Transportation Research Part A 59 (2014) 306–330

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Evaluating air carrier fuel efficiency in the US airline industry

Bo Zou [a,*], Matthew Elke [b], Mark Hansen [c], Nabin Kafle [a]

[a] Department of Civil and Materials Engineering, University of Illinois at Chicago, 842 West Taylor Street, Chicago, IL 60607, USA
[b] Department of Civil and Environmental Engineering, University of California at Berkeley, 107 McLaughlin Hall, Berkeley, CA 94720, USA
[c] Department of Civil and Environmental Engineering, University of California at Berkeley, 114 McLaughlin Hall, Berkeley, CA 94720, USA

ARTICLE INFO

Article history:
Received 26 November 2012
Received in revised form 10 November 2013
Accepted 3 December 2013

Keywords:
Airline fuel efficiency
Mainline airline
Regional carrier
Routing circuity
Frontier model

ABSTRACT

We employ ratio-based, deterministic, and stochastic frontier approaches to investigate fuel efficiency among 15 large jet operators (mainline airlines) in the US. Given the hub-and-spoke routing structure and the consequent affiliation between mainline and regional carriers, we consider not only fuel efficiency of individual mainline airlines, but also the joint efficiency of each mainline and its regional subsidiaries, as well as efficiency in transporting passengers from their origins to destinations. We find that: (1) airline fuel consumption is highly correlated with, and largely explained by, the amount of revenue passenger miles and flight departures it produces; (2) depending on the methodology applied, average airline fuel efficiency for the year 2010 is 9–20% less than that of the most efficient carrier, while the least efficient carriers are 25–42% less efficient than the industry leaders; (3) regional carriers have two opposing effects on fuel efficiency of mainline airlines: higher fuel per revenue passenger mile but improved accessibility provision; (4) the net effect of routing circuity on fuel efficiency is small; (5) potential cost savings from improved efficiency for mainline airlines can reach the magnitude of billion dollars in 2010.

1. Introduction

Airlines are more intent than ever to improve fuel efficiency in their flight operations. With rising fuel prices, airlines are grounding and retiring older, less fuel-efficient aircraft, upgrading their fleets by introducing more fuel efficient models, and adjusting operating practices, for example, single-engine taxi procedures, to reduce fuel consumption and ease financial burden. Concern about anthropogenic climate change has added another layer of potential financial strain for airlines. Aviation induced carbon dioxide (CO_2), one of the most important greenhouse gases, and regulated under the European Emissions Trading Scheme (ETS), is directly tied to the amount of fuel consumed in flight operations. Any monetization of CO_2 further spurs airlines to improve their fuel efficiency by increasing the effective price of fuel. On the demand side, passengers are also becoming more environmentally conscious. Passengers worldwide have voluntarily participated in carbon offsetting programs in their air travel (IATA, 2012). Travel management companies (TMCs), responsible for airline and airfare selection in business travel, are considering incorporating fuel efficiency in their decision making process.[1] A track record of good fuel efficiency, and the consequent lower carbon foot-print, will improve the public image of an airline, which in turn contributes to

* Corresponding author. Tel.: +1 312 996 3404.
E-mail addresses: bzou@uic.edu (B. Zou), matthew.elke@berkeley.edu (M. Elke), mhansen@ce.berkeley.edu (M. Hansen), nkafle89@gmail.com (N. Kafle).

[1] The decision process of TMCs typically involve three boxes: fare, availability (e.g. when and where tickets are available), and intangible parts such as corporate social responsibility (CSR). While the environmental piece remains largely missing in the decision making process, TMCs have the tendency to introduce greenhouse gas emissions as a factor in the intangible parts and place more weight on the third box (through personal communication with the International Council on Clean Transportation).

0965-8564/$ - see front matter
http://dx.doi.org/10.1016/j.tra.2013.12.003

maintaining, or even attracting, new, environmentally conscious demand. As the public's environmental awareness grows, airlines may devote more resources to increasing their fuel efficiency in the future.

The airline efficiency literature is vast and encompasses multiple methodologies, ranging from partial and total factor productivity measures (Caves et al., 1981; Gillen et al., 1985; Windle, 1991; Windle and Dresner, 1992; Oum and Yu, 1995; Oum et al., 2005), to unit cost measurement (Windle, 1991; Oum and Yu, 1998), and to frontier based approaches, under the latter of which the observed production behavior is measured against the "best practice" frontier. The existing frontier literature is dominated by two competing paradigms, which use either mathematical programming or econometric techniques to construct frontiers. The Data Envelopment Analysis (DEA) employs mathematical programming techniques, and does not require an explicit functional form for the airline production technology. Partly because of this, DEA has gained considerable popularity in assessing airline efficiency. Classic inputs in airline DEA models are labor, fuel, materials, and capital, either in physical units (Distexhe and Perelman, 1994; Alam and Sickles, 1998; Coelli et al., 2002; Fare et al., 2007; Michaelides et al., 2009) or monetary values, if information about the physical units for some inputs is not available (Ray, 2008; Lozano and Gutierrez, 2011). Sometimes capacity (e.g. available seat miles) and operation cost of airlines are also considered as substitutes (Schefczyk, 1993; Tofallis, 1997; Scheraga, 2004; Merkert and Hensher, 2011). Typical output variables include revenue passenger miles/kilometers, revenue freight ton miles/kilometers, or combined total revenue ton miles/kilometers. With similar choices for inputs and outputs, the econometrics-based frontier approach specifies explicit production function forms,[2] and allows for statistical inferences about the parameters related to airline production technology (Coelli et al., 1999; Inglada et al., 2006; Michaelides et al., 2009; Assaf, 2009; Sjögren and Söderberg, 2012).

Despite the multitude of internal and external forces that push airlines to pursue greater fuel efficiency and the long history and extensive literature to measure airlines' overall technical efficiency, existing studies dedicated to assessing airline fuel efficiency have been, somewhat surprisingly, scarce. Within the limited body of airline fuel efficiency literature, Miyoshi and Merkert (2010) evaluate carbon and fuel efficiency of fourteen European airlines between 1986 and 2007, with emphasis on the relationship between fuel efficiency and fuel price, distance flown, and load factors. The potential for greater fuel efficiency through the use of larger aircraft and different operational patterns is examined in Morrell (2009). Babikian et al. (2002) compare fuel efficiency of different aircraft types (regional jets, narrow- and wide-body aircraft, and turboprops), and highlight that differences in aircraft-specific fuel efficiency are largely explained by operational differences, such as stage length, fraction of time spent on the ground taxiing and in the air climbing, rather than technology. While all these studies employ ratio based metrics to characterize fuel-related efficiency, a comprehensive examination of the relationship between fuel consumption and production output, in particular by comparing results from using different efficiency measurement methodologies, has not been seen in the literature. On the practical side, with rising fuel price and mounting environmental concerns, having the capability to evaluate airline fuel efficiency is also critical to inform industry stakeholders, policy makers, and the public about industry fuel usage, and help shape future strategies to improve fuel efficiency.

This paper contributes to the literature on assessing airline fuel efficiency. First, we systematically compare a range of different assessment methodologies. We focus on ratio, deterministic and stochastic frontier methods, the latter two using econometric techniques, to measure airline fuel efficiency. We also use the DEA approach in one case. These methods provide different depictions of the relationships between airline fuel consumption, output, and production efficiency. Comparison of results yields useful insights about the differences between these methodologies and how they affect fuel efficiency rankings. Additionally, in applying these methods, we take into account––to our knowledge for the first time—that affiliations between large jet operators and regional carriers must be taken into account when assessing the fuel efficiency of the mainline airlines. We also measure airline fuel efficiency with respect to passenger trips, by using a passenger origin–destination (O–D) based airline output metric as an alternative to the standard passenger–mile metric, which ignores the effect of circuitous routings. In addition to creating a comprehensive assessment of airline efficiency and its sensitivity to assessment methodology, the present study provides a simple and transparent airline fuel efficiency assessment scheme that is generic and can be extended to other airlines around the globe as long as equivalent data are available.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of the organization of the US airline industry. Three methodologies for airline fuel efficiency measurement are presented in Section 3. We apply these methodologies in Section 4 to 15 US large jet operators (which later on are referred to as mainline airlines), and present detailed analysis and comparison of results under different approaches, with and without considering mainline–regional carrier affiliations, and routing circuity. Further discussions on the correlation of different efficiency results and potential cost savings from fuel efficiency improvement are conducted in Section 5. Conclusions are presented in Section 6.

2. Airline industry organization in the US

The US air transportation system is characterized by the coexistence of hub-and-spoke and point-to-point network structures. Large, legacy carriers, such as United, Delta, American, and US Airways, provide air services by relying extensively upon a relatively small number of hub airports. For these airlines, 30–50% of passengers completed their trips by connecting at least once at an intermediate hub airport.[3] The advent of hubbing since industry deregulation in the late 1970s has allowed

[2] It is also possible to use the econometric based frontier approach to estimate airline cost frontiers (see, e.g. Liu and Lynk, 1999; Inglada et al., 2006).

[3] This is based on authors' calculation using the Bureau of Transportation Statistics Airline Origin and Destination Survey data in 2010.