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U.S.–LATIN AMERICA AIRLINE FUEL EFFICIENCY RANKING, 2017–2018

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EXECUTIVE SUMMARY

Public information on airline fuel efficiency remains scarce. The International Council on Clean Transportation (ICCT) has assessed the fuel efficiency of U.S. airlines based on their domestic operations from 2010 to 2018. The ICCT has also analyzed the fuel efficiency of major airlines operating transatlantic and transpacific routes, with the most recent report based on 2017 data. U.S.–Latin America is another key route group; 42% of international flights departing the United States in 2018 were in this market, and it is growing rapidly. For the first time, this paper compares the fuel efficiency of nonstop, passenger flights in this market, based on data for calendar years 2017 and 2018. In order to control for differences in stage lengths, we divided the market into two segments—Mexico, Central America, and the Caribbean (MCC) is one, and South America (SA) is the other.

Figures ES1a and ES1b compare the fuel efficiency of 15 U.S.–MCC carriers and 10 U.S.–SA carriers. These "major" carriers were selected because they have the greatest capacity in terms of available seat-kilometers (ASKs). Passenger-based fuel efficiency was estimated after correcting for cargo carried on passenger flights, referred to as belly freight, which increases the absolute fuel burn of a particular flight but also improves the fuel efficiency per unit of mass carried.

U.S. carrier Frontier and Mexican carrier Volaris tied as the most fuel-efficient airlines on U.S.–MCC operations in 2018, with an average fuel efficiency of 37 passenger-kilometers per liter of fuel (pax-km/L), which is 16% better than the industry average. Interjet ranked as the least fuel-efficient in the U.S.–MCC market, on average burning 32% more fuel per passenger-kilometer than Frontier and Volaris.

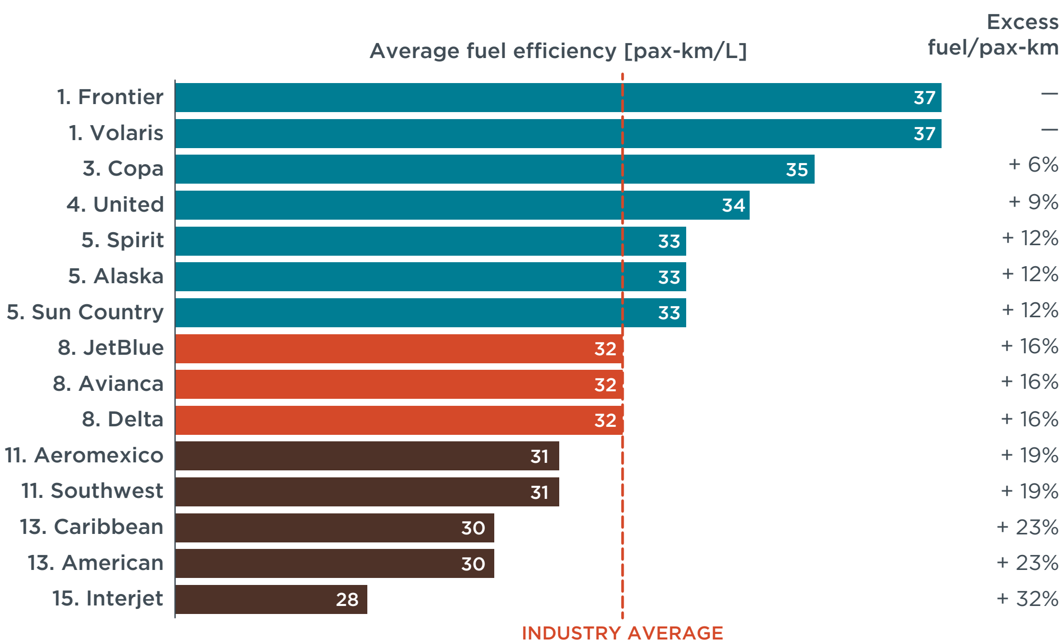

Figure ES1a. Fuel efficiency of 15 major airlines in the U.S.–MCC market, 2018.

The best performing U.S.–SA carrier in terms of fuel efficiency in 2018 was Brazilian airline Azul, with an average of 44 pax-km/L, which is 19% better than the industry average of 37 pax-km/L. Our analysis identified Ecuadorian airline TAME as the least fuel-efficient among U.S.–SA carriers. On average, TAME burned 52% more fuel per passenger-kilometer than Azul.

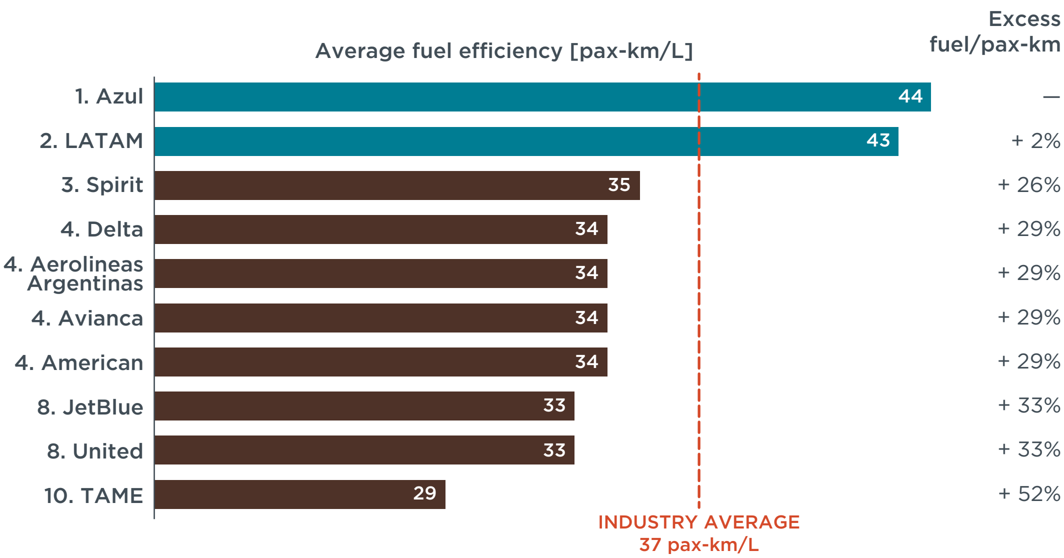

Figure ES1b. Fuel efficiency of 10 major airlines in the U.S.–SA market, 2018.

A variety of operational factors contribute to fuel efficiency, and consumers are not always aware of or informed about them. We analyzed key drivers of the fuel efficiency gap across ranked carriers in order to better understand their relative importance (Figure ES2). Factors investigated include aircraft fuel burn, seating density, passenger load factor, and freight share of total payload. Among these factors, freight share was found to be the most important driver, explaining approximately half of the variation across carriers. This is followed by aircraft fuel burn (19%), seating density (17%), and passenger load factor (15%).

Other findings from this work include:

» The average fuel efficiency of the U.S.–SA market was 3 pax-km/L higher than that of transatlantic market and 6 pax-km/L higher than that of transpacific market, mainly as a result of denser seating configurations and a more fuel-efficient fleet.

» From 2017 to 2018, the average fuel efficiency of the U.S.–MCC market improved by 0.5 pax-km/L, mainly as a result of investments by carriers in newer, narrow-body aircraft.

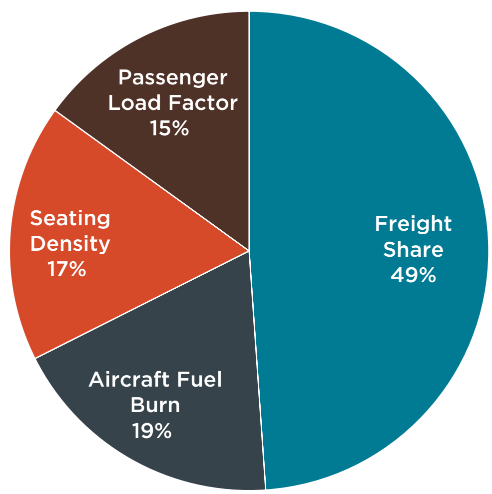

Figure ES2. Key drivers of airline fuel efficiency for the U.S.–Latin America market.

» Major improvers from 2017 to 2018 include Volaris (34 to 37 pax-km/L), Sun Country (31 to 33 pax-km/L), Interjet (26 to 28 pax-km/L), and Azul (42 to 44 pax-km/L). The improvements are linked to a variety of operational changes, specifically new aircraft with lower fuel burn for Volaris, denser seating configurations for Sun Country and Azul, and higher load factors for Interjet.

- Overall demand for U.S.–Latin America flights grew substantially from 2013 to 2018. Total capacity, measured in ASKs, increased by 29% during the 6-year timespan. Additionally, low-cost carriers gradually expanded their share of the U.S.–MCC market from 19% in 2013 to 30% in 2018.

1. INTRODUCTION

Fuel efficiency, as measured by the amount of jet fuel used to move payload over a distance, is important because the more fuel airlines burn, the more carbon dioxide (CO_2) they emit. However, public information on airline fuel efficiency remains scarce. U.S. carriers report quarterly fuel burn and operations by aircraft type and market, whether domestic or international, to the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation (DOT). Fuel burn data is not required from foreign carriers, and similar granular data sets are not published by governments outside of the United States.

Several online carbon calculators, including those from the International Civil Aviation Organization (ICAO), ClimateCare, and individual airlines, can be used to estimate fuel burn and CO_2 emissions over origin-destination pairs for passengers and air freight.[1] However, these calculators do not provide carrier- or flight-specific comparisons, and they are designed mostly to support carbon-offsetting programs, rather than to help consumers choose more fuel-efficient flights.

In 2013, the International Council on Clean Transportation (ICCT) began assessing the fuel efficiency of U.S. airlines with its benchmark study of domestic operations for 2010. Subsequently, there were updates for 2011 through 2018.[2] Most recently, we found that the gap between the most and least fuel-efficient airlines based on U.S. domestic operations was 26% in 2018 (Zheng, Graver, & Rutherford, 2019). This domestic work led the ICCT to compare the fuel efficiency of major airlines by capacity that operated transpacific (between the mainland United States and East Asia and Oceania) and transatlantic (between the mainland United States and Europe) flights. We found the gap between the most and least fuel-efficient airlines was 64% for the transpacific market and 63% for the transatlantic market, in 2016 and 2017, respectively (Graver & Rutherford, 2018a, 2018b). Overall, airlines with more fuel-efficient aircraft, less premium seating, and higher passenger and freight load factors were found to operate more fuel-efficient flights.

Having ranked airline fuel efficiency on transpacific and transatlantic routes, for the first time, this report assesses airline fuel efficiency on nonstop, passenger flights between the United States and Latin America. Of the international departures from the United States in 2018, 42% were in the U.S.–Latin America route group. According to an ICAO forecast, the total revenue passenger kilometers (RPKs) of flights between North America and Latin America will double from 2015 to 2035, and the high growth rate will continue beyond 2035 (ICAO, 2018).

The U.S.–Latin America market differs from the transatlantic and transpacific markets in several ways. In this report, the market is divided into two distinct segments. One segment includes flights between the United States and South America (SA), which have

1 ICAO's carbon emissions calculator can be accessed at https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx. The carbon calculator developed by ClimateCare can be accessed at https://climatecare.org/calculator/. United Airline's carbon offset calculator can be accessed at https://united.conservation.org/.

2 Reports on U.S. domestic airline fuel efficiency rankings include: Zeinali, Rutherford, Kwan, and Kharina, 2013; Kwan, Rutherford, and Zeinali, 2014; Kwan and Rutherford, 2014, 2015; Olmer and Rutherford, 2017; Zheng, Graver, and Rutherford, 2019.

a similar stage length and belly freight load as transpacific and transatlantic flights.[3] The other segment is flights between the United States and Mexico, Central America, and Caribbean (MCC), where the average stage length is much shorter, and little belly freight is transported. This market segmentation is necessary because variation in stage length can affect fuel efficiency for flights under 2,000 km in particular (Graver, Zhang, & Rutherford, 2019).[4]

U.S. legacy carriers make up a substantial part of the transpacific and transatlantic markets, but their dominance is especially pronounced in the U.S.–Latin America market, where they claim about 46% of the U.S.–MCC market and about 54% of the U.S.–SA market. The influence of large U.S. carriers in the two markets is expected to expand through joint ventures (JV) and new partnerships. There are the existing Delta-Aeromexico JV and the planned United-Avianca-Copa JV (CAPA, 2019a). Delta recently shook up the planned American-LATAM JV when it bought a 20% equity stake in LATAM (Rucinski, 2019). Although U.S. low-cost carriers do not compete with foreign low-cost carriers in the transpacific and transatlantic markets, they are active in the U.S.–Latin America market alongside the quickly expanding set of Latin American low-cost carriers. Nevertheless, the market is still dominated by full-service carriers, which our data show provided 70% of the total capacity in 2018.

The rest of this paper is structured as follows. Section 2 explains the methodology used to estimate airline fuel efficiency. Section 3 presents and discusses the average fuel efficiency of the airlines and aircraft included in the study and considers the differences in efficiency among carriers serving key routes. Finally, Section 4 offers conclusions and identifies potential areas for future work.

3 Stage length refers to the average distance flown, measured in statute miles, per aircraft departure. Stage length is calculated by dividing total aircraft miles flown by the number of total aircraft departures performed.

4 The market segmentation ensures a low sensitivity of rounded fuel efficiency (<1 pax-km/L) to airline average stage length within each segment. See Figure 2 for an illustration of the sensitivity of aircraft fuel efficiency to stage length by aircraft type.

2. METHODOLOGY

A previous ICCT study (Graver & Rutherford, 2018a) estimated airline fuel efficiency on nonstop transatlantic routes. Operational data reported to the U.S. DOT's BTS and route data from an international flight schedule database were used to model airline fuel burn.

All airlines operating flights to, from, and within the United States must report operations data to the BTS. The data are made available to the public via the BTS T-100 database. For this study, we purchased T-100 International Segment data from Airline Data Inc., which completes quality assurance and control procedures on the BTS data. Included in T-100 data is information on air carrier, flight origin and destination, flight frequency, distance, aircraft type, available seats, passenger load factor, and freight transported. Separately, fuel burn reported through BTS Form 41 Financial Data was used to validate the fuel burn modeling. Model validation is detailed in Appendix A. This analysis used data for calendar years 2017 and 2018.

2.1 AIRLINE SELECTION

This paper compares the 15 airlines with the greatest capacity, measured in available seat kilometers (ASKs), that provide nonstop flights between the United States and MCC regions, and the 10 airlines with the greatest capacity providing nonstop flights between the United States and South America. The ranked airlines represent 98% of the total capacity in each of the two markets.

Table 1a summarizes key statistics for the 15 airlines analyzed for the U.S.–MCC market, and Table 1b shows those of the 10 airlines analyzed for the U.S.–SA market. The statistics include total number of departures, average stage length, share of ASKs, share of available tonne kilometers (ATKs), and the most prevalent aircraft used by each airline.

Table 1a. Airlines evaluated in the U.S.–MCC market, 2018.

Airline	Departures	Average stage length (km)	Share of ASKs	Share of ATKs	Most prevalent aircraft
Aeromexico	34,954	2,417	7%	8%	Boeing 737-800
Alaska	14,667	2,333	3%	3%	Boeing 737-900ER
American	139,445	1,790	18%	20%	Boeing 737-800
Avianca	12,826	2,807	3%	4%	Airbus A320-200
Caribbean	6,406	2,541	1%	2%	Boeing 737-800
Copa	22,378	3,039	6%	5%	Boeing 737-800
Delta	66,876	2,244	14%	15%	Boeing 737-900ER
Frontier	4,563	2,291	1%	1%	Airbus A321
Interjet	19,420	1,952	4%	3%	Airbus A320-200
JetBlue	63,101	1,924	11%	11%	Airbus A320-200
Southwest	38,425	1,875	5%	5%	Boeing 737-700
Spirit	13,229	1,701	2%	2%	Airbus A321
Sun Country	3,156	2,704	1%	1%	Boeing 737-800
United	87,860	2,259	15%	15%	Boeing 737-800
Volaris	22,826	2,371	6%	6%	Airbus A320neo
Total	**550,480**	**2,152**	**100%**	**100%**	**Boeing 737-800**

Note: Most prevalent aircraft were identified based on number of departures (Airline Data Inc., 2019)

Table 1b. Airlines evaluated in the U.S.–SA market, 2018.

Airline	Departures	Average stage length (km)	Share of ASKs	Share of ATKs	Most prevalent aircraft
Aerolineas Argentinas	2,168	7,561	4%	3%	Airbus A330-200
American	27,524	5,340	30%	30%	Airbus A319
Avianca	14,178	3,307	9%	9%	Airbus A320-200
Azul	2,875	6,000	4%	4%	Airbus A330-200
Delta	7,243	6,605	11%	10%	Boeing 767-300ER
JetBlue	4,619	2,749	2%	1%	Airbus A320-200
LATAM	14,457	6,058	23%	27%	Boeing 767-300ER
Spirit	3,194	2,518	1%	1%	Airbus A320-200
TAME	1,133	3,974	1%	2%	Airbus A330-300
United	10,122	5,979	14%	12%	Boeing 767-300ER
Total	**87,165**	**5,083**	**100%**	**100%**	**Boeing 767-300ER**

Note: Most prevalent aircraft were identified based on number of departures (Airline Data Inc., 2019)

2.2 FUEL BURN MODELING

Similar to the ICCT's previous fuel efficiency rankings (Graver & Rutherford, 2018a, 2018b), aircraft fuel burn was modeled using Piano 5, an aircraft performance and design software (Lissys Ltd., 2017). Piano 5 requires various inputs to model aircraft fuel burn. Table 2 contains a list of the key modeling variables and sources used in this study.

Table 2. Key modeling variables

Type	Variable	Sources
Airline scheduled flights	Route	BTS T-100 International Segments
	Aircraft used	
	Available seats	
	Departures	
	Passenger load factor	
	Freight carriage	
Airline-specific aircraft parameters	Type and count	Ascend Fleets
	Engine	
	Winglets/scimitar	
	Maximum takeoff mass	
	Seats	
Aircraft weights	Operating empty weight	Piano 5
	Passenger weight	Industry standard
	Seat and furnishings weight	ICAO default
Aircraft fuel burn	Engine thrust	Piano 5
	Drag	
	Fuel flow	
Other operational variables	Taxi time	BTS T-100 International Segments, FAA Part 121, Piano 5
	Fuel reserves	
	Flight levels	
	Speed	

The archived Ascend Fleets database was used to assign representative Piano 5 aircraft to each airline by matching aircraft type, use of wingtip device, engine type, seat count, and maximum takeoff mass as closely as possible (FlightAscend Consultancy, 2017). For flight distance, the great circle distance for each route was adjusted upward by 50, 100, or 150 km based on the raw distance, to account for traffic and weather-driven inefficiencies (ICAO, 2017).[5]

International passenger flights carry both passengers and freight, so the fuel burn of individual flights must be apportioned between passengers and freight based on mass. The average payload per flight was estimated using Equation 1 for each airline-aircraft-seat count-distance flight group given the reported number of departures, available seats, passenger load factor, and freight carriage. The industrywide standard mass of 100 kg for a passenger and their luggage was used (ICAO, 2017). The model accounts for different seating configurations on the same aircraft type by adjusting the default number of seats in Piano and assuming 50 kg per seat.

$$payload\ [kg] = \left(\frac{seats}{departures}\right)(load\ factor_{pax})\left(\frac{100\ kg}{pax}\right) + \left(\frac{freight\ [kg]}{departures}\right) \quad (1)$$

Default Piano 5 values for operational parameters such as engine thrust, drag, fuel flow, available flight levels, and speed were used because of the lack of airline- and aircraft-specific data. Cruise speeds were set to allow 99% maximum specific air range. Taxi times were set at 34 minutes, as estimated by T-100 International Segments data for transpacific flights by the three U.S. carriers (Bureau of Transportation Statistics [BTS], U.S. Department of Transportation, 2018). This is equal to the average taxi time used in previous transatlantic and transpacific rankings (Graver & Rutherford, 2018a, 2018b). Fuel reserves were set for a 370 km diversion distance, 10% mission contingency fuel to account for weather, congestion, and other unforeseen events, and 45 minutes at normal cruising fuel consumption, corresponding to U.S. Federal Aviation Administration's *Operations Specification B043* (FAA, 2015).

In order to increase the efficiency of Piano modeling, we interpolated the fuel burn value for each airline-aircraft-seat count-origin-destination group from a payload-distance-fuel burn matrix generated by automated Piano runs. The accuracy of the interpolation has been tested and showed variances within 1% compared to actual Piano runs.

2.3 FUEL EFFICIENCY CALCULATION

The fuel efficiency of each flight was calculated using the method developed for the ICCT's previous transpacific ranking (Graver & Rutherford, 2018a). The average fuel efficiency for each airline, represented by index *a*, was calculated using a bottom-up approach.

After modeling each unique airline-aircraft-seat count-distance-payload flight group, represented by index *i*, the total fuel consumption for the full set of nonstop flights between the United States and Latin America flown by each of the ranked airlines was calculated according to Equation 2.

$$fuel\ [L]_a = \Sigma_i (fuel\ [L]_{a,i})(departures_{a,i}) \quad (2)$$

5 For flights shorter than 550 km, a +50 km correction is applied; for flights between 550 and 5,500 km, a correction of +100 km is applied; for flights longer than 5,500 km, a correction of +150 km is applied.

Aircraft fuel use is proportional to the total payload mass transported. For passenger flights that also carry cargo, or belly freight, payload is calculated as the total mass of passengers and freight per flight. Belly freight, while increasing the absolute burn of a given flight, also improves the fuel efficiency of an airplane per unit of mass moved because the airframe is loaded closer to its maximum payload capability. The ratio of payload-distance to fuel burned for each airline was used as a starting point for the average fuel efficiency metric. This was then converted to the passenger-based metric, passenger-kilometers per liter of fuel (pax-km/L), using the passenger weight factor, as shown in Equation 3.

$$pax \times km/L_a = \frac{\Sigma_i (payload\ [kg]_{a,i})(distance\ [km]_{a,i})}{(fuel\ [L]_a)(100\ kg\ /\ pax)} \tag{3}$$

The modeled fuel efficiencies for the 44 U.S. airline-aircraft pairs were validated using Form 41 fuel burn data, as described in Appendix A.

3. RESULTS

The bottom-up methodology allows for comparison of fuel efficiencies at the airline, aircraft, and route levels. Section 3.1 presents the overall fuel efficiency results for 2018. Section 3.2 then relates the overall results to the aircraft types, and Section 3.3 explains the findings in terms of key drivers of fuel efficiency, including aircraft fuel burn, seating configuration, passenger load factor, and freight carriage. Finally, Sections 3.4 and 3.5 provide context for individual airlines and selected routes. Results for calendar year 2017 are summarized in Appendix B.

3.1 AIRLINE COMPARISONS

The average fuel efficiencies in pax-km/L of the 15 major airlines operating U.S.–MCC routes in 2018 are shown in Figure 1a. The orange dashed line indicates the industry average of 32 pax-km/L. U.S. carrier Frontier and Mexican carrier Volaris both achieved the highest average fuel efficiency of 37 pax-km/L, which is 16% better than the industry average. Interjet operated the least fuel-efficient flights, burning on average 32% more fuel per passenger-kilometer than the two top carriers. This gap is only half of that previously seen in transpacific and transatlantic rankings (Graver & Rutherford, 2018a, 2018b), likely because of smaller variation in belly freight carriage and seating configurations.

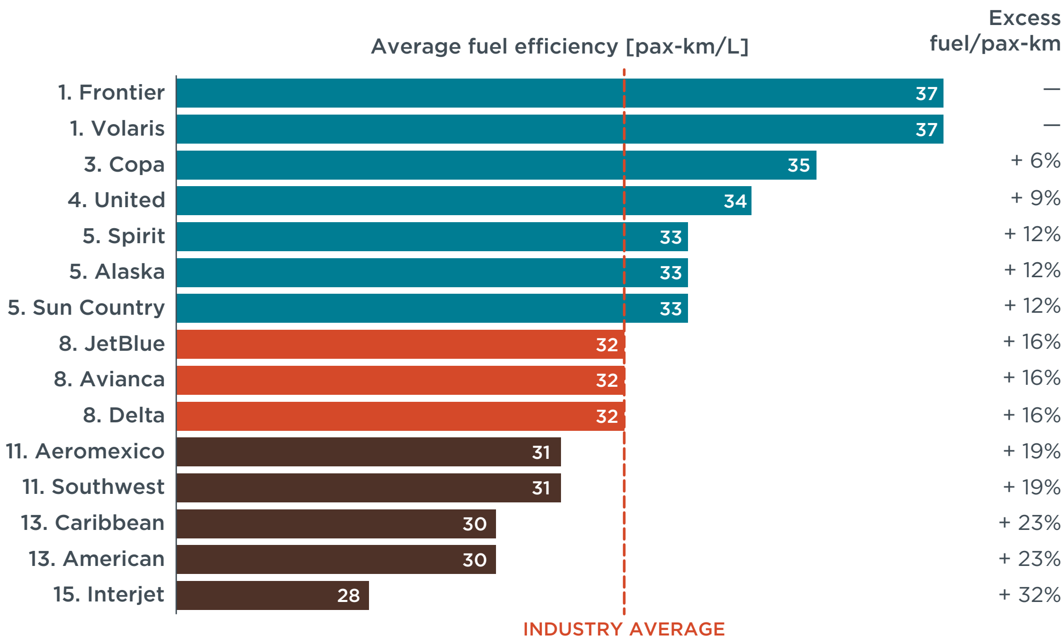

Figure 1a. Fuel efficiency of 15 major airlines in the U.S.–MCC market, 2018.

Figure 1b shows the average fuel efficiencies of 10 major airlines operating U.S.–SA routes in 2018. The orange dashed line indicates the industry average of 37 pax-km/L. Brazilian airline Azul ranked as the most fuel-efficient airline in this market with an average fuel efficiency of 44 pax-km/L, 19% better than the industry average. LATAM closely followed with an average fuel efficiency of 43 pax-km/L. Ecuadorian airline TAME operated the least fuel-efficient flights in this market, burning on average 52% more fuel per passenger-kilometer than Azul. This gap between the most and least efficient carriers is comparable to that previously seen in transpacific and transatlantic rankings

(Graver & Rutherford, 2018a, 2018b). It is worth noting that, if Azul, LATAM, and TAME are not considered, the gap in fuel efficiency among the remaining seven carriers is relatively small.

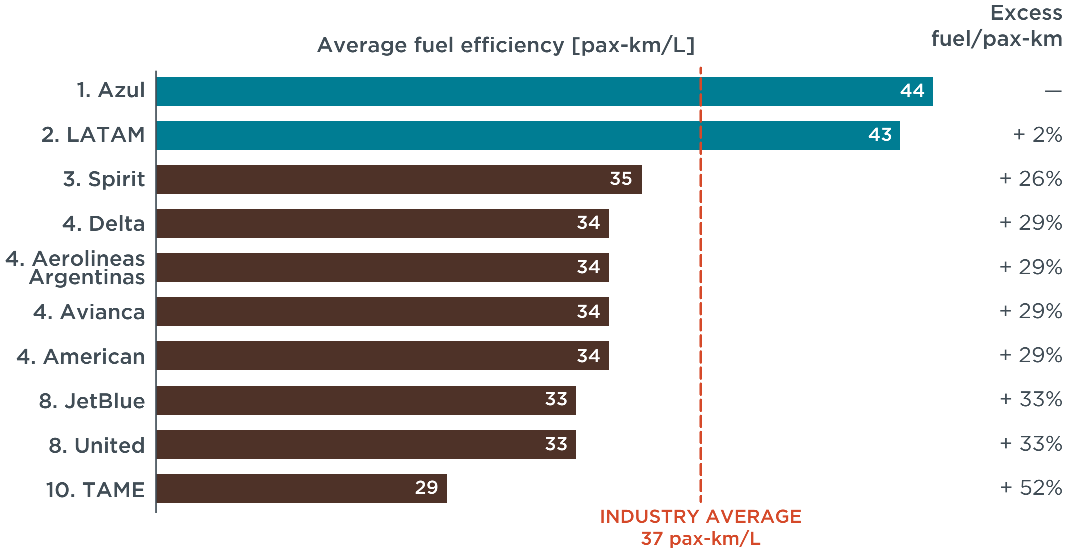

Figure 1b. Fuel efficiency of 10 major airlines in the U.S.–SA market, 2018.

The three largest carriers in the U.S.–MCC market by ASK share are all U.S. legacy carriers, and their fuel efficiencies in 2018 were all near the industry average. American Airlines, with the greatest ASK share of 18%, ranks second to last. Even though the overall fuel efficiency gap is narrow in the U.S.–MCC market, improvements in fuel efficiency by American would significantly reduce fuel use, considering its large market share. The top three carriers in the U.S.–MCC ranking are all smaller carriers, and among them, Copa has the largest ASK share of 6%. The U.S.–SA market, on the other hand, has two dominant players—American and LATAM. Both carriers have an ASK share greater than 20%, but LATAM was the second most fuel-efficient in 2018, whereas American's fuel efficiency was below average.

We also see some patterns in fuel efficiency by country carrier. In the U.S.–SA market, the five U.S. carriers operated at similar fuel efficiencies, with Spirit performing best at 35 pax-km/L and United lagging behind at 33 pax-km/L. However, the top carriers—Azul and LATAM—so outperformed in fuel efficiency that all the U.S. carriers fell below the industry average. In the U.S.–MCC market, the eight U.S. carriers spread out in different tiers of fuel efficiency, and a large fuel efficiency gap can be observed among the three Mexican airlines. Volaris tied for first, whereas Aeromexico was below industry average, and Interjet came in last.

The U.S.–MCC and U.S.–SA markets exhibited different trends over time. From 2017 to 2018, the U.S.–MCC market saw a 2.5% increase in total fuel consumed by all ranked airlines, along with a 4.1% increase in RPKs. This indicates an improvement in fleetwide fuel efficiency of about 1.4%. The U.S.–SA market, on the other hand, has shown comparable growth in both RPKs and fuel burn from 2017 to 2018, but there is no material change in fuel efficiency.

The weighted average fuel efficiency of the U.S.–MCC market increased by 0.5 pax-km/L from 2017 to 2018, or 1.4%. The gap in fuel efficiency also narrowed from 46% in 2017 to 32% in 2018, due to a drop in Frontier's efficiency from 38 to 37 pax-km/L and an increase in Interjet's efficiency from 26 to 28 pax-km/L. Several other carriers made major improvements, including Volaris (34 to 37 pax-km/L) and Sun Country (31 to 33 pax-km/L). The carriers improved through different operational changes. Specifically, these changes are more fuel-efficient aircraft for Volaris, higher seating density for Sun Country, and higher load factor for Interjet.[6] The only U.S.–MCC carrier with a decrease in fuel efficiency by more than 1.5 pax-km/L was Spirit, which went from 35 to 33 pax-km/L. This was mainly a result of decreased average passenger load factor.

The two major changes to U.S.–SA carrier fuel efficiency from 2017 to 2018 came from Azul and Aerolineas Argentinas. Azul's fuel efficiency surpassed LATAM's in 2018, mainly as a result of Azul's fleet modernization whereas LATAM largely operated on the same fleet and loads. Meanwhile, the fuel efficiency of Aerolineas Argentinas fell by 2 pax-km/L in 2018, mostly due to average passenger load factor falling from 82% in 2017 to 76% in 2018. This is a major drop considering the overall passenger load in the U.S.–SA market only decreased from 83% to 82% during the same period. The demand for international travel has slowed in Argentina as a result of currency devaluation and other economic uncertainties (CAPA, 2019b).

3.2 AIRCRAFT-SPECIFIC DISCUSSIONS

Figure 2 illustrates the average fuel efficiency for each aircraft model operated on U.S.–Latin America routes in 2018 as a function of modeled stage length. These aircraft-specific efficiencies are also compared to the U.S.–MCC market average of 32 pax-km/L and the U.S.–SA market average of 37 pax-km/L.

The Boeing 737 family of aircraft was the most widely used on U.S.–MCC routes in 2018, accounting for 45% of all flights. The second most widely used was the Airbus A320 family. The fuel efficiency of the Boeing 737 aircraft averaged about 2 pax-km/L better than the U.S.–MCC market average. The Airbus A320neo, Boeing 737 MAX 8, Airbus A321neo, and Boeing 787-900 models were notably more fuel-efficient with average fuel efficiencies above 40 pax-km/L. Although the Airbus A320neo family and Boeing 737 MAX series are highly fuel-efficient and have the potential to replace older aircraft models on U.S.–MCC flights, the future deployment of the 737 MAX series remains uncertain after the fatal crashes in late 2018 and early 2019 (Gelles, 2019).

6 This report distinguishes low fuel burn at the aircraft level from high fuel efficiency at the carrier level. An aircraft type with low fuel burn represents one with technologies that reduce fuel consumption independent of operational parameters such as load factor, seating density, and freight carriage. A fuel-efficient carrier, conversely, is one that achieves a high fuel efficiency in pax-km/L based upon any or all of these strategies.

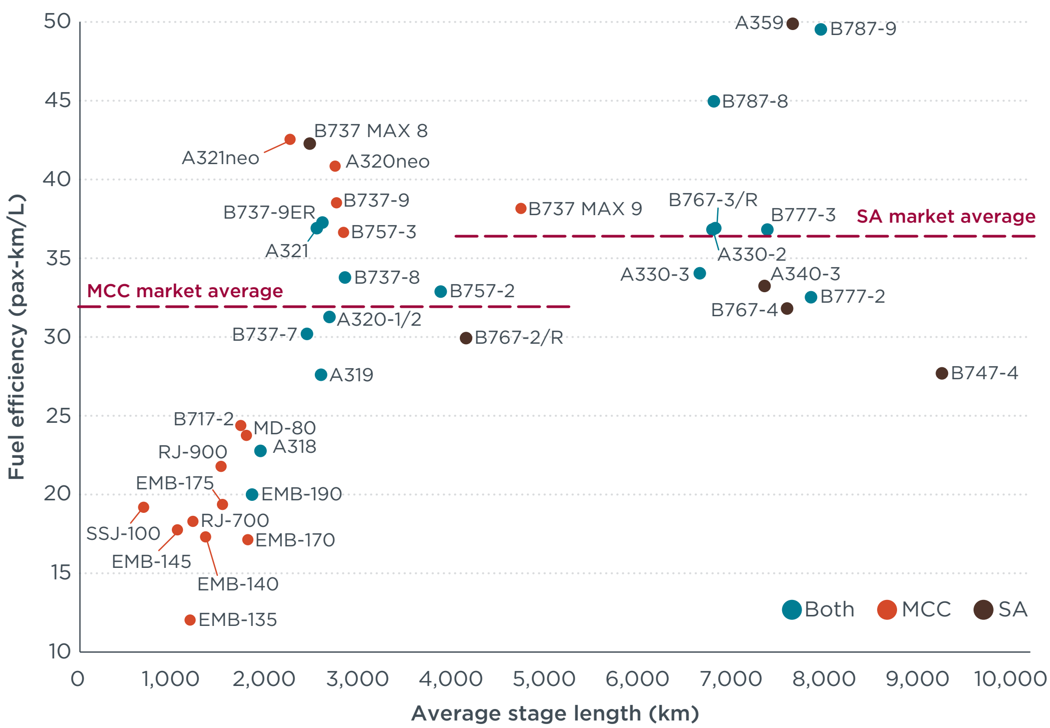

Figure 2. Fuel efficiency of aircraft types used on U.S.–Latin America routes, 2018.

On U.S.–SA routes, the Airbus A320 family aircraft were the most widely used in 2018, accounting for 29% of all flights; second most widely used were the Boeing 767 family aircraft. The fuel efficiency of the Airbus A320 family aircraft averaged about 5 pax-km/L below the U.S.–SA market average. The Airbus A350-900 and Boeing 787 Dreamliners, in contrast, were notably more fuel efficient, with average fuel efficiencies above 40 pax-km/L. The higher average fuel efficiency in the U.S.–SA market compared to the U.S.–MCC market can be attributed mainly to the absence of low-efficiency regional jets, but the deployment of highly fuel-efficient models of wide-body aircraft (i.e., 13% of all RPKs operated on the A350-900 or B787 family) also contributed.

It is important to note that variations in passenger load factors, seating density, and freight carriage also affect the fuel efficiency of different aircraft types. Even among carriers flying Dreamliners, the average seat count varies between 219 and 250 on Boeing 787-800s, and between 252 and 301 on Boeing 787-900s. This results in a fuel efficiency spread from 37 to 48 pax-km/L among 787-800s and from 27 to 53 pax-km/L among 787-900s.

Of the five carriers flying Boeing 767-300ERs on U.S.–SA routes, LATAM operated at the highest fuel efficiency of 40 pax-km/L in 2018. This was due to its high average freight share of 26%, its average of 233 seats per aircraft, and a 79% passenger load factor. American, on the other hand, placed only 207 seats on its 767s and operated at a lower load factor and freight share. It therefore demonstrated a fuel efficiency of 33 pax-km/L using the same aircraft type on similar routes.

3.3 DRIVERS OF U.S.–LATIN AMERICA AIRLINE EFFICIENCY

Tables 3a and 3b summarize key airline operational parameters for nonstop U.S.–MCC and U.S.–SA flights respectively, by carrier and in order of fuel efficiency in 2018. The parameters include passenger load factor, freight share, overall seating density, and relative fuel burn of the aircraft operated.[7]

Table 3a. Airline operational parameters in the U.S.–MCC market, 2018.

Rank	Airline	Passenger load factor	Freight share of total tonne-km	Overall seating density (seats/m²)[a]	Aircraft fuel burn[b]
T1	**Frontier**	77%	0%	1.71	+6%
T1	**Volaris**	76%	0%	1.67	-5%
3	**Copa**	85%	3%	1.50	+5%
4	**United**	84%	1%	1.54	+4%
T5	**Spirit**	78%	0%	1.67	+5%
T5	**Alaska**	84%	0%	1.53	+9%
T5	**Sun Country**	74%	0%	1.68	+5%
T8	**JetBlue**	82%	0%	1.44	+4%
T8	**Avianca**	83%	2%	1.41	+6%
T8	**Delta**	86%	2%	1.51	+9%
T11	**Aeromexico**	78%	3%	1.49	+3%
T11	**Southwest**	83%	0%	1.73	+5%
T13	**Caribbean**	73%	3%	1.46	+5%
T13	**American**	80%	1%	1.44	+5%
15	**Interjet**	74%	1%	1.40	+7%
Industry Average		**82%**	**1%**	**1.51**	**+5%**

[a]As measured by seats per square meter or RGF. See footnote 7 for details.
[b]As measured by the average margin of aircraft to ICAO's CO_2 standard. See footnote 7 for details.

Table 3b. Airline operational parameters in the U.S.–SA market, 2018.

Rank	Airline	Passenger load factor	Freight share of total tonne-km	Overall seating density (seats/m²)[a]	Aircraft fuel burn[b]
1	**Azul**	89%	35%	1.10	+1%
2	**LATAM**	82%	31%	1.11	-1%
3	**Spirit**	83%	0%	1.65	+4%
T4	**Delta**	84%	17%	1.09	+4%
T4	**Aerolineas Argentinas**	76%	24%	1.13	+3%
T4	**Avianca**	82%	14%	1.12	+2%
T4	**American**	79%	22%	0.97	+5%
T8	**JetBlue**	86%	0%	1.42	+4%
T8	**United**	83%	21%	1.01	+6%
10	**TAME**	79%	0%	1.19	+1%
Industry Average		**82%**	**22%**	**1.07**	**+3%**

[a]As measured by seats per square meter or RGF. See footnote 7 for details.
[b]As measured by the average margin of aircraft to ICAO's CO_2 standard. See footnote 7 for details.

7 Seating density is measured in seats per square meter (m²) of Reference Geometric Factor, or RGF. RGF is a close proxy for the pressurized floor area of an aircraft. It was developed by the ICAO as a means to assess aircraft fuel efficiency. See Rutherford (2013) for further details. Relative fuel burn of aircraft is measured by margin from the ICAO's fuel efficiency or CO_2 standard, which established an internationally agreed means of assessing and comparing aircraft efficiency. Negative values indicate the use of more fuel-efficient fleets, whereas positive values indicate more fuel-intensive aircraft. See Kharina & Rutherford (2017) for details.

The U.S.–MCC market as a whole operated at a much higher average seating density of 1.51 seats/m² compared to the U.S.–SA market, which averaged 1.07 seats/m². The seating density of individual carriers also varied greatly. In the U.S.–MCC market, Southwest and Frontier both had seating density greater than 1.70 seats/m², and Interjet had the lowest seating density of 1.40 seats/m². Despite the overall lower seating density in the U.S.–SA market, Spirit and JetBlue operated densely filled flights due to their low-cost business models. American operated flights with the fewest seats per unit of floor area within the U.S.–SA market.

Both markets have an average passenger load factor of 82%, and there is relatively little variation among carriers. Frontier, despite claiming first place in fuel efficiency, flew aircraft with relatively higher fuel burn compared to its peers in the U.S.–MCC market. Volaris, in contrast, benefited from a fleet with the lowest fuel burn in the U.S.–MCC market by a wide margin. The average margin of aircraft fuel burn to ICAO's CO_2 standard is about 2% higher in the U.S.–MCC market than in the U.S.–SA market, reflecting, on average, fleets with higher fuel burn. This trend is likely to change, though, as low-cost carriers serving U.S.–MCC routes have ordered a substantial number of new, fuel-efficient aircraft (CAPA, 2019a).

One major difference between the two markets concerns the amount of belly freight carried. As shown in the tables, carriers in the U.S.–MCC market carry almost no belly freight, but for carriers in the U.S.–SA market, on average 22% of the payload is freight. The exceptions are Spirit, JetBlue, and TAME, which fly relatively shorter routes with almost no belly freight. The typical perishable goods transported via U.S.-bound flights include flowers from Colombia, salmon from Chile, and berries from Argentina and Peru (The International Air Cargo Association, 2018).

The variation in operational parameters among carriers helps explain the size of the fuel-efficiency gaps observed within the U.S.–MCC and U.S.–SA markets. The smaller gap of 32% in the U.S.–MCC market can be attributed to almost no variation in belly freight among ranked U.S.–MCC carriers and modest variation in seating density, compared to the U.S.–SA market.

We developed a multivariate regression model to relate overall airline fuel efficiency to technological and operational parameters, or drivers. These include aircraft fuel burn, seating density, passenger load factor, and freight share of total payload, which is the same approach as taken in the previous transatlantic rankings (Graver & Rutherford, 2018b). The Shapley method was used to quantify the relative importance of each driver to fuel efficiency, and the results are shown in Figure 3. This approach explained about 85% of all variance, and metrics are normalized to sum to 100%.

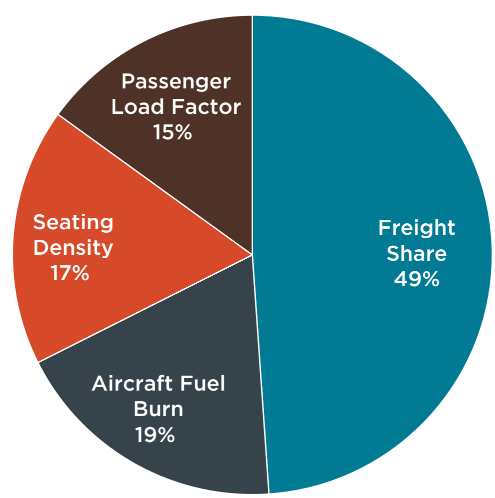

Figure 3. Key drivers of airline fuel efficiency for the U.S.–Latin America market.

Freight share of total payload, or belly freight, was the most important factor, explaining approximately half of the variance across carriers. The remaining variance was explained in largely equal measures by aircraft fuel burn, seating density, and load factor. Bootstrapping analysis indicates significant overlap in the normalized 95% confidence interval for all four estimated drivers: aircraft fuel burn, 2%–34%; passenger load factor, 2%–29%; freight share, 13%–55%; and seating density, 8%–28%. Nonetheless, it is fair to say that freight share was the most important driver of U.S.–Latin America route fuel efficiency in 2018.

The specific fuel efficiency drivers for the U.S.–MCC and U.S.–SA markets were different.[8] Freight share of total payload played a critical role in U.S.–SA market fuel efficiency, but its impact was limited in the U.S.–MCC market, where freight share of total payload was low across all flights. The four operational parameters do not explain a significant portion of the variance in the U.S.–MCC market, suggesting that other factors such as fleet age played an important role.

Two of the major trends in the U.S.–Latin America market between 2013 and 2018 were an increase in service by low-cost carriers and increased utilization of newer aircraft (Baker, 2019). Over this 6-year timespan, low-cost carriers steadily increased their collective share in the U.S.–MCC market from 19% in 2013 to 30% in 2018. Meanwhile, the U.S.–MCC market as a whole grew 44% in ASKs. Among the seven low-cost airlines in the U.S.–MCC market, the carriers with the most growth in ASKs between 2013 and 2018 were Southwest (+554%) and Interjet (+272%).

Also during this 6-year period, carriers serving U.S.–Latin America routes deployed increasing numbers of Airbus A321, Boeing 787, and Airbus A330 series aircraft, while retiring some of the older Boeing 757 and 767 aircraft. Freight share of total payload and passenger load factor varied little between 2013 and 2018.

Because the average stage length of the U.S.–SA market is similar to those of the transpacific and transatlantic markets, we can compare the contribution of operational parameters to fuel efficiency in different markets, albeit in slightly different years (Table 4). The average fuel efficiency of the U.S.–SA market was 3 pax-km/L higher than that of the U.S. transatlantic market and 6 pax-km/L higher than that of the U.S. transpacific market, mainly because aircraft serving U.S.–SA routes tended to be more densely configured and more fuel-efficient.

8 Combined results for both the U.S.–MCC and U.S.–SA markets are presented here because they achieved statistical significance across both markets. A multivariate regression model was also built for the U.S.–MCC and U.S.–SA data separately. Although U.S.–MCC results did not achieve statistical significance, the part of variance explained by the linear model indicated that seating density has a higher relative importance. The model for U.S.–SA data explained 96% of the variance, with differing relative importance allocated to freight share of total payload (51%), passenger load factor (22%), aircraft fuel burn (17%), and seating density (10%).

Table 4. Airline operational parameters by U.S.–international market (Graver & Rutherford, 2018a, 2018b).

Aviation market (year)	Average stage length (km)	Passenger load factor	Freight share of total tonne-km	Overall seating density[a] (seats/m²)	Aircraft fuel burn[b]	Fuel efficiency (pax-km/L)
Transpacific (2016)	10,738	82%	25%	0.87	+4%	31
Transatlantic (2017)	7,028	81%	21%	1.01	+5%	34
U.S.–SA (2018)	5,083	82%	22%	1.07	+3%	37

[a]As measured by seats per square meter or RGF. See footnote 7 for details.
[b]As measured by the average margin of aircraft to ICAO's CO_2 standard. See footnote 7 for details.

3.4 AIRLINE-SPECIFIC DISCUSSIONS

Having shown that aircraft type, seating density, passenger load factor, and freight carriage are key determinants of airline fuel efficiency, this section outlines how each airline could make improvements in these parameters to increase fuel efficiency.

3.4.1 Carriers only in U.S.–MCC ranking

Frontier Airlines (T-1st: 37 pax-km/L), a U.S. ultra-low-cost carrier and the most fuel-efficient carrier based on U.S. domestic operations in 2017 and 2018 (Zheng et al., 2019), served routes between 10 U.S. airports and five destinations in Mexico and the Caribbean in 2018. Dense seating configurations significantly contributed to the airline's high fuel efficiency on these routes. The majority of U.S.–MCC flights were served by Airbus A321 and A320-200 aircraft. If Frontier were to deploy more of the Airbus A320neo aircraft it operates and has ordered on U.S.–MCC routes, its fuel efficiency might further improve.

Volaris (T-1st: 37 pax-km/L) is Mexico's second largest and a low-cost carrier. It provided nonstop services between 31 U.S. airports and 20 Mexican destinations and one airport each in El Salvador and Guatemala in 2018. Volaris deployed aircraft with exceptionally low fuel burn for its U.S.–MCC routes; specifically, more than half of the RPKs were flown by Airbus A320neo and A321neo aircraft. The switch from A320 to A320neo aircraft in 2018 improved the fuel efficiency of the carrier by 3 pax-km/L, and this was the largest improvement from 2017 among ranked carriers in the two markets. Furthermore, the carrier made a large order for 80 new A320neo family aircraft, with delivery set to begin in 2022 (Volaris, 2017).

Compania Panamena, Copa (3rd: 35 pax-km/L), the flag carrier of Panama and a member of Star Alliance, served nonstop flights between Panama City and 14 U.S. airports in 2018. The majority of these flights used Boeing 737-800 aircraft. Copa's current orders from the Boeing 737 MAX series are about 55 aircraft in total, and it plans to expand the use of 737 MAX 9 for flights to and from the United States (Liu, 2018). However, as the safety issues with 737 MAX aircraft remain unsolved, there is some uncertainty about this fleet renewal plan. The carrier also operated with the highest load factor among all ranked U.S.–MCC carriers. Copa is currently setting up a JV with Avianca and United (CAPA, 2019a).

Alaska Airlines (T-5th: 33 pax-km/L), the fifth largest U.S. airline with its main hub at Seattle-Tacoma International Airport, flew between eight airports in Pacific U.S. states and 12 MCC destinations in 2018. The airline deployed mostly Boeing 737-900ER and 737-800 planes on these routes. The carrier's capacity expanded after it merged with Virgin America, and 19% of the departures in 2018 were flown by Virgin's Airbus A320 aircraft. However, the average fuel burn of the Alaska U.S.–MCC fleet also became the highest among ranked carriers after the merger. The carrier still achieved above average fuel efficiency thanks to its relatively dense seating configuration and above-average passenger load factor.

Sun Country Airlines (T-5th: 33 pax-km/L) is a U.S. ultra-low-cost carrier with its base at Minneapolis–Saint Paul International Airport. The airline served nonstop flights between six U.S. airports and 14 MCC destinations in 2018, mainly with Boeing 737-800 aircraft. The carrier operated with the highest seating density among ranked U.S.–MCC carriers in 2018. The reconfiguration of 737-800s from an average of 166 seats to 176 seats helped improve the carrier's fuel efficiency by 2 pax-km/L in 2018.

Aeromexico (T-11th: 31 pax-km/L), the flag carrier and largest airline in Mexico, operated nonstop flights between 24 U.S. airports and seven Mexican destinations in 2018. The airline claims the largest share of both Mexico's domestic and international aviation markets (CAPA, 2018). The carrier also operates under a JV with Delta Airlines (CAPA, 2019a). The most common aircraft used on these routes include Boeing 737-800, Embraer 190, Boeing 737-700, and 787-900. The 54 planes from the 737 MAX series aircraft that have been ordered could help improve the carrier's fuel efficiency, if the aircraft model is cleared of safety issues and returns to service (Navarro, 2019).

Southwest Airlines (T-11th: 31 pax-km/L), a low-cost U.S. carrier, served 27 U.S. airports and 14 MCC destinations in 2018, mainly using Boeing 737-700 and 737-800 aircraft. Southwest flights tended to operate with high passenger load factors and seating density. However, because 737-700s have inherently higher fuel burn than other models, Southwest's overall fuel efficiency was below average. The plan to replace older 737-700 aircraft with planes from the 737 MAX series could improve the efficiency of the Southwest fleet by a large margin, but the replacement is currently delayed due to 737 MAX groundings (Josephs, 2019).

Caribbean Airlines (T-13th: 30 pax-km/L), the national airline and flag carrier of Trinidad and Tobago, flew only Boeing 737-800 aircraft between four U.S. airports and eight Caribbean destinations. Although Caribbean operated aircraft with lower fuel burn and denser seating configurations than the industry average, it had the lowest passenger load factor among all 15 ranked U.S.–MCC carriers. The potential replacement of Boeing 737-800 with 737 MAX 8 aircraft might improve the carrier's fuel efficiency, although Caribbean is currently reconsidering the lease due to 737 MAX accidents (Wint, 2019).

Interjet Airlines (15th: 28 pax-km/L), a low-cost carrier based in Mexico, served routes between 10 U.S. airports and seven Mexican cities in 2018 using Airbus A320 family aircraft. The carrier started to deviate from its low-cost model in 2018, when it began offering extra-legroom seats and a more generous luggage allowance (Interjet, n.d.). Nevertheless, Interjet improved its fuel efficiency by 2 pax-km/L from 2017 to 2018, mainly by increasing its passenger load factor from 69% to 74%. Because of the change in the carrier's business model, it is uncertain whether the current seating density will be maintained.

3.4.2 Carriers only in U.S.–SA ranking

Azul Airlines (1st: 44 pax-km/L), is a low-cost airline and Brazil's third largest. The airline recently expanded its service from domestic flights only to nonstop international flights. In 2018, the airline used Airbus A320neo and A330-200 aircraft to fly between two Florida airports and six Brazilian destinations. The carrier came in first among the 10 U.S.–SA carriers by operating its fuel-efficient fleet at the highest load factor and freight share of payload. The reconfiguration of A330 aircraft in 2017 also helped Azul to carry more passengers on the same flights. Azul's fleet is likely to further improve in the near future, as the carrier has ordered 25 A320neo, 10 A321neo, and four A330-900neo aircraft (Azul Airlines, 2019).

LATAM Airlines (2nd: 43 pax-km/L), is a Chilean airline group with subsidiaries in Argentina, Brazil, Colombia, Ecuador, Paraguay, and Peru. The group collectively served routes between seven U.S. airports and 13 South American cities in 2018, with hubs in Santiago, Lima, and Bogota. The group operated with the second highest freight share among ranked U.S.–SA carriers in 2018. A mix of Boeing 767-300, 787-800/900, 777-300, and Airbus A359 aircraft were used by different subsidiary airlines and made up a relatively fuel-efficient fleet. The carrier's investment in new A321neo aircraft could further improve its fleet (CAPA 2019a). Figure 4 shows that the fuel efficiency of individual subsidiaries varies, with LATAM Chile leading and LATAM Colombia (the d/b/a name of Aerovias de Intergracian Regional S.A.) lagging behind, largely as a result of flying different types of aircraft. LATAM is establishing a partnership with Delta, which recently purchased a 20% equity stake in LATAM (Rucinski, 2019).

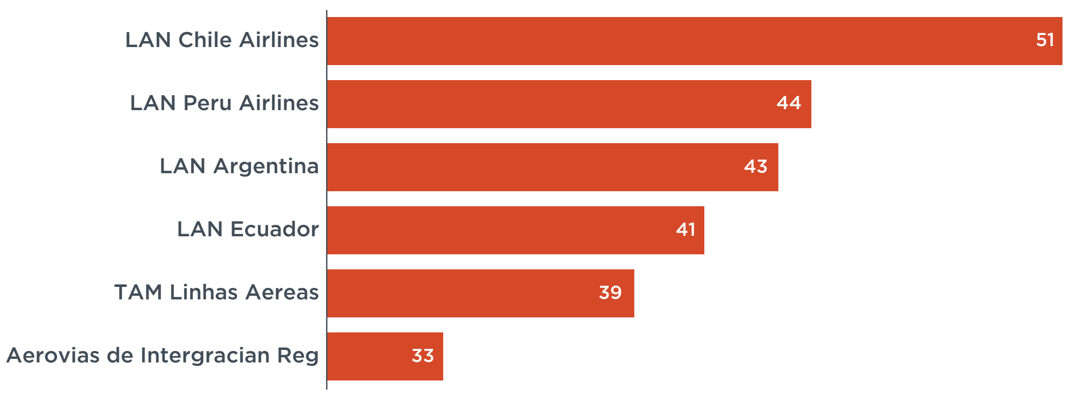

Figure 4. Fuel efficiency in pax-km/L of LATAM subsidiaries on U.S.–SA nonstop routes.

Aerolineas Argentinas (T-4th: 34 pax-km/L), the largest airline in Argentina and a SkyTeam member, served nonstop flights between Buenos Aires and two U.S. airports—Miami International and John F. Kennedy International—in 2018. Most of these flights were flown with Airbus A330-200 aircraft. The carrier's average passenger load factor fell from 82% in 2017 to 76% in 2018, mostly on the Miami–Buenos Aires route. This change impacted the fuel efficiency of the airline overall; it dropped from third place in the 2017 ranking to tying for fourth place in 2018, surpassed by Spirit and Delta.

TAME EP Linea Aera del Ecuador (10th: 29 pax-km/L), the flag carrier of Ecuador, provided services between two U.S. airports and two Ecuadorian destinations in 2018. Airbus A330-300 and A320-200 aircraft were commonly used for these routes. As one of the three ranked U.S.–SA carriers with no belly freight, TAME operated the least fuel-efficient operations in this market, despite an above average seating density as well as about average aircraft fuel burn and passenger load factor.

3.4.3 Carriers in both rankings

American Airlines (U.S.–MCC T-13th: 30 pax-km/L; U.S.–SA T-4th: 34 pax-km/L), the largest carrier in the world by RPKs, claimed the biggest market share in both the U.S.–SA and U.S.–MCC markets in 2018. The carrier flew mainly Airbus A319 and Boeing 777 family aircraft between four U.S. airports and 21 SA destinations. Plans to replace older Boeing 777-200ERs with 787-900s and to replace 767-300ERs with 787-800s (American Airlines, 2018) could improve the carrier's fleet, which had the highest fuel burn among ranked peers. However, continued use of fuel-inefficient A319 aircraft on shorter routes would not be favorable for fuel efficiency gains. The airline also operated between 23 U.S. airports and 68 MCC destinations with mostly Boeing 737-800 and Airbus A320 family aircraft in 2018. American's fuel efficiency was below average in both markets. Improvement in load factor and seating configuration could also increase the carrier's fuel efficiency.

Avianca (U.S.–MCC T-8th: 32 pax-km/L; U.S.–SA T-4th: 34 pax-km/L) is the flag carrier of Colombia, the second-largest airline in Latin America, and a member of Star Alliance. Avianca served 12 U.S. airports, seven SA destinations, and four MCC destinations in 2018. The carrier flew Airbus A320 and A330 family aircraft on its U.S.–SA routes, and only Airbus 320 family aircraft on U.S.–MCC routes. Avianca had more than 100 of A320neo family aircraft on order but recently cancelled 17 of these and delayed another 35 to slow down its fleet renewal (Yeo, 2019). The carrier ranked close to industry average in both markets, but it deployed different strategies for the two. Specifically, Avianca operated relatively fuel-efficient aircraft at low seating density in the U.S.–SA market, and did the opposite in the U.S.–MCC market. Variation in fuel efficiency can be observed among different subsidiaries of Avianca (Figure 5).

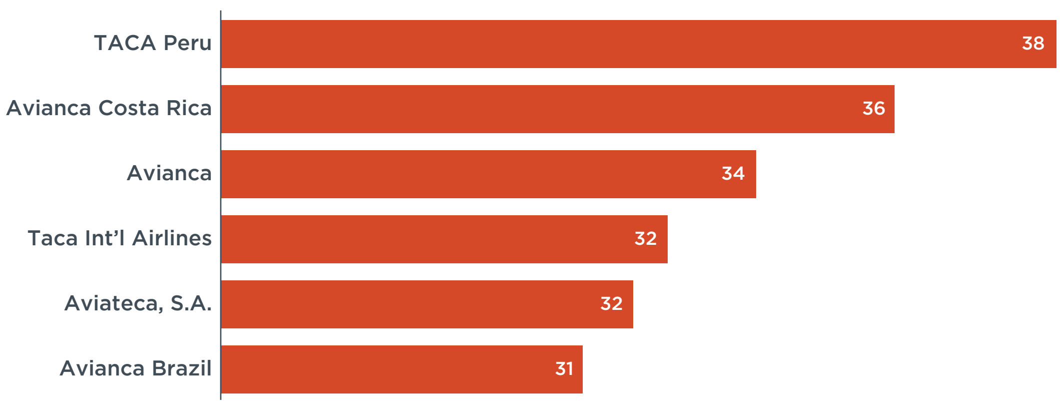

Figure 5. Fuel efficiency in pax-km/L of Avianca subsidiaries on U.S.–Latin America nonstop routes.

Delta Air Lines (U.S.–MCC T-8th: 32 pax-km/L; U.S.–SA T-4th: 34 pax-km/L), a U.S. legacy airline and the second-largest carrier in the world by RPKs, offered flights between six U.S. airports and eight SA cities, and services between 30 U.S. airports and 41 MCC destinations in 2018. In both markets, Delta operated with above average load factor, low seating density, and aircraft with high fuel burn. The fuel efficiency is likely to improve as the airline starts to operate newer and more fuel-efficient aircraft. The most flown Boeing 767-300ER for U.S.–SA routes are expected to be replaced by Airbus A330-900neo aircraft, and the new Airbus A321neo aircraft on order will replace older Airbus A320 aircraft starting in 2021 (Delta, 2017; Delta, 2018).

JetBlue Airways (U.S.–MCC T-8th: 32 pax-km/L; U.S.–SA T-8th: 33 pax-km/L), a major low-cost U.S. carrier, offered services to five cities in Colombia, Ecuador and Peru, as well as to 29 MCC destinations in 2018. JetBlue used mainly Airbus A320 family aircraft for its flights to Latin America. The carrier is currently converting its A320 aircraft from 150 seats to 162 seats, and this could substantially increase its fuel efficiency (Yeo, 2018). The carrier operated at below average fuel efficiency in both markets and was disadvantaged by having no belly freight carriage in the U.S.–SA market.

Spirit Airlines (U.S.–MCC T-5th: 33 pax-km/L; U.S.–SA 3rd: 35 pax-km/L), a low-cost U.S. carrier with highly fuel-efficient domestic operations, served eight U.S. airports, 17 MCC destinations, and seven cities in Colombia, Ecuador, and Peru in 2018 with Airbus A320 family aircraft. Spirit deploys an ultra-low-cost model with notably dense seating configurations, and it achieved above average fuel efficiency in both the U.S.–MCC and U.S.–SA markets despite carrying no belly freight on its U.S.–SA routes, which also have relatively short stage length. Spirit's fleet performance is likely to improve in both markets when the carrier receives the A320neo aircraft it has ordered (Spirit Airlines Inc., 2018).

United Airlines (U.S.–MCC 4th: 34 pax-km/L; U.S.–SA T-8th: 33 pax-km/L), a U.S. legacy airline and the third-largest carrier in the world, provided services between five U.S. airports and eight SA destinations, and between 24 U.S. airports and 51 MCC destinations in 2018. The most frequently used aircraft for U.S.–Latin America flights included Boeing 767-300ER, 777-200, and 737 family aircraft; among these, the 777-200 aircraft are expected to be replaced by some of the 45 highly fuel-efficient Airbus A350-900 on order (Russell, 2017).

3.5 ROUTE COMPARISONS

In addition to these high-level results, we selected three routes with the most airline competition as case studies to evaluate how aircraft type, passenger load factor, and freight carriage affect fuel efficiency.

Los Angeles–Mexico City. The U.S.–MCC route with the most competition was between Los Angeles and Mexico City. In 2018, seven airlines completed a total of 9,637 flights between the two cities.

High-efficiency carriers on this route deployed different strategies. Volaris operated highly fuel-efficient Airbus A320neo aircraft for more than two-thirds of its flights, while the average passenger load factor of these flights was as low as 72%. The relatively high seating density helped Volaris to achieve high fuel efficiency on this route, as well. Aeromexico, on the other hand, paired relatively fuel-efficient Boeing 737-800 aircraft with an average load factor of 85% and operated at a similarly high fuel efficiency. At 38 and 37 pax-km/L of fuel, respectively, flights on both carriers were more fuel efficient than the average on this route, 34 pax-km/L.

The rest of the carriers operating on this route all demonstrated fuel efficiency near the U.S.–MCC industry average of 32 pax-km/L. They tended to fly older Airbus A319 or A320-200 aircraft and Boeing 737-800s with low passenger load factors.

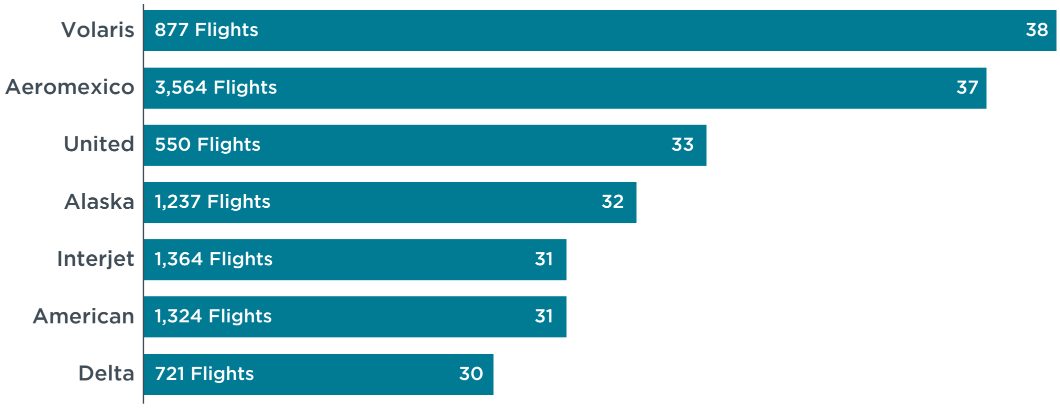

Figure 6. Fuel efficiency in pax-km/L for airlines serving the Los Angeles–Mexico City route.

New York–São Paulo. The U.S.–SA route with the most competition was between the New York City metropolitan area (JFK and Newark) and São Paulo. Five airlines completed 3,615 flights between the two cities in 2018.

The type of aircraft flown played a critical role in fuel efficiency on this route, as shown in Figure 7. LATAM Airlines used mostly Airbus A350-900 aircraft and exceeded the fuel efficiency of its competitors by 44%–68%. The high average freight share of 40% helped the carrier achieve high fuel efficiency despite a low average passenger load factor of 66%. On the other end of the spectrum, Avianca flew Airbus A330-200 aircraft on all of its flights with an average load factor of 75% and a freight share of 23%, which led to the lowest fuel efficiency among competitors on this route.

It is worth noting that the fuel efficiency of LATAM flights varies greatly among routes and subsidiaries. For instance, for flights between the U.S. and Brazil, LATAM operated at fuel efficiencies between 25 and 56 pax-km/L, depending on aircraft used and average load factors.

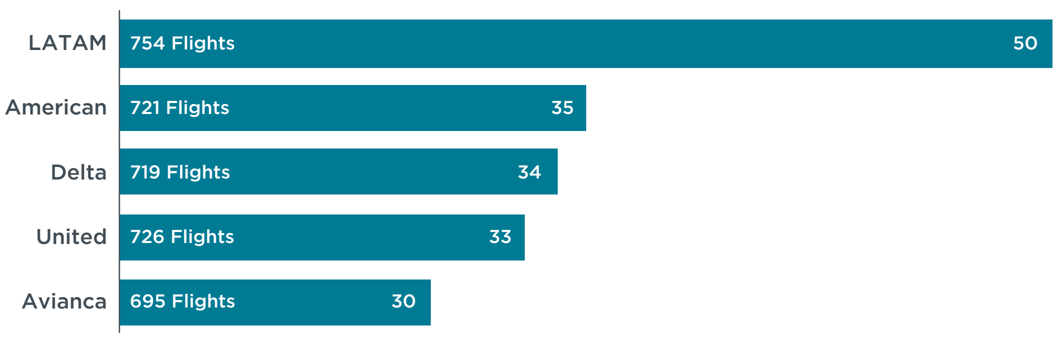

Figure 7. Fuel efficiency in pax-km/L for airlines serving the New York–São Paulo route.

New York–Santo Domingo. For flights between the United States and the Caribbean, the most airline competition was observed on the New York City metropolitan area (JFK and Newark) to Santo Domingo route. Five airlines completed a total of 7,273 flights in 2018, and these were with a variety of Boeing 737 family and Airbus A320 family aircraft. Note that American Airlines performed only 12 flights on this route in 2018 and is not included in the discussion.

A majority of the flights on this route achieved fuel efficiency higher than the U.S.–MCC industry average (32 pax-km/L). One major reason is the deployment of larger single-aisle aircraft, such as Delta's Boeing 737-900ER, JetBlue's Airbus A321, and United's Boeing 737-900. Delta and United also operated at high average load factors of 90% and 91% on this route.

In contrast, the same three carriers operated at much lower fuel efficiency on shorter Caribbean routes to and from the southern states of the United States, because smaller regional jets (e.g., Embraer 175) and older models of single-aisle aircraft (e.g., Airbus A319 and A320) were used.

Figure 8. Fuel efficiency in pax-km/L for airlines serving the New York–Santo Domingo routes.

These route-based analyses can be compared with findings from other resources. For example, as part of its CO_2 calculator, ICAO estimates the average total fuel burn per route using a fuel consumption formula derived from fuel burn data reported by U.S. airlines to BTS.[9] Emissions estimates provided by the ICAO CO_2 calculator are not useful for selecting more fuel-efficient carriers on a specific route. For example, ICAO estimates total fuel use of 116.4 tonnes for a round trip between New York City (JFK) and São Paulo (GRU). However, our analysis shows that Delta burned the least fuel per flight on this route last year, an average of 93 tonnes, followed by Avianca (97 tonnes), LATAM (104 tonnes), and American (124 tonnes). Despite modeling uncertainty in both methods, the large differences of fuel burn among carriers points to the need for carrier-specific information.

9 ICAO's carbon emissions calculator can be accessed at https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx

4. CONCLUSIONS AND NEXT STEPS

4.1 CONCLUSIONS

Among the 15 major carriers serving nonstop flights to MCC destinations, there is a moderate gap of 32% between the fuel efficiency of the best- and worst-performing airlines. Two low-cost carriers, Frontier and Volaris, tied for most fuel efficient, but they operated with different strategies. Frontier flew relatively fuel-efficient Airbus A321 and A320 aircraft with high seating density, and Volaris operated aircraft with the lowest fuel burn in 2018 by flying mostly A320neo family aircraft. The lowest-ranked carrier, Interjet, operated the least fuel-efficient flights to MCC destinations at 28 pax-km/L by using a fleet of Airbus A320-200 aircraft at low load factors.

Among the 10 major carriers operating U.S.–SA routes, there is a wide gap of 52% between the fuel efficiency of industry leader Azul and bottom-ranked TAME. Two Latin America-based carriers—Azul, with the highest load factor and freight share, and LATAM, with fuel-efficient aircraft and high freight share—excelled in fuel efficiency. TAME operated the least fuel efficient flights to SA destinations at 29 pax-km/L with no belly freight. The main driver of the fuel-efficiency gap in the U.S.–Latin America market was freight share of total payload, followed by aircraft fuel burn and seating density; together these explain more than 80% of the variation in airline fuel efficiency.

More generally, we see that carriers with very different combinations of aircraft type, passenger load factors, freight carriage, and seating configurations operate with similar fuel efficiencies. Within the U.S.–SA market, four airlines averaged 34 pax-km/L—Delta, Aerolineas Argentinas, Avianca, and American. These carriers tended to be strong performers in one of the four major operational parameters. For example, Avianca and American operated aircraft with low fuel burn, and Delta and Aerolineas Argentinas had high seating density.

The gap in U.S.–MCC market fuel efficiency is only half of that previously seen in our transpacific and transatlantic rankings. The gap in the U.S.–SA market is also slightly smaller than seen in the other two U.S.–international rankings. The average fuel efficiency of the U.S.–SA market is 3 pax-km/L higher than that of the transatlantic market and 6 pax-km/L higher than that of the transpacific market. The difference is mainly due to fleets with lower fuel burn, on average.

The introduction of more fuel-efficient wide-body aircraft, such as the Airbus A350 and the Boeing 787, can help further improve the fuel efficiency of the U.S.–Latin America market. As the demand for air travel increases, more new aircraft will be purchased. Models like the A350, 787, and A330neo, as well as models under development like the 777X, eventually will come to dominate the global wide-body fleet. All other things being equal, airlines operating aircraft with lower fuel burn tend to be more fuel efficient, but operational parameters such as belly freight carriage are also important and should be tracked.

The ICAO, which acts as the de facto regulator of commercial aviation worldwide, has adopted an aspirational goal for airlines to improve their fleet fuel efficiency by 2% annually. Although ICAO has developed a fuel efficiency standard for new aircraft (Kharina & Rutherford, 2017), it has not yet adopted mandatory policies to boost efficiency in the existing fleet. ICAO's goal of carbon-neutral growth from 2020 onward is likely to be met through carbon offsetting, not improved aircraft efficiency or alternative fuels (Pavlenko, 2018). Further, fuel prices alone, while important, have been found to be an inconsistent driver of aviation fuel efficiency (Kharina, McDonnell, & Rutherford, 2015). Additional policies to promote emission reductions from the in-service fleet will likely be needed if industry is to meet its long-term climate goals.

4.2 NEXT STEPS

This study presented our first analysis of fuel efficiency for airlines operating between the United States and Latin America. As the market grows, future updates to the ranking will help evaluate changes in fuel efficiency due to fleet expansion and renewal, the increased connectivity as a result of JVs, and the continued growth of low-cost carriers.

Additionally, we will continue to work with DOT and our data provider to ensure that airlines report accurate operational data for use in subsequent airline fuel efficiency rankings. Finally, assuming widespread cooperation from ranked airlines, our methodology could be shifted from a modeling approach to one in which primary fuel burn data from all carriers are analyzed to encompass the full range of operational measures that affect airline fuel efficiency (Zou, Elke, & Hansen, 2012).

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APPENDIX A: MODEL VALIDATION

Aircraft fuel burn modeled according to the methodology described in Section 2 was validated using fuel burn data reported to the BTS by nine U.S. carriers for each aircraft type operating U.S.–Latin America routes (BTS, 2018).[10] The average fuel efficiency for each aircraft type was calculated directly from these data and compared with the modeled fuel efficiency. By doing this, the uncertainty introduced by modeling fuel burn with Piano using standardized assumptions for operating parameters was assessed. A total of 44 airline-aircraft type combinations were included in the model validation analysis shown in Figure A1.

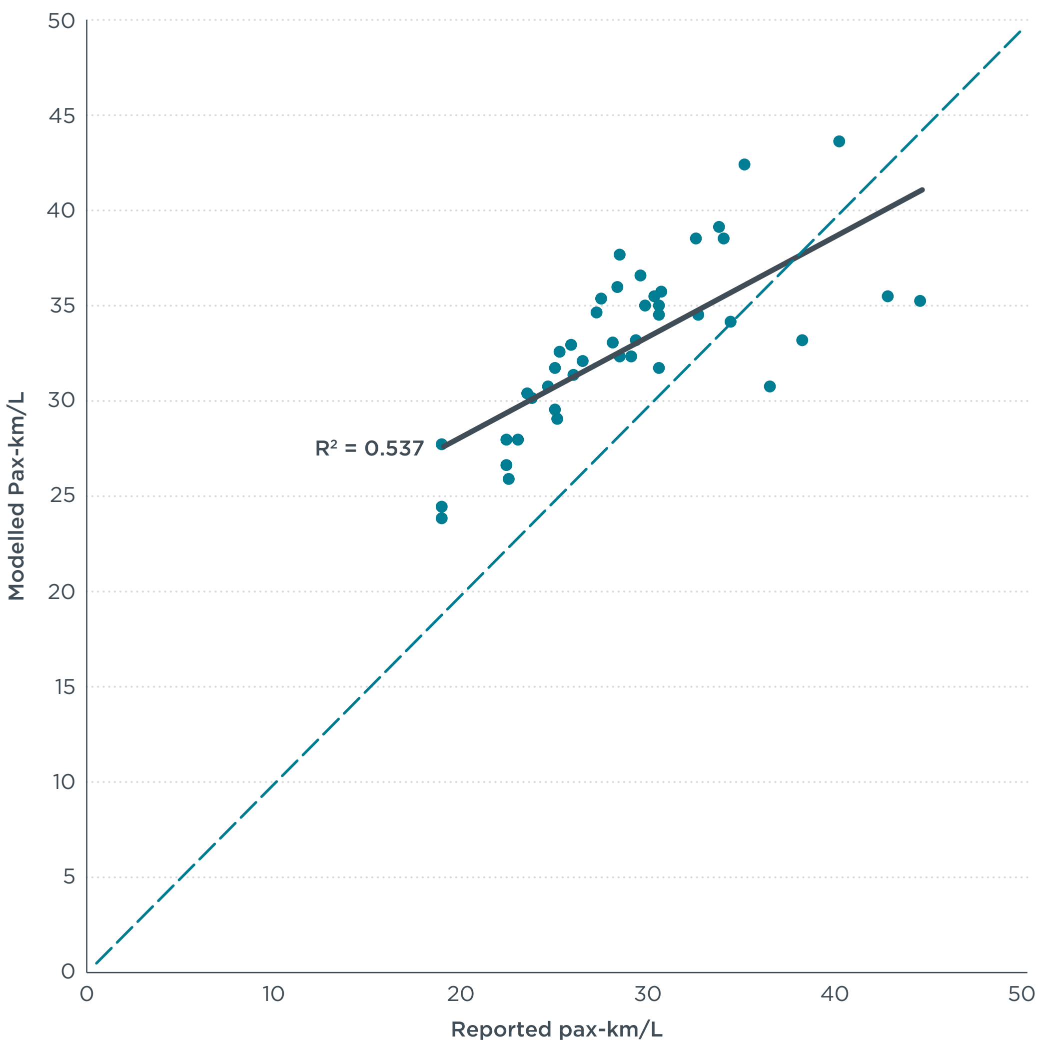

Figure A1. Airline-reported versus modeled fuel efficiency, 2018.

These validation results suggest that our modeling approach is robust and appropriate for the purpose of comparing the relative fuel efficiency of U.S.–Latin America

10 The U.S. carriers include Alaska Airlines, American Airlines, Delta Air Lines, Frontier Airlines, JetBlue Airways, Southwest Airlines, Spirit Airlines, Sun Country Airlines, and United Airlines. Only aircraft types with annual departures greater than 500 are included in the validation.

operations. Although the model overestimates fuel efficiency compared with reported fuel burn data by approximately 20%, a good linear fit (R^2 of 0.54) was observed. Additionally, these validation findings are broadly consistent with those reported in the Intergovernmental Panel on Climate Change's report, *Aviation and the Global Atmosphere*.[11] This indicates that changes to the modeling parameters are unlikely to lead to major shifts in the rankings.

11 "The assumption of great circle flight paths results is an underestimate of distance flown. A combination of factors [e.g., deviation from great circle distance, delay, engine deterioration, etc.] results in systematic underestimation of total fleet fuel burned by 15%–20% for domestic operations." (Intergovernmental Panel on Climate Change, 1999)

APPENDIX B: 2017 U.S.–LATIN AMERICA FUEL EFFICIENCY

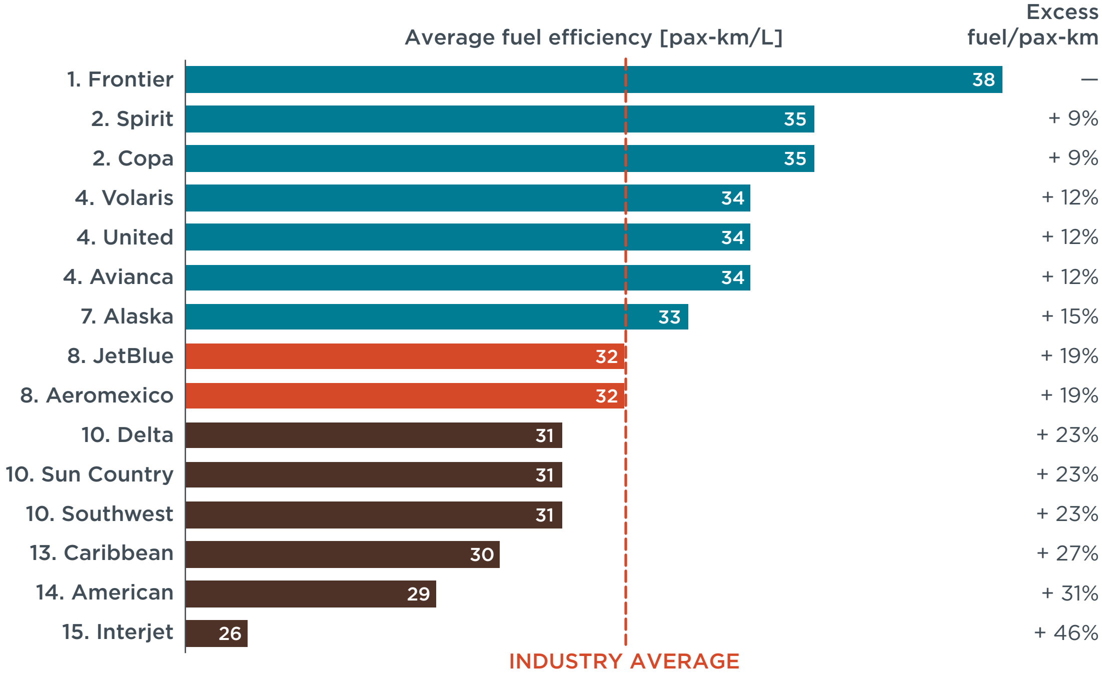

Figure B1a. Fuel efficiency of 15 major airlines in the U.S.–MCC market, 2017.

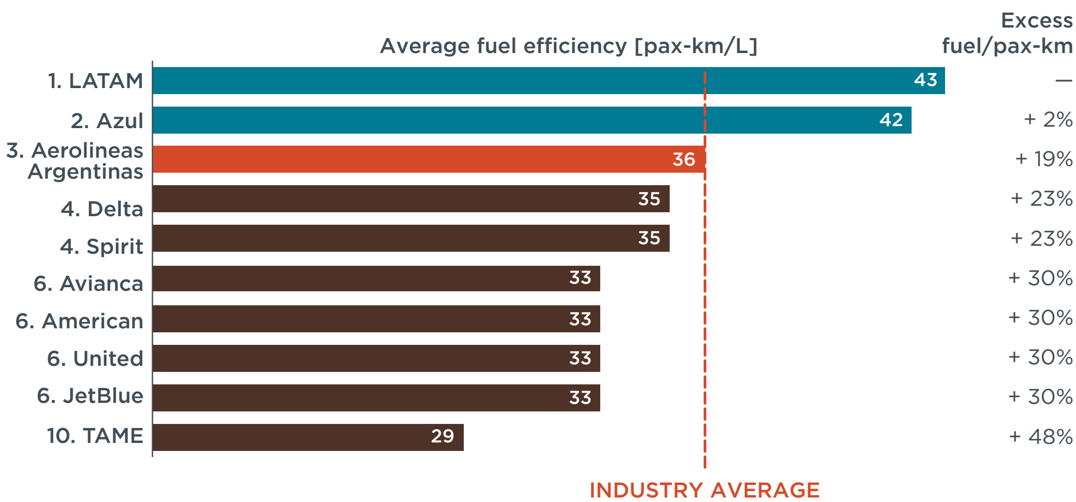

Figure B1b. Fuel efficiency of 10 major airlines in the U.S.–SA market, 2017.

The average fuel efficiencies of 15 major airlines operating U.S.–MCC routes in 2017 are shown in Figure B1a. The industry average fuel efficiency was 32 pax-km/L. U.S. carrier Frontier operated the most fuel-efficient U.S.–MCC flights with an average fuel efficiency of 38 pax-km/L, 19% better than the industry average. Interjet ranked as the least fuel efficient, burning on average 46% more fuel per passenger-kilometer than Frontier. This gap narrowed significantly in 2018, as described in Section 3.1.

Figure B1b shows the average fuel efficiencies of 10 major airlines operating U.S.–SA routes in 2017, with an industry average of 36 pax-km/L. Chilean airline group LATAM stood out as the most fuel-efficient airline in this market, with an average fuel efficiency of 43 pax-km/L, 19% better than the industry average. Azul closely followed with an average fuel efficiency of 42 pax-km/L. Ecuadorian airline TAME ranked as the least fuel-efficient airline on this market, burning on average 48% more fuel per passenger-kilometer than LATAM.

Table B1a. Airline operational parameters in the U.S.–MCC market, 2017.

Rank	Airline	Passenger load factor	Freight share of total tonne-km	Overall seating density (seats/m²)[a]	Aircraft fuel burn[b]
1	**Frontier**	81%	0%	1.71	+7%
T2	**Spirit**	81%	0%	1.68	+4%
T2	**Copa**	86%	3%	1.50	+5%
T4	**Volaris**	78%	0%	1.66	+2%
T4	**United**	84%	1%	1.54	+4%
T4	**Avianca**	85%	3%	1.41	+6%
7	**Alaska**	81%	0%	1.54	+10%
T8	**JetBlue**	83%	0%	1.43	+4%
T8	**Aeromexico**	77%	4%	1.48	+3%
T10	**Delta**	86%	2%	1.49	+10%
T10	**Sun Country**	74%	0%	1.59	+5%
T10	**Southwest**	80%	0%	1.73	+5%
13	**Caribbean**	71%	3%	1.48	+5%
14	**American**	79%	1%	1.43	+6%
15	**Interjet**	69%	0%	1.41	+7%
Industry Average		**81%**	**1%**	**1.51**	**+6%**

[a]As measured by seats per square meter or RGF. See footnote 7 for details.
[b]As measured by the average margin of aircraft to ICAO's CO_2 standard. See footnote 7 for details.

Table B1b. Airline operational parameters in the U.S.–SA market, 2017.

Rank	Airline	Passenger load factor	Freight share of total tonne-km	Overall seating density (seats/m^2)[a]	Aircraft fuel burn[b]
1	LATAM	87%	29%	1.09	-1%
2	Azul	93%	33%	1.04	+2%
3	Aerolineas Argentinas	82%	24%	1.13	+3%
T4	Delta	87%	17%	1.08	+4%
T4	Spirit	84%	0%	1.65	+5%
T6	Avianca	84%	14%	1.12	+2%
T6	American	78%	21%	0.98	+5%
T6	United	80%	22%	1.00	+4%
T6	JetBlue	86%	0%	1.40	+4%
10	TAME	80%	0%	1.18	+1%
Industry Average		**83%**	**22%**	**1.06**	**+3%**

[a]As measured by seats per square meter or RGF. See footnote 7 for details.
[b]As measured by the average margin of aircraft to ICAO's CO_2 standard. See footnote 7 for details.

From 2017 to 2018, the average fuel burn of aircraft operated on U.S.–MCC routes fell (improved) from 5.6% to 4.8%, as measured relative to ICAO's CO_2 emission standard. During the same time, the average passenger load factor, seating density, and freight share of total payload stayed relatively constant. Volaris and Delta were the carriers that improved their fleets the most during these two years.

For the U.S.–SA market, there was little variation in passenger load factors, seating density, and freight share between 2017 and 2018, except for the significant decrease in load factor for certain carriers, as previously mentioned. The U.S.–SA fleets' average exceedance of the ICAO CO_2 emission standard improved only slightly from 2.9% in 2017 to 2.8% in 2018, suggesting an absence of major fleet-modernization efforts during this period.