary beverages, do not provide corporate programs, or participate in codesharing or international alliances. As an LCC feature, they also operate homogenised fleets, with a high percentage of leased aircraft that have a corresponding high level of annual utilisation in terms of flight hours. An airline following this hybrid model also offers a reduced number of fare options. None of the nine airlines in the group are a perfect match for the theoretical model. The airlines most representative of the Hybrid 1 type are Sun Express Germany and Air Italy, both being one characteristic apart from the mode of Hybrid 1.

4.3. Hybrid 2 cluster

Hybrid 2 has mostly LCC characteristics, although, as in the case of Hybrid 1, the gap between the number of FSC and LCC attributes is small; eight attributes were previously perceived as FSC, and 12 as LCC. The retained FSC features only partially overlap with the FSC features maintained by Hybrid 1. Hybrid 2 airlines, as with Hybrid 1 airlines, also operate a hub-and-spoke network structure, allow for the free carry-on bag allowance, offer loyalty programs to their frequent flyers, and recognise unions. However, unlike Hybrid 1, they operate younger aircraft and try to appeal to business travellers by implementing corporate discounts and high flight frequency on their routes. They also offer less in on-board comfort metrics by densifying the aircraft layouts and only providing economy seating. Hybrid 2, in contrast with Hybrid 1, provides less in the labour metric, with a low number of employees to PAX and a small number of employees to the size of the fleet. As well as the labour and comfort metrics, other LCC-like features in Hybrid 2 are the lack of complimentary beverages, the limited codesharing and the absence of participation in international alliances, in addition to the operation of a homogenised fleet, with few twin-aisle aircraft, and high utilisation in terms of the number of cycles, but not by flight hours. A high percentage of owned aircraft also characterises this business model. The members of this cluster are mostly Western European regional carriers and carriers from Eastern Europe. This model type is most closely illustrated by Vueling, Binter Canarias, and Air Dolomiti, although none of the 17 airlines in the group perfectly match the theoretical model.

4.4. LCC cluster

As with the FSC, the LCC model appears to have departed to some extent from the hypothesised expectation and has adopted a couple of FSC characteristics. The LCC model's final summary is close to the theoretical expectations apart from two variables, "Bag" and "Union"; excluding these two variables, the signal for the LCC model is a flat line corresponding to "0". The LCC model is the only one in which airlines operate a point-to-point network and have high utilisation of aircraft in terms of flight hours and flight cycles simultaneously; airlines in all the other business models may operate with high flight hours or high flight cycles, but not both. This is also the single model in which airlines do not offer frequent flyer loyalty programs to their customers; airlines following all the other three business models offer frequent flyer programs. The carry-on luggage fee introduced by some LCCs is not a dominant feature. Two-thirds of the airlines classified as LCCs allow carry-on bags free of charge, on condition of specific restrictions such as a maximum weight of 8 kg.

The LCC model is consistent with the rest of the general expectations, such as low flight frequency, the absence of complimentary beverages, lack of corporate programs, codesharing, and involvement with alliances. Also, in keeping with these expectations, the fleets of the airlines labelled as LCCs are highly densified and offer limited non-economy seating; in fact, most of the airlines in this group only offer economy seats. The fleets of airlines in the LCC group have a high share of leased aircraft and have a homogenous composition by aircraft type, consisting of young vintages of single-aisle aircraft, and they are highly utilised.

While none of the nine airlines grouped in the LLC cluster precisely match the model's characteristics, five of them (Ryanair, easyJet, Wizz Air, Transavia, and Volotea) are within two attributes of the overall LCC features. Moreover, Wizz perfectly matches the expectation of a flat line, scoring LCC values for all the variables in the model, replacing Ryanair as the ultimate LCC in Europe.

4.5. Cluster composition

Table 1 lists the airlines as grouped by the classification algorithm. It is worth reiterating that the interest lies in the business model characteristics and not on the airlines themselves. The focus of this study is not to identify which airlines correspond to a specific business model, but to determine what are the general characteristics of each model type.

Table 1
List of airlines, as grouped by the *k*-modes algorithm. The order of listing variables in each group is dictated by their fleet size and is not relevant to the interpretation of results.

No	FSC	Hybrid 1	Hybrid 2	LCC
1	Lufthansa	Condor	Norwegian	Ryanair
2	British Airways	Aer Lingus	Eurowings	easyJet
3	Air France	Icelandair	Vueling Airlines	TUI
4	KLM Royal Dutch Airlines	Air Serbia	Jet2.com	Wizz Air
5	SAS	Edelweiss Air	Flybe	Transavia Airlines
6	Alitalia	SunExpress Germany	Aegean Airlines	Volotea
7	SWISS International Air Lines	Air Italy	Wideroe	Blue Panorama Airlines
8	Iberia	Air Malta	airBaltic	Neos
9	Austrian Airlines		Loganair	
10	TAP Air Portugal		Belavia Belarusian Airlines	
11	LOT Polish Airlines		Iberia Express	
12	Brussels Airlines		Blue Air	
13	Finnair		Binter Canarias	
14	Virgin Atlantic Airways		Luxair	
15	Air Europa		DAT- Danish Air Transport	
16	TAROM		Croatia Airlines	
17			Air Dolomiti	

5. Discussion of the results

This paper aimed to accomplish several goals. First, it identified the unknown number of business models currently present in the European airline space. Estimating the number of clusters/airline business models as $k = 4$, of which two are hybrid models, is an interesting finding and is also perhaps the most significant one. We should emphasize that $k = 4$ is an estimate based on a sample of European airlines, and k may be different in other regions or at other points in time. The paper also established that there is more than one prevailing type of hybrid. Our result is in contrast with the approach introduced by Lohmann and Koo (2013) and Jean and Lohmann (2016). In their view, the business models are on a continuum between the two extremes, the LCC and the FSC. In this way, hybrid airlines are listed sequentially in the middle of the spectrum and not in separate categories. This may be a reasonable approach for the US market, which has a small number of participants, but it is not suitable in Europe, where the market is not consolidated to the same level as in the US. Moreover, if the interest lies in identifying the overall characteristics of a business model, it is less relevant that one specific airline is relatively closer than another towards the extremities of the spectrum when in fact, both define the same business model.

The second goal to be accomplished was the identification of the dominant characteristics of each business model. Several key findings have emerged from the analysis of these characteristics.

First, we noticed that the FSC model had migrated to a slightly more efficient version of itself, embracing LCC characteristics such as high annual utilisation (flight hours) and young fleets. It also distinguishes itself as being the only model in which airlines compete by offering high-fare segmentation and leveraging their membership to international alliances, and their codesharing partnerships. The migration is not a feature common to all airlines classified as FSC, but at least half of the airlines share the LCC characteristics on two variables: fleet age and flight hours utilisation. Therefore, future research should seek to monitor and report on updates to this process. The core elements of the FSC model remain the same. This matches the initial observations made by Daft and Albers (2013), who noticed that among the German airlines, the FSC in the sample (Lufthansa) did not change its business model. The same authors (2015) also confirmed, though on a larger scale, that the business models of European FSCs remained stable and preserved their core elements.

The second key finding was that the LCC business model is substantially in line with its original characteristics and has not moved towards hybridisation. We observe FSC characteristics only in terms of the free carry-on bag allowance and the recognition of labour unions. Since both variables are classified as FSC features in all the clusters, their presence has less impact on our understanding of the LCC model. Our algorithm picks up on a cluster of eight airlines, represented by this LCC model. Its findings are different from those of Daft and Albers (2015), which identified Ryanair as the only LCC left in the sample they used. In the meantime, Wizz Air has entered this group, meeting, in fact, more of the archetypical LCC characteristics than Ryanair. As per Daft and Albers (2015), the majority of airlines stereotyped as LCCs in 2004 had migrated towards hybrid models by 2012. Indeed, our research confirms that most of these low-cost airlines developed into hybrid types. Norwegian, Eurowings and Vueling Airlines are part of the Hybrid 2 group in our study.

The papers by Mason and Morrison (2008) and Mason et al. (2013) demonstrated that two different business models were being pursued within the LCC sector. The "truly low-cost" type, represented in their study by easyJet and Ryanair, was shown to change very little between 2005 and 2010. Their finding holds in our classification, as easyJet and Ryanair continue to be allocated to the LCC category. Mason and Morrison's "full-service airline competitor" type, represented by Air Berlin, FlyBe and Norwegian, has shown a significant migration towards the FSC model. This finding also holds in our classification, which labels FlyBe and Norwegian as hybrid types models.

Our results confirm the classification for airlines that are typically recognised as LCCs (Ryanair, easyJet, Wizz Air) or FSCs (Lufthansa, British Airways, Air France, KLM, SAS). Furthermore, our classification helps identify the middle space of the hybrid types.

The third key finding is that the airline business model hybridisation is highly nuanced. The initial empirical evidence described the hybrid model as a heterogenous blend of LCC and FSC characteristics. We can now say it is made up of two very distinct groups which are as different from one another as from the pure strategies. Based on the papers of Lohmann and Koo (2013) and Jean and Lohmann (2016), there was a presumption of a gradual change from FSC towards LCC via the hypothesised steps of the hybrid model. However, this is not confirmed by our findings. In Klophaus et al. (2012) there is a premise that there are "hybrid carriers with dominating low-cost characteristics" and "hybrid carriers with domination full-service airlines characteristics". Our study and Klophaus et al. (2012) agree on the number of business models being four, and furthermore, our study provides evidence for why $k = 4$. Also, while our approach picks up on substantially clean representative FSC and LCC business models at the extremities, the two other business models are not pegged to these in terms of one hybrid with dominant FSC characteristics and one hybrid with dominant LCC characteristics. We, therefore, refer to these business models as Hybrid 1 and Hybrid 2 and observe that they are as distinct from one another as they are from the LCC and FSC business models.

The Hybrid business models have certain common features, such as hub-and-spoke networks, frequent flyer programs, no codesharing, and no alliance participation. They are also rendered distinct by their choices, such as corporate program offerings, densification of the cabin layout, non-economy seating, leased versus owned fleets, fleet age, and widebodies in the fleet composition. We, therefore, advise that the business model migration should not be thought of as a linear process from the LCC aspect towards FSC, or vice-versa. To illustrate this, we consider two airlines in the hybrid category, Aer Lingus, and Vueling. According to the classification by Klophaus et al. (2012), these airlines score the same total number of LCC characteristics. They are therefore labelled together as "Hybrid carriers with dominating LCC characteristics". In our study, the same two airlines are marked as separate hybrid types, because despite the similarity in the total number of LCC characteristics, the actual features are different. The two airlines are discrepant on nearly 50% of the variables. Hence the algorithm assigned one airline to Hybrid 1 and the other to Hybrid 2.

The grouping of mostly Western European regional carriers and carriers from Eastern Europe in Hybrid 2 may suggest that there are commonalities in status quo business models that lead airlines to pursue hybridisation along certain patterns. The composition of the two hybrid clusters is a mixture of both established airlines and more recent entrants, which reinforces the observation by Teece and Linden (2017) that both types can experiment with business models.

In our study, 51% of all airlines in the sample are classified as having a hybrid business model. The large concentration of airlines in the middle, as Hybrid 1 and Hybrid 2, may suggest there is evidence of a switch in managerial preference from LCC and FSC to hybrid strategies. The shift in emphasis from pure to hybrid strategies has been highlighted by Salavou (2015), who argue that hybrids can are more difficult to "pinpoint and imitate" and therefore may yield "multiple sources of advantage over rival firms". Hybrid strategies have also been described as "more flexible" and better at responding to "changing customer preferences and needs and shifting market landscapes". For the airline industry, it might mean that a hybrid strategy is no longer equivalent to being stuck in the middle. Future research could establish if this is a transient situation or one designed to last.

The choice of this specific dataset was driven partially by a lack of homogenised data reporting by European airlines. Unlike the US market, for which standardised financial and operational reporting exists, the European airlines do not meet this condition. We offset this uncertainty by transforming the data from numerical to categorical. However, it is possible to combine categorical data with numerical values and apply clustering via the *k*-prototype algorithm, as described in Huang (1998). Implementing the *k*-prototype algorithm in *R* packages such as *clustMixType* can cluster mixed data (Szepannek, 2018). Future work could use this approach.

The authors acknowledge certain limitations regarding the approach. A series of attributes, such as cost structures, pricing strategies, and utilisation of secondary airports, were left aside for reasons related to data availability. The authors are aware that certain LCCs are shifting some operations from regional and secondary airports to primary airports, as analysed by Dobruszkes et al. (2017).

As other researchers have indicated, the lack of homogenised reporting (Lohmann and Koo, 2013), poses challenges to building a database for multiple airlines. We also observed this in relation to reporting period mismatches and consolidated reporting by European airline groups. Despite these challenges, it is worth taking an inventory of the status of the industry periodically in order to assess the position and the direction it takes. The study of the temporal component is also reserved for future work. Although not discussed in this paper, since the data collection occurred pre-2020, a repeat study of the European airlines business models in a stabilised period after the COVID-19 crisis will reveal how airlines responded and adapted to a pandemic.

6. Conclusion

This paper presented a way of summarising the spectrum of business models classified according to four clusters (FSC, Hybrid 1, Hybrid 2 and LCC). It used data from 49 European airlines to illustrate the general characteristics of these four types of business models. The results capture a recent snapshot of airline positions on the spectrum between LCC and FSC, highlighting the results of hybridisation and the fact that there is a growing number of airlines now located in the middle. The study concludes that the FSC model partially embraced LCC characteristics related to efficiency, while the LCC model is still aligned with the original no-frill characteristics. An interesting finding discussed in this paper is that the migration process between LCC and FSC is not linear. This paper adds to previous research, which already demonstrated evidence of airline business model convergence (Mason et al., 2013; Daft and Albers, 2015; Jean and Lohmann, 2016). We are in a position to describe the defining characteristics of the convergence space and to identify two classes of hybrids: Hybrid 1 and Hybrid 2. Each is as distinct from the other as it is from LCC and FSC.

As per the Introduction, improved understanding of the landscape of airline business models and their classification is relevant to practitioners in their aim to secure superior performance and change strategies. In 2020, the aviation industry was already seeing airlines modifying their strategic position in response to the COVID-19 pandemic. The compiling of an inventory of the airline business model characteristics just before this industry shock will be useful for future researchers who may wish to analyse the consequences of the pandemic on airlines and measure the unfolding structural changes to business models.

Declaration of competing interest

None. The authors are affiliated with FPG Amentum Limited, an aircraft leasing company. The opinions expressed in the article do not necessarily reflect those of FPG Amentum Limited, its subsidiaries, affiliates, owners, and employees. The authors of this article are solely responsible for its content. The authors do not identify any potential conflict of interest in this research paper.

APPENDIX

Appendix 1: Variable outlines

Variable Name	Details
Network density	We create a proxy variable based on an airline's ratio between the total number of routes and the total number of destinations. If this ratio is high, the "point-to-point" aspect dominates, and the network density is then treated as an LCC characteristic.
Flight frequency	We calculate the flight frequency as the ratio between the total number of flights and the total number of routes (unique city-pairs) operated within a month, in this case, October 2019.
Carry-on bags	We define the variable as an LCC attribute if an airline charges a fee for on-board luggage that weighs less than 8 kg.
Complimentary beverages or snacks	We define the variable as an LCC attribute if all menus on board are chargeable. However, we define the variable as an FSC attribute if an airline offers complimentary beverages and/or snacks on its lowest fare for flights longer than 45 min.
Corporate discounts	For the purpose of this paper, we do not differentiate between the benefits offered by various airline corporate discounts. If the airline has a corporate program in place, then it is coded as FSC.
Frequent flyers	The FSCs were the original developers of frequent flyer programs. LCCs did not immediately adopt the loyalty programs out of concerns about additional cost and complexity. As LCCs developed over time, some gradually started to introduce frequent flyer programs, although in a simplified format. We consider an airline to have a reward program only if the program is free of charge and offers flight/miles rewards.
Codesharing policy	Codesharing agreements are formal commitments whereby airlines cooperate on selected routes. The variable is calculated as the total number of codesharing partners.
Alliance cooperation	Seredyński et al. (2017) estimated that, across the industry, 25% of the total possible codesharing connections between the members of the same alliance are not utilised. Given that the two concepts are interconnected, but are not the same, we include them as separate variables: codesharing and alliance membership.
Cabin densification	Maximisation of seat density is an LCC tool for minimising per passenger production costs. As a proxy, we calculate it as the total number of seats relative to the maximum seating capacity approved for emergency evacuation, across all possible configurations. The total number of installed seats is sourced from Cirium data (Cirium, 2019), and the maximum seating capacity is obtained from EASA, FAA, and Transport Canada Type Certificates. If the densification ratio is above the median, 89%, it is coded as LCC.
Non-economy seating	LCCs typically configure aircraft cabins with economy seats only. In rare situations, LCCs offer non-economy seating. The percentage of non-economy seating is derived from the total number of seats and the total number of economy seats. If the ratio of non-economy seats for an airline is below the median, 3.55%, then the variable is labelled LCC.
Employee/PAX	We apply two measures of employee productivity. The first measure is calculated as the number of employees relative to the number of flying passengers. Because of lean production and avoidance of complexity and non-core activities in the LCC business model, we associate a low number of employees per PAX with LCCs.
Employee/aircraft	The second measure of labour productivity can be expressed as the number of employees relative to the fleet size.
Unions	Employment in the aviation industry has changed since the liberalisation process that took place in the 1990s. The traditional approach, direct employment, moved to alternative forms of employment, such as self-employment and agency work. Consequently, the engagement of trade union engagement with LCCs has, at times, been challenging. Some LCCs, e.g., easyJet, recognise and engage with labour unions, while others do not recognise any form of unionisation, e.g., Wizz Air. It is notable that Ryanair, the largest LCC in Europe, has recognised labour unions since 2017.
Percentage of leased aircraft	Traditionally, FSCs could afford orderbooks with OEMs and owned their fleets directly, while LCCs, with less capital, often chose to lease aircraft. The percentage of aircraft leased via operating leases in the sampled airlines is high; the median is 59%, with 5 out of the 49 airlines leasing 100% of their fleet.
HHI	Fleet uniformity reduces operating and maintenance costs and is recognised as an LCC feature. We measure fleet uniformity using the Herfindahl-Hirschman Index (HHI) on the aircraft type. The index takes values on a scale from 0 to 10,000. The higher values of the index indicate a high level of homogeneity, while the lower values indicate a highly segmented fleet with many aircraft types.
Age of the fleet	Many LCCs opt for young fleets, as high aircraft utilisation, in terms of flight cycles, coupled with short scheduled turnaround times and the network structure (point-to-point operations away from hub airports with strong MRO presence), emphasize the importance of dispatch reliability. On the other hand, where FSCs hold capacity available for peak-hour operations, which are crucial to business travellers, lower capital costs on older aircraft can be key.
Widebodies	FSCs were traditionally the carriers that operated twin-aisle aircraft on their high volume or long-haul routes. The percentage of twin-aisle aircraft in the sampled airlines is low; in fact, 22 out of the 49 airlines operate single-aisle aircraft only.
Fare segmentation	LCCs typically have a no-frills type of service offering, where a charge for any extra service is added to the ticket price (unbundling). Archetypical FSCs packaged services combining ticket, seat allocation, meals, beverages, entertainment, checked baggage, or free changes to bookings. Today, FSCs often offer unbundled, basic economy fares to compete with the LCCs as well as several fare segments in between these two extremes.
Average annual utilisation-cycles	High utilisation is a crucial feature of classic LCC business models and a key driver for reducing per unit production costs. We employ two measures of aircraft utilisation. The first measure is the utilisation calculated as the average annual number of flight cycles, where a cycle is defined as a takeoff and a landing, regardless of the length of the flight. Typical LCCs optimise aircraft utilisation by operating their aircraft with a high number of flight cycles, especially on shorter sectors.
Average annual utilisation-hours	Our second measure of aircraft utilisation is the number of operating hours.

Appendix 2: *List of variables. Mapping the data into categories depends on the nature of the variable: if the measurement is on one side of the median, it is categorised as LCC; and if it is on the other side of the median, it is categorised as FSC. Since most of these variables are skewed, we chose the median as the measure of centrality. The choice of median as the cut-off point between LCC and FSC characteristics is motivated by the desire to offer a common approach to categorisation across all variables. The median, as a threshold between the two categories, is less punitive for the extremities of a continuous variable. We are interested in the middle ground, rather than the extreme characteristics of a variable. The only exception to this rule occurs in the first variable, network density. In this case, the cut-off point between LCC and FSC is the third quartile, which is preferred over the median for identifying multi-hub airlines, which have hub-and-spoke characteristics, rather than point-to-point characteristics*

No	Variable name and Abbreviation	Description	Original scale	Median or Counts	Coding LCC = "0" FSC = "1"
1	Network density ("Network")	#Routes/#Destinations	[0.96, 8.75]	2.04*	If ≥ Q3 then 0, else 1
2	Flight frequency ("Freq")	#Flights/#Routes	[5.62, 178.45]	69.97	If ≤ Median then 0, else 1
3	Carry-on baggage policy ("Bag")	One free carry-on bag of max 8 kg, on short-haul, the cheapest fare	Categorical: Yes/No	45 Yes/4 No	If No then 0, else 1
4	Complimentary beverage or snack ("Drink")	Free food or drink on board of flights longer than 45 min & lowest fare	Categorical: Yes/No	20 Yes/29 No	If No then 0, else 1
5	Corporate programs ("Corp")	Corporate agreements for cheaper fares or more flexible flight terms	Categorical: Yes/No	32 Yes/17 No	If No then 0, else 1
6	Frequent flyer programs ("FF")	Loyalty programs for individual customers. It is restricted to free programs that allow points to accumulate and be redeemed for miles, goods or services.	Categorical: Yes/No	38 Yes/11 No	If No then 0, else 1
7	Codesharing ("Code")	Total number of codesharing partners	[0,38]	8	If ≤ Median, then 0, else 1
8	International Alliance ("Alliance")	Membership of an international airline alliance (SkyTeam, Star Alliance, oneworld)	Categorical: Yes/No	17 Yes/32 No	If No then 0, else 1
9	Cabin densification ("Densif")	Total number of installed seats relative to the maximum seating capacity approved for emergency evacuation, across all possible configurations	[64.31%, 99.99%]	89.65%	If ≥ Median then 0, else 1
10	Non-economy seating ("Econ")	Percentage of non-economy seats out of the total number of seats offered by the airline	[0.00%, 23.95%]	3.55%	If ≤ Median then 0, else 1
11	Employee/PAX ("Em/PAX")	Total number of employees divided by total number of passengers	[0.10,1.26] per 1000 passengers	0.468	If ≤ Median then 0, else 1
12	Employee/number of aircraft ("Em/AC")	Total number of employees divided by the total number of aircraft operated by the airline	[20.58, 156.94]	66.7	If ≤ Median then 0, else 1
13	Unions ("Union")	Airline recognises trade unions and has in place collective agreements	Categorical: Yes/No	45 Yes/4 No	If No then 0, else 1
14	Leased aircraft (%) ("% leased")	Percentage leased aircraft in the operated fleet	[0%, 100%]	58.93%	If ≥ Median then 0, else 1
15	HHI index ("HHI")	Fleet homogeneity as measured by the Herfindahl-Hirschman Index (HHI)	[888, 10,000]	3388	If ≥ Median then 0, else 1
16	Age ("Age")	Average age of the fleet (years)	[4.90, 24.43]	12.02	If ≤ Median then 0, else 1
17	Widebodies ("WB")	Percentage of widebodies relative to the operated fleet	[0.00%, 100%]	10.06%	If ≤ Median then 0, else 1
18	Fare segmentation ("Fare")	Total number of fare categories on sale	[1, 14]	5	If ≤ Median then 0, else 1
19	Average annual flight cycles utilisation ("CY")	Average annual utilisation of the fleet (cycles)	[572.57, 2849.73]	1522.80	If ≥ Median then 0, else 1
20	Average annual flight hours utilisation ("HR")	Average annual utilisation of the fleet (hours)	[1612.36, 4626.23]	2977.68	If ≥ Median then 0, else 1

Appendix 3: *Simulation results. The total number of unique partitions generated increases with k. For k = 7 there are almost as many unique partitions as steps in the simulation, suggesting that we can limit the domain of k at 7, as the results from k = 7 onwards become too fragmented*

	#unique partitions	Most frequent partition	W = total within cluster distances	B = total between cluster distances	H = log(B/W)	$H^r = H_{k+1} - H_k$ (distance to the right)	$H^l = H_k - H_{k-1}$ (distance to the left)	$H'' = H^r - H^l$
$k = 1$	1	10,000	391	0	–	–	–	–
$k = 2$	8	5380	232	15	−1.1894	0.4067	–	–
$k = 3$	378	1902	194	32	−0.7826	0.3490	0.4067	−0.0577
$k = 4$	1951	794	171	63	−0.4337	0.2488	0.3490	−0.1002
$k = 5$	4091	1987	150	98	0.1849	0.2125	0.2488	−0.0363
$k = 6$	6511	215	137	146	0.0276	0.1517	0.2125	−0.0607
$k = 7$	9106	52	131	198	0.1794	–	0.1518	–

Author statement

Ana Magdalina: Conceptualisation, Data curation, Formal analysis, Writing
Martin Bouzaima: Conceptualisation, Writing

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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