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TRANSITIONING TO MORE FUEL-EFFICIENT AIRCRAFT: A MODEL OF AIR TRAVELER RESPONSE IN SINGLE-AISLE SEGMENT

Alencar Bravo, Darli Vieira

UNIVERSITÉ DU QUÉBEC À TROIS-RIVIÈRES, CANADA

Geraldo Ferrer

NAVAL POSTGRADUATE SCHOOL, UNITED STATES

Abstract: In single-aisle aviation industry, aircraft manufacturers are now fully transitioning to reengineered aircraft types with more efficient power plants, which provide significant environmental advantages. However, the extent to which the customers of various airlines value the availability of remotorized variants of famous aircraft is unclear. We explore passengers' ticket purchasing behavior in connection to aircraft types, airlines, ticket pricing, and individuals' degree of fear of flying in this research. We discover that airline selection is mostly determined by ticket price and that a fear of flying has limited impact on consumers' choice of one airline over another. Individuals who have a significant fear of flying prefer larger aircraft, particularly if the ticket price is high. When the same fearful passengers fly in smaller planes, they seem to shun reengineered aircraft models. Avoiding certain aircraft models seems to be linked to a choice mechanism characterized by a minimum threshold of acceptable familiarity with ticket features on the part of the passenger. If an air ticket has features with a level of unfamiliarity past this threshold, the passenger selects a different alternative.

Keywords: Fear of Flying, Passenger Behavior, Boeing, Airbus, Embraer

1. INTRODUCTION

Aviation is a sector that has been severely affected by the COVID-19 pandemic (Adrienne et al., 2020; Albers & Rundshagen, 2020; Pongpirul et al., 2020). Before this crisis, this sector had always experienced remarkable year-to-year growth of 4.5% on average (Staples et al., 2018). The pandemic confirmed the previously held belief that only major world events, such as the two oil crises, the September 11 terrorist attacks and the 2008 financial crisis, could disrupt this trend (Sobieralski, 2020; Wood & Gokhale, 2017). The COVID-19 pandemic led many countries to close their borders, with severe quarantine restrictions imposed on international travelers, greatly reducing demand for international flights (Chinazzi et al., 2020; Gössling et al., 2020; Nicola et al., 2020). This in turn affected domestic air traffic due to its symbiotic relationship with international travel and the generalized fear among many segments of the population, causing a dramatic reduction in demand for commercial air travel in general.

The airlines that continued to fly in the early days of the pandemic (even without passengers) soon realized that it was unsustainable to maintain the same flight schedules (Forsyth et al., 2020; Suau-Sanchez et al., 2020). Therefore, a large part of the fleets went into "hibernation" mode. Commercial airplanes are designed to be on the ground as little as possible and in the air as much as possible, but they had to be stored.

Despite the serious economic consequences, with many workers furloughed or dismissed from their jobs, some environmental groups were delighted with the drastic drop in air pollution generated by commercial aircraft (Berman & Ebisu, 2020; Chen et al., 2020; Ibn-Mohammed et al., 2021). Regardless, one day the COVID-19 pandemic will end, and it is expected that the aviation sector will resume its typical growth trajectory that started some six decades ago (Climate Action Tracker, 2020; Serrano & Kazda, 2020).

Therefore, despite the environmental benefits that the pandemic has caused with the reduction in aviation pollution, these benefits are unlikely to be permanent. **Figure 1** illustrates the evolution of the annual pollution generated by international aviation in tons of CO2 equivalent from 1990 to the present. The red dotted lines are the prepandemic projections of air pollution caused by aviation, and the continuous green lines show the updated projections incorporating the impact of the pandemic. As the figure shows, in the long run, it will not matter that aviation is currently in a period of low demand. Most projections estimate that CO2 emissions will remain between the green lines.

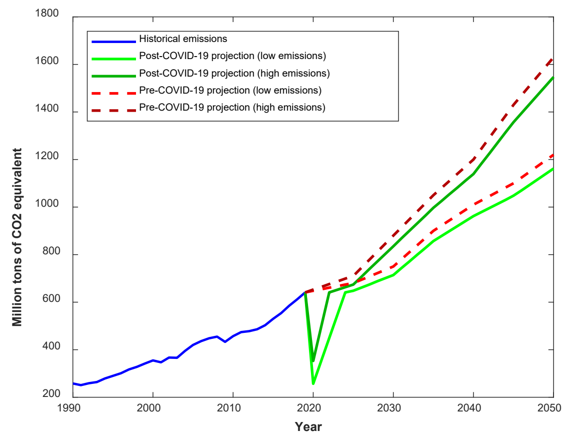

FIGURE 1 HISTORICAL AND PROJECTED INTERNATIONAL AVIATION EMISSIONS (TONS OF CO2 EQUIVALENT PER YEAR). SOURCE: (Climate Action Tracker, 2020)

There is a need for technologies to reduce the pollution generated by commercial aviation. The decrease in air transportation cannot be expected to last indefinitely. Because incentive policies have limited effect, the most promising vector for reducing air transportation pollution is not by restricting the market but by changing passengers' preferences for environmentally friendly airplanes (Gardiner, 2011).

Some initiatives to develop electric air transport (Schäfer et al., 2019; Staack et al., 2020) or even aircraft powered by hydrogen cells have raised hopes (Arat & Sürer, 2018; Baroutaji et al., 2019), but there remain much development, testing and certification to be done for these types of aircraft to become commercially viable at the scale needed to have an impact. Innovations such as electrification of engines or designs of blended wings are still many years from having a functional prototype and even more distant from obtaining an eventual certification for commercial use.

Realistic efforts to make aviation greener are encapsulated in two alternatives: using environmentally friendly materials (Khalil, 2017; D. Vieira & A. Bravo, 2016; D. R. Vieira & A. Bravo, 2016) or reducing the pollution generated by aircraft engines (Berg et al., 2020; Piancastelli et al., 2018; Yilmaz & Atmanli, 2017). In this second line of research, there are two fronts: the use of biofuels or the design of new engines with drastic increases in efficiency. These directions have been taken by many aircraft manufacturers (Gegg et al., 2014; Hari et al., 2015). It is expected that there will be an evolution in this direction in commercial aviation in the coming decades.

There have been few studies conducted of passenger choices of air tickets. One study (Hagmann et al., 2015) examined passenger attitudes toward 12 airlines and found that the general population has little concern about airlines' perceived environmental impacts. Passengers prefer to pay for practicalities, such as more leg room, over paying to travel with a greener company. Another study (Medina-Muñoz et al., 2018) conducted at a large international airport in Spain found that there are eight categories of attributes that affect the attractiveness of flying with a company. Among these attributes, safety and punctuality, ticket price and attention and service during the customer's journey are the most important. The relative importance of several attributes was considered for passengers in South Korea (Kim & Park, 2017). Those flying on full-service airlines prioritize safety, flight schedules, cabin interiors and fast check-in; those flying on low-cost airlines prioritize, in addition to safety, air fares, convenience, fair ticket purchasing procedures, and additional charges. A study of passengers in Turkey (Gurcan et al., 2019) examined how online presence, cabin, flight services, and personnel characteristics could affect customer satisfaction. An exploratory study (Faiyetole & Yusuf, 2018) on international travelers identified five latent variables among the 17 considered: primary preflight considerations (price, safety and availability), in-flight services (onboard comfort, crew courtesy, in-flight entertainment), postflight luggage handling, timeliness of luggage delivery and ease of online booking. However, another study surveying 853 respondents (Milioti et al., 2015) explored factors that impact passengers' decisions regarding airline choice. According to the study, the determining factors influencing the choice were fare, safety and reliability, and friendly and helpful flight staff.

There is a lack of scientific studies that model passengers' preference for aircraft with new-generation engines and the way that this preference interacts with other factors that influence ticket purchases, such as fear of flying, company banners and ticket prices. One study (Fleischer et al., 2012) analyzed the hypothesis that psychometric aspects, such as fear of flying, affect passengers' choices of itinerary. Although that study included different types of aircraft, it did not consider different generations of the same model, nor did it report the influence of aircraft model on passenger choices. Other studies have sought to obtain a general expression of passenger behavior based on price, crew courtesy, preflight experience, booking convenience and customer loyalty (Bravo & Vieira, 2019; Kurtulmuşoğlu et al., 2016). However, no studies have attempted to uncover the impact of cutting-edge aircraft motorization – with its substantially reduced environmental impact – on customers' preference for one air ticket or another.

This article proposes to model passenger behavior with regard to the major features of an air ticket, simulating tickets offered at different price levels by three major Canadian carriers for flights on nine different aircraft types (including a few that use cutting-edge technology), considering passengers' latent fear of flying. The following section discusses commercial aircraft that have become available in the past decade. The next sections present the methodology, analysis and discussion of the results. Finally, this study ends by offering conclusions.

2. GREENER VERSIONS OF CLASSICAL AIRCRAFT THROUGH REENGINING

As discussed, one of the best strategies for reducing the environmental impact of commercial airlines is to introduce more efficient aircraft and upgrade the engines of existing aircraft models to achieve higher efficiency. To appreciate how this can be achieved, it is important to understand the operation of modern engines. The most common design, the so-called turbofan, has a larger inlet fan feeding the coupling of a turbine with a compressor. In this way, air with little energy enters from the front and is transformed before entering the turbine into a gas with a high pressure and temperature. The combustion energy is partly reabsorbed in the turbine and transformed into kinetic energy to the compressor and fan.

An ideal engine operates according to the Brayton cycle. The working fluid is compressed isentropically (i.e., with constant entropy), shown as process 1 in the diagram in **Figure 2**; it is burned isobarically (i.e., with constant pressure) inside the combustion chamber, shown as process ; expanded isentropically through the turbine, shown as process 3 ; and finally cooled isobarically to the initial state, shown as process 4 .

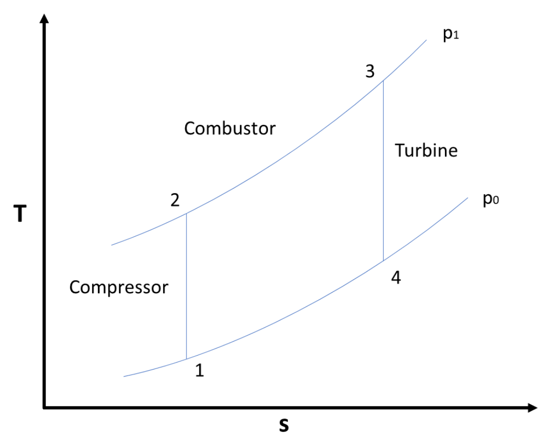

FIGURE 2 TEMPERATURE X ENTROPY () DIAGRAM OF AN IDEAL BRAYTON CYCLE

In practice, there are many irreversibilities in the system, causing loss of energy. The addition of fuel makes it possible to overcome this loss and to produce useful work. However, the amount of fuel that can be fed into the system is limited by the materials and the strength of the parts. This constrains the engine's operating temperature and the high stress on the components due to centrifugal forces. In other words, the limiting factor on engine performance is the temperature and pressure that can be supported by the equipment and its parts.

To increase engine efficiency and make it greener, the main challenges are to increase the temperature of the turbine and the compression ratio. Moreover, as the system turns faster, the tip of the inlet fans reaches higher peripheral speeds; if the inlet fans reach supersonic speeds, efficiency decreases. However, a significant feature of cutting-edge engines is the use of a reducer on the common axis between the compressor and the fan. This allows the compressor to run at very high speeds without loss of fan performance. It is thus possible to increase the fan diameter without exceeding the speed of sound at the tip of the inlet fans.

One of the innovations in Pratt & Whitney's PurePower family of engines is the so-called geared turbofan, which incorporates a gear system capable of differentiating fan rotation from the rotation of high-pressure and low-pressure compressors. In the geared turbofan, a gearbox attached to the fan allows each set to work in almost ideal rotation. Hence, the fan rotates at a lower speed than the compressor and the turbine, translating into a significant reduction in fuel consumption and noise. For example, in the Airbus A320neo (where *neo* stands for new engine option), the use of this engine leads to a 16% reduction in fuel consumption, a 50% reduction in NOx emissions and a 75% noise reduction compared to the engines in previous-generation aircraft (Pratt & Whitney, 2020).

A successor of the long-established CFM56 line of engines is the Leading Edge Aviation Propulsion (LEAP) turbofan engine, designed by CFM International – a consortium between GE Aviation and Safran Aircraft Engines. The LEAP engine was launched at the Paris Air Show in 2005 after being in development since 1999. To increase engine efficiency, many technologies have been applied, most notably ceramic matrix composites (CMCs), which have several properties superior to those obtained with most ceramic materials: high hardness, high resistance to wear, and excellent chemical and thermal stability, even at temperatures of up to 1300 °C (approx. 2400 °F). This heat resistance allows the use of the material in the manufacture of several parts, which makes the engine lighter.

Another important feature in the newly designed LEAP engines is the combination of blades and disks into so-called *blisks*. In addition, new materials and the two-stage high-pressure turbine vastly improve the thermal efficiency of the engine, leading to double-digit improvement in fuel efficiency (Teketay, 2017). All of these improvements and others amount to a 15% reduction in fuel consumption, a 50% reduction in NOx emissions, and a noise reduction of 15 effective perceived noise in decibels (EPNdB) compared to the previous-generation CFM56-7B and CFM56-5B engines, which power the Boeing 737 Next Generation (B737NG) and the Airbus A320, respectively (Safran, 2011).

The two engine families – Pratt & Whitney PurePower and CFM International LEAP – are largely responsible for the new generation of greener aircraft that were introduced at the Farnborough Airshow in 2008. In that event, the Canadian regional aircraft company also announced the launch of its largest commercial aircraft, called the CSeries. With a capacity just above 100 passengers, these aircraft straddle the small regional and midsized aircraft categories. In this way, the Canadian company could venture into a market dominated by the giants Airbus and Boeing. To convince airlines to forego the aircraft offered by this duopoly and adopt the CSeries, Bombardier strived to make the aircraft the most efficient in its class. The plane would have many modern technologies, including extensive use of composites and a new-generation engine with greater efficiency (Gomes, 2012).

The CSeries generated some interest among airlines. However, Airbus quickly orchestrated a response. The first possibility for action was to propose a design entirely its own from scratch, but the costs associated with a new design were on the order of 7 billion dollars, and the project would take approximately 6 years. Having a very solid platform already, Airbus chose to adopt one of the fuel economy technologies found in the CSeries in its successful A320 aircraft. Thus, the Airbus A320neo was born in 2010 (Petrescu et al., 2017). The new engines available are the Pratt & Whitney PW1000G (similar to the engine used in the CSeries) and the LEAP-1A. This proved to be a successful choice, as this new proposition broke many sales records. By 2018, 6500+ aircraft had already been sold, capturing 60% of the market (Airbus, 2020).

Although 1%-2% of the savings provided by the new engines is lost when the engines are retrofitted onto the existing airframe, it seems that the determining factor of the aircraft's success is the combination of market familiarity with the airframe and the adoption of new-generation engines. Boeing followed a similar path, and in 2011, it launched a program to reequip its B737NG. In this new version, called the Boeing 737 MAX (B737 MAX), the engine used was the LEAP-1B (Teal, 2014). The market reception was similar to that of the A320neo, with 5000+ cumulative sales by the end of 2018. In response, the Brazilian manufacturer Embraer followed this same path to reengine its most successful aircraft. The E2 versions of its E-Jet family were launched at the 2013 Paris Air Show with strong market support. This new version of the classic E-jets uses Pratt & Whitney PurePower engines, similar to those used in the A220, A320neo. Upon the launch alone, 215 aircraft were sold (Gomes et al., 2018). While the CSeries did not sell well initially, with just 137 units sold by 2017 (Bombardier, 2016), it attracted the attention of Airbus, which acquired a majority stake in Bombardier and rebranded the series as A220 in 2018. Since then, the A220 has been a commercial success, in part due to the extensive use of composite materials, cutting-edge engine design and the significant Airbus brand.

The International Council of Clean Transportation analyzed the CO_2 emissions of all major commercial aircraft from 2013 to 2019 (Graver et al., 2020). In some cases, multiple versions of the aircraft were considered, but the B737 MAX was notoriously excluded because of the grounding. Because of the effort required to lift the aircraft at take-off and the fuel consumed to taxi, aircraft that are usually scheduled on short flights tend to be penalized in this kind of study because of their frequent landings and take-offs. To allow fair comparison, the study presents the emissions at various flight distances. On trips of length between 1500 km and 2000 km, regional jet emissions per passenger-kilometer are approximately 50% higher than wide-body jet emissions, which are 25% higher than narrow-body jet emissions. Table 1 shows the average performance, measured in grams per revenue passenger-kilometer (g/RPK), for some of the aircraft in this study.

TABLE 1 APPROXIMATE CO2 EMISSIONS OF MAJOR COMMERCIAL AIRCRAFT. SOURCE: (Graver et al., 2020)

	Embraer E190*	Boeing B737NG**	Airbus 320	Airbus A320neo	Boeing B777***
CO2 emissions (g/RPK)	150-155	79-100	80	65	90-93

* Includes E190 and E195
** Includes B737-700, B737-800 and B737-900
*** Includes B777-200 and B777-300

3. METHODOLOGY

The purpose of the current study is to detect the most important choice drivers when travelers buy flight tickets. Survey participants from the province of Quebec (Canada) received simulated ticket alternatives, all of them offering a round trip with departure from Montreal and Mexico City as the destination. The trip was presented to participants as a sun-seeking vacation, a common choice for Canadian residents in the winter (Coates et al., 2002; Desrosiers-Lauzon, 2009). Each participant was then asked to choose the best ticket from a set of nine options.

All aircraft mentioned in the previous section were included in the study, along with two others, for a total of nine aircraft. The first addition was the Boeing 777, which is well recognized and flown by many airlines on transatlantic and transpacific flights, having earned a good reputation in the industry (Stewart, 2014). This is the only twin-aisle (wide-body) aircraft in the study, and it serves as a benchmark comparison with single-aisle (narrow-body) aircraft models. The other inclusion is the Russian Sukhoi Superjet 100 (SSJ100). Unlike other Russian commercial aircraft, this aircraft was developed with an international perspective, with many international suppliers, support from Boeing and marketing efforts by the Italian firm Alenia Aeronautica (Corallo et al., 2010). The model is a single-aisle aircraft with a capacity slightly under 100 passengers.

An exclusive focus on aircraft models would limit the scope and results of the study since one cannot buy a ticket with just aircraft information. For this reason, the study included three airlines associated with the tickets: Air Canada (AC), WestJet (WJ) and Sunwing (SW). The first is a legacy airline offering full service to most major airports in the world. Although it was privatized in 1989, it is still considered the Canadian national airline by many and is the largest among the three airlines in the study. Canada's second largest airline is WestJet, which flies many domestic routes as well as routes from Canada to the rest of North America. Some consider it a low-cost airline, unlike Air Canada. The third airline is Sunwing, and as the name implies, SW focuses on traveling south to touristic destinations. It is also known for being a low-cost airline, and its flights are often associated with travel packages by tour companies.

Each of these airlines has a distinct image with the general public, but a passenger is unlikely to choose one ticket over another solely because of the plane model and the airline; an often-decisive factor is the price of the ticket. The study considered nine price levels, rising from Can$600 to Can$1400 in Can$100 intervals. This price range was chosen because it is in the range offered on the airlines' websites for travel on this route, as shown in Table 2.

TABLE 2 ACTUAL AND SIMULATED ROUNDTRIP TICKET PRICES. SOURCE: KAYAK.COM IN MAY 2020

	Actual ticket prices (economy) Montreal to Mexico City	Prices used in the experiment
Min	US$478 (Can$678)	Can$600
Max	US$1000 (Can$1410)	Can$1400

Finally, we included a few questions to assess participants' fear of flight (FoF) and the way passengers' inherent fear of air travel affects their selection of air tickets from different airlines and for flights on different aircraft.

To decrease the number of comparisons and to maximize the significance of the results, we assigned the three attributes (aircraft, airline, price) to the air tickets according to an orthogonal fractional factorial model.

To measure participants' air ticket preferences, we prepared a questionnaire organized into three sessions. The first section collected demographic information, and the second section contained an established instrument with 11 questions to assess participants' FoF (Fleischer et al., 2012). The third section proposed nine sets of potential air tickets, from which participants selected their top choice. **Figure 3** shows a typical set (translated from the French original). The ticket sets were deconflicted such that no two tickets cost the same or used the same aircraft, and there were exactly three alternatives for each of the three airlines.

Which of the following plane tickets would you select for your 2019 vacation?

Your destination is Mexico City, with the flight departing from Montreal. The price is for a roundtrip flight. The scheduled departure date is December 23, 2019, and the return date is January 3, 2020.

- Sunwing flying on a Sukhoi Superjet 100 aircraft at a price of Can$700.
- WestJet flying on an Embraer E190 aircraft at a price of Can$1400.
- Sunwing flying on an Airbus A320 aircraft at a price of Can$1000.
- Air Canada flying on an Airbus A220 aircraft at a price of Can$1200.
- Sunwing flying on a Boeing 737 MAX aircraft at a price of Can$1300.
- WestJet flying on an Airbus A320neo aircraft at a price of Can$800.
- Air Canada flying on an Embraer E190-E2 aircraft at a price of Can$900.
- WestJet flying on a Boeing 777 aircraft at a price of Can$1100.
- Air Canada flying on a Boeing 737NG aircraft at a price of Can$600.

FIGURE 3 TYPICAL SET OF FICTIONAL TICKETS

In view of the population sampled, we used a mixed logit model (random parameter logit model). With this model, the parameters vary from one individual to another – a plausible assumption since people have different levels of travel experience and different fears of flying. This random utility model uses the following notation: each person *q* chooses ticket among all alternatives in choice opportunity *t* (one among the sets evaluated by the participant). Each person *q* has complete knowledge about the proposed alternatives, and he or she understands what is proposed in each ticket. The participant associates a utility value with each proposal and opts for the offer with the highest relative utility, as defined below (Jones & Hensher, 2004):

$$U_{itq} = \beta'_q X_{itq} + \epsilon_{itq} \qquad (1)$$

In this general utility expression, is a vector of explanatory observed variables (the choices). The stochastic variables and are not observable; is a coefficient associated with each observable characteristic, and is the error term (unobservable effects). A condition of this model is that is an independent and identically distributed (IID) extreme value of a type 1 variable (Hensher & Greene, 2003). The IID consideration is restrictive, given that it does not allow the error components of alternative results to be correlated. To include this restriction, the stochastic component of the model is partitioned into two unrelated additive parts: one part is correlated with alternative and heteroscedastic results, and the other part is IID on alternatives and individuals (Jones & Hensher, 2004), as follows:

$$U_{iq} = \beta' x_{iq} + (\eta_{iq} + \varepsilon_{iq}) \qquad (2)$$

where is a random term with zero mean for which the distribution depends, in general, on the underlying parameters and the observed data related to alternative *i* and participant *q* (Hensher & Greene, 2003). In this case, is also a random term with zero mean on the alternatives and does not depend on the underlying data.

The mixed logit model class assumes a general type 1 IID distribution for . That is, can take several distribution forms – we assume a normal distribution. We denote the density function by , where is the fixed parameter of the distribution. For a given value of , the conditional probability of result *i* is logit because the remaining error term is the IID extreme value:

$$L_i(\eta) = \frac{e^{(\beta' x_i + \eta_i)}}{\sum_j e^{(\beta' x_j + n_j)}} \qquad (3)$$

Since is not provided, the (unconditional) probability of the result is this logit formula integrated over all values of weighted by the density of .

$$P_i = \int L_i(\eta) f(\eta|\Omega) d\eta \qquad (4)$$

The data were processed on a computer equipped with an i7-6770 processor with 16 GB of DDR4 RAM using the R language (v.3.6.2) for Windows (32/64 bits). The mlogit package was used to obtain the solution of the mixed logit model, assuming that the parameters were normally distributed.

4. RESULTS

There were N = 102 participants in this study. In each questionnaire, participants were offered nine sets of nine tickets, and from each set, participants were asked to select their preference. Table 3 shows participant demographics according to level of education. Half of the respondents held a graduate degree. The second largest group had completed their undergraduate education. The gender distribution was 62 males and 40 females. Regarding the age distribution, the median age was 26 years, ranging from 19 to 56. The average sample age was 29.34 years old with a standard deviation of 7.94.

TABLE 3 LEVEL OF EDUCATION OF PARTICIPANTS IN THIS STUDY

Levels	Counts	% of Total	Cumulative %
Technical	1	1.0%	1.0%
College	7	6.9%	7.8%
Undergraduate	40	39.2%	47.1%
Graduate	51	50.0%	97.1%
Postgraduate	3	2.9%	100.0%

To compare preferences for each aircraft, we used the Boeing 777 (B777) as the benchmark, and we used SW as the reference for the air carriers. The first column in Table 4 shows the model variables. The other columns include the estimation values, followed by standard errors and z-values. Most z-values are outside the (-1.96, 1.96) range, indicating that the coefficients are statistically significant. Parameters with z-values close to zero (FoF AC and FoF WJ) are identified in italics, indicating low statistical significance.

TABLE 4 ESTIMATED COEFFICIENTS, STANDARD ERRORS, AND Z-VALUES

Parameter	Estimate		Std. Error	z-value
B737NG	2.860	***	0.470	6.089
FoF B737NG	-0.275	***	0.074	-3.722
Price B737NG	-0.250	***	0.048	-5.237
B737 MAX	3.570	***	0.472	7.565
FoF B737 MAX	-0.424	***	0.086	-4.901
Price B737 MAX	-0.297	***	0.045	-6.633
A320	4.742	***	0.536	8.841
FoF A320	-0.398	***	0.073	-5.438
Price A320	-0.406	***	0.062	-6.595
A320neo	3.805	***	0.500	7.611
FoF A320neo	-0.431	***	0.076	-5.631
Price A320neo	-0.274	***	0.047	-5.789
A220	4.610	***	0.529	8.721
FoF A220	-0.408	***	0.082	-4.950
Price A220	-0.425	***	0.060	-7.110
E190	3.969	***	0.490	8.101
FoF E190	-0.270	***	0.080	-3.386
Price E190	-0.377	***	0.050	-7.481
E190-E2	4.243	***	0.601	7.057
FoF E190-E2	-0.456	***	0.099	-4.622
Price E190-E2	-0.422	***	0.063	-6.668
SSJ	4.025	***	0.590	6.822
FoF SSJ	-0.406	***	0.091	-4.466
Price SSJ	-0.400	***	0.074	-5.417
AC	1.125	***	0.341	3.297
FoF AC	-0.008		0.053	-0.156
Price AC	-0.066	*	0.031	-2.093
WJ	0.871	*	0.344	2.535
FoF WJ	0.059		0.052	1.136
Price WJ	-0.105	**	0.035	-3.019

*Significant at the $p < 0.05$ level. **Significant at the $p < 0.01$ level. ***Significant at the $p < 0.001$ level.

As previously discussed, the model built in this article contains many variables. As expected, all coefficients for price interaction parameters have negative values, indicating that as ticket prices increase, passengers tend to shy away from the option.

The first analysis considers the airline choice only, regardless of the airplane model, and the interaction of the ticket price with the passenger's latent fear of flying. These results are detailed in **Figure 4**. In this image, the red line represents a preference for AC, the blue line represents a preference for SW and the green line represents a preference for WJ. At all levels of FoF, regardless of the price, Air Canada is the airline of choice. This might be related to the fact that AC is considered the national airline by the general public, and it has the strongest marketing presence among the three airlines, promoting a premium experience.

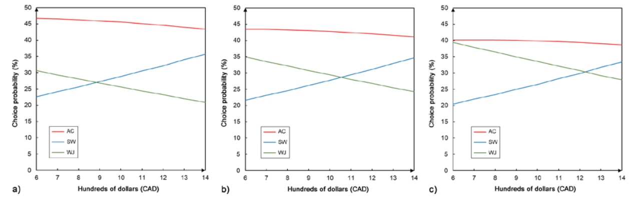

FIGURE 4 CARRIER PREFERENCE ACCORDING TO TICKET PRICES: A) LOW FOF, B) INTERMEDIATE FOF AND C) HIGH FOF

The preference for Air Canada is more pronounced at intermediate prices, especially if the passenger is less sensitive to fear of flying. In that case, there is a choice probability difference of 18.9% between AC and the other airlines at the Can$883.41 price point. If the passenger has an intermediate FoF, the difference in choice probability peaks at 13.9% at the Can$1054.59 price point. If the passenger has a high FoF, the difference is the lowest. In fact, at the Can$600 price point, the choice probability difference between AC and WJ for passengers with high FoF is immaterial, and it peaks at just 9.0% when the price is Can$1225.96.

The second preferred airline is not the same at both ends of the scale. WestJet is preferred over Sunwing if the price is low, and Sunwing is preferred over WestJet if the price is high, possibly because Sunwing travel is associated with spending holidays in resorts abroad, where travelers are less price sensitive. On the other hand, WestJet is known for opening new routes to travelers that have limited access to air travel, and they might be more price sensitive than average. Finally, FoF has limited influence on passengers' choice of one airline over another; AC's leadership decreases only slightly in this case.

It seems that other factors are more important than the airline option when the passenger has a high fear of flying. For this reason, it is important to examine the interaction between aircraft alternatives, price levels and fear of flight.

Figure 5 describes passenger behavior when choosing between single-aisle and twin-aisle aircraft at different price points. Continuous lines represent passengers with a low FoF, and dotted lines represent passengers with a high FoF. Blue lines represent twin-aisle aircraft (in our study, the B777 only), and red lines represent single-aisle aircraft (i.e., all other aircraft in this study).

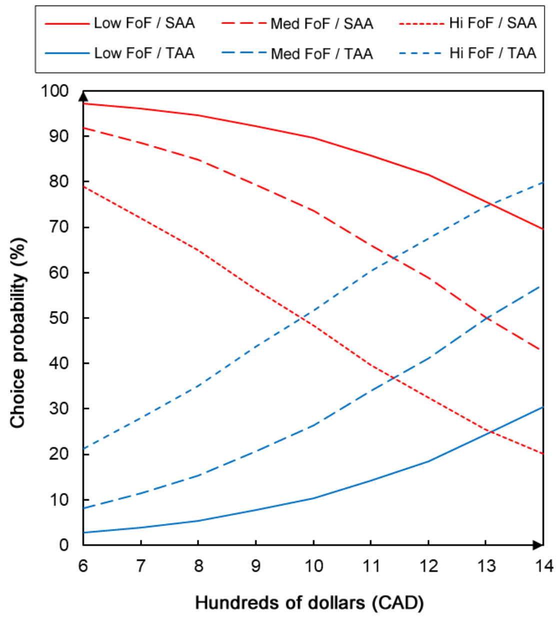

FIGURE 5 SINGLE-AISLE VS TWIN-AISLE PREFERENCE ACCORDING TO FEAR LEVELS

If customers were indifferent to the type of aircraft, the blue lines should stay at approximately the 11.1% mark, and the red lines should stay at approximately 89.9%. In other words, the choice probability would be the same 1/9 for each aircraft. In practice, this is true only for passengers with intermediate or low levels of fear at low price points. As the price increases, passengers become more sensitive to the size of the aircraft and to their fear, and the preference for the B777 increases. For passengers with an intermediate FoF, that preference for the B777 is greater than the preference for all other aircraft combined when the price is greater than Can$1300; if they have a high FoF, the preference for the B777 dominates the preference for all other models when the price is greater than Can$979.25. At the high end of the price scale, passengers with a high FoF have a choice probability of approximately 79.8% for the B777.

This phenomenon of the Boeing 777 choice concentration among respondents with a high FoF is rather surprising, considering that there are a large number of alternatives, including modern aircraft with lower noise and emission levels. Size definitely matters for those individuals who are afraid of flying, especially those who are also willing pay a higher fare for ticket. This massive preference choice for the B777 is can be explained by large airplanes being considered more comfortable and less sensitive to turbulence.

Figure 6 shows the single-aisle aircraft represented in their classic denominations only. The new more ecological variants of the classic models (the B737 MAX and A320neo) and the twin-aisle B777 are not included. When the FoF level is low, passengers' favorite aircraft are the classic models of the aeronautical giants Airbus and Boeing, but the preferred aircraft model varies greatly depending on the price range. At the low end of the price scale, the A320 choice probability peaks at 18.5%. The A320 is the preferred aircraft for prices lower than Can$1127.64, when it has the same choice probability of 11.8% as the B737NG. For higher price points, the B737NG is preferred; at the high end of the price scale, the B737NG choice probability is 12.1%.

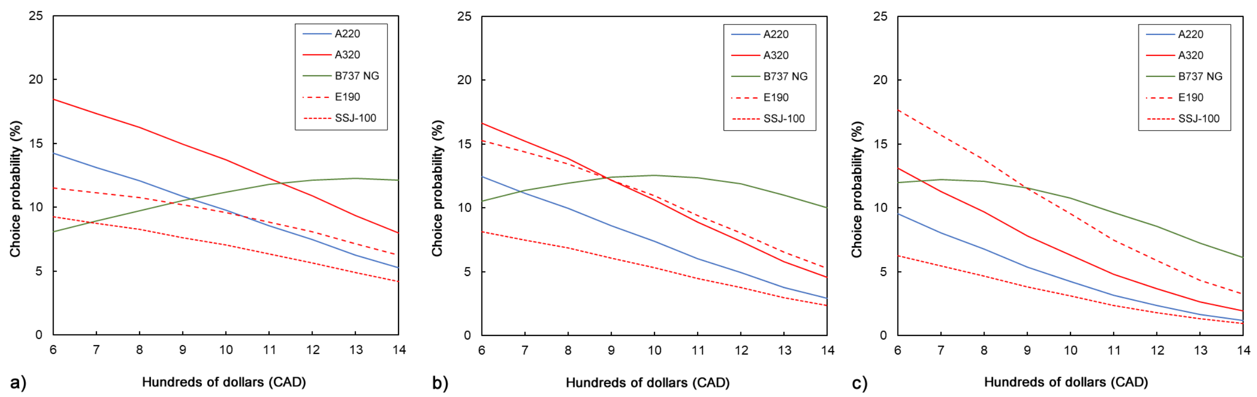

FIGURE 6 AIRCRAFT MODEL PREFERENCE ACCORDING TO TICKET PRICES: A) LOW FOF, B) INTERMEDIATE FOF AND C) HIGH FOF

Three aircraft (the A320, A220 and SSJ100) have monotonically decreasing and approximately linear price-preference relationships at low or intermediate levels of FoF. That relationship becomes slightly convex but still decreases at high FoF levels. The choice probability differences for the three aircraft are higher at Can$600 (the lowest price in the survey), and these choice probability differences decrease as price increases.

The preference for the A220 is 2.7%-4.2% lower than the preference for the A320 when the passenger has a low FoF and 0.7%-3.6% lower when the passenger has a high FoF. Among the planes in the study, the least preferred is the SSJ100; its preference level is always 1.1%-5% lower than the preference for the A220 at a low FoF and 0.2%-3.3% lower at a high FoF.

Passengers seem to be somewhat indifferent to differences across the three aircraft models at the high end of the price scale. At Can$1400, the choice probability difference between the A320 and the A220 and between the A320 and the SSJ100 are 0.7% and 1%, respectively. This is a surprising result, considering that the A320 is a classic aircraft with a great safety history; one would expect passengers to have a greater preference for the A320 against these newcomers. The A220 is a completely new aircraft without much history, while the SSJ100 is basically unknown to most travelers in North America, and it comes from a manufacturer outside the Airbus-Boeing duopoly. A possible explanation for this result is not that passengers are equally confident in these three aircraft but that the distortion caused by the interaction between high FoF and high price renders all three alternatives somewhat undesirable: in this scenario, passengers are more concerned with aircraft size than aircraft model, allowing the B777 to dominate in terms of customer preference (according to **Figure 5**).

Looking back at **Figure 6a**, the preference for the B737NG monotonically increases with price for passengers with a low FoF, from the least preferred option with 8.1% choice probability to the preferred one with 12.1% choice probability. At a medium level of FoF, the preference for this aircraft is relatively constant independent of price at approximately 10.0-12.5%. We note a slope inversion in the choice probability of the B737NG of function of price for those with high FoF; in this case, the B737NG is the aircraft with the second highest preference in the low end of the price range with a 12.0% choice probability, but at the high end price, this value drops to 6.1%, despite being the preferred option at this point. The slope inversion that occurs when we compare low-FoF with high-FoF respondents is due to the high-FoF passengers' preference for the B777. Interestingly, the regional jet E190 is the second most competitive aircraft for passengers with a high FoF, particularly at prices lower than Can$898. At the low-end of the price offered, this airplane shows some popularity, having a 17.7% chance of being chosen. Nonetheless, like the other options analyzed in **Figure 6c**, the preference for this option drops sharply to only 3.3%. The effects of the decreasing preference for these smaller planes as prices increase are linked to, as previously observed, those who are afraid of flying tending to prefer airplanes such as the B777 (twin-aisle) as prices increase.

Since it was possible to verify that twin aisles inspire comfort and safety, a similar phenomenon could occur since the choice of certain passengers could be driven by the factor of aircraft brand rather than aircraft type. **Figure 7** compares the three major brands: Airbus, Boeing and Embraer. It is worth including Embraer in this comparison with the giants due to the large presence of its regional jets in the North American market. To separate only the effect of branding on the single-aisle aircraft market, we include only the A320, B737 and E190 models in this comparison, not distinguishing between the classical and more ecological, re-motorized equivalent models.

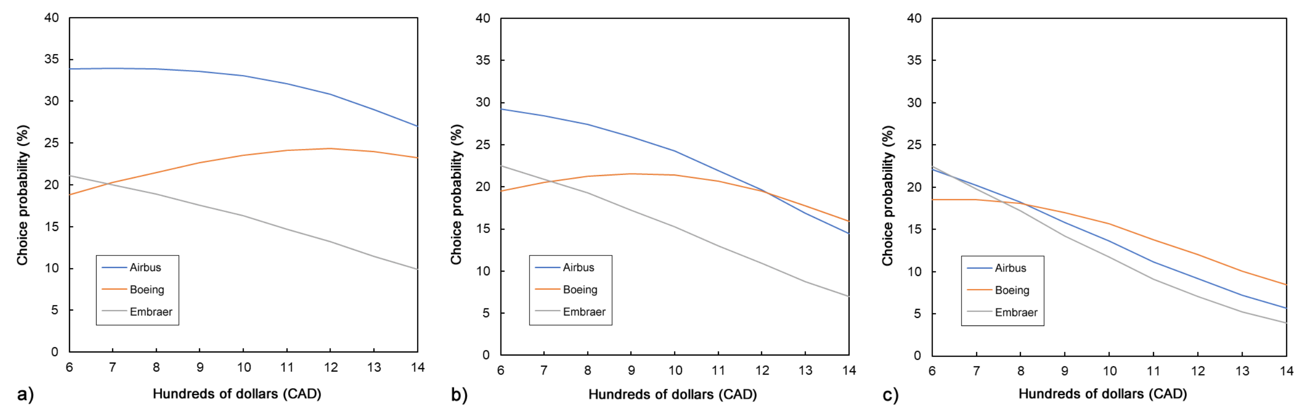

FIGURE 7 MANUFACTURER PREFERENCE AT DIFFERENT TICKET PRICES (EXCLUDING THE B777 AND A220): A) LOW FOF, B) INTERMEDIATE FOF AND C) HIGH FOF

When the FoF is high, all curves have a negative slope, meaning that the choice probability drops as the price increases. This results from the preference for the B777 among high-FoF passengers. At the high end of the price scale, the combined preference for aircraft of this analysis is only 18.0%, the highest being Boeing with an 8.4% choice probability and the lowest being Embraer with a 3.9% choice probability. It can be seen that as fear subsides, the distinctions across brands are more visible. **Figure7c** demonstrates that passengers are rather indifferent to aircraft brand when they have high FoF, with the preference between brands being marginal in this situation, confirming that, in this scenario, aircraft size would be the main deciding factor.

This outcome is not the case when FoF decreases, and it is possible to see in **Figure 7a** a substantial differentiation among brand preferences. In this scenario, Airbus has the public's preference at all price points, ranging from a 27% to a 34% choice probability, while Boeing holds second place in public preference at most price points. Among the three brands, Embraer usually has the lowest choice probability except when the price is at Can$700 or lower. This is a positive outcome, considering that the CO_2 emissions of modern single-aisle aircraft from Boeing and Airbus are lower than those from any other aircraft (Graver et al., 2020). On the other hand, the low preference for Embraer aircraft may arise because it is a company outside the Airbus-Boeing duopoly and headquartered in a developing country, which might create discomfort to some passengers. Quite the opposite reasoning is valid for both Boeing and Airbus. Boeing is preferred in the high-FoF scenario when the price is higher than Can$788.06, and it is preferred in the medium-FoF scenario when the price is higher than Can$1211.58. Airbus is preferred in all other scenarios, except at the low end of the price scale for high-FoF passengers.

These results indicate that accidents with the B737 MAX and subsequent grounding of the type have not affected the image of the Boeing company, only of that particular plane. To assess whether this is the case, **Figure 8** compares the two single-aisle Boeing aircraft to determine whether passengers have a clear preference for either model. In addition, the chart shows the interaction between single-aisle Boeing aircraft and airline preference to identify any significant preference created by this interaction. **Figure 8a** shows that the choice probability for each 737 model is approximately the same for low-FoF passengers but that the B737 MAX draws a slightly higher preference, regardless of the airline, except at the high end of the price scale. Low-FoF passengers traveling on B737 usually prefer Air Canada over Sunwing or WestJet.

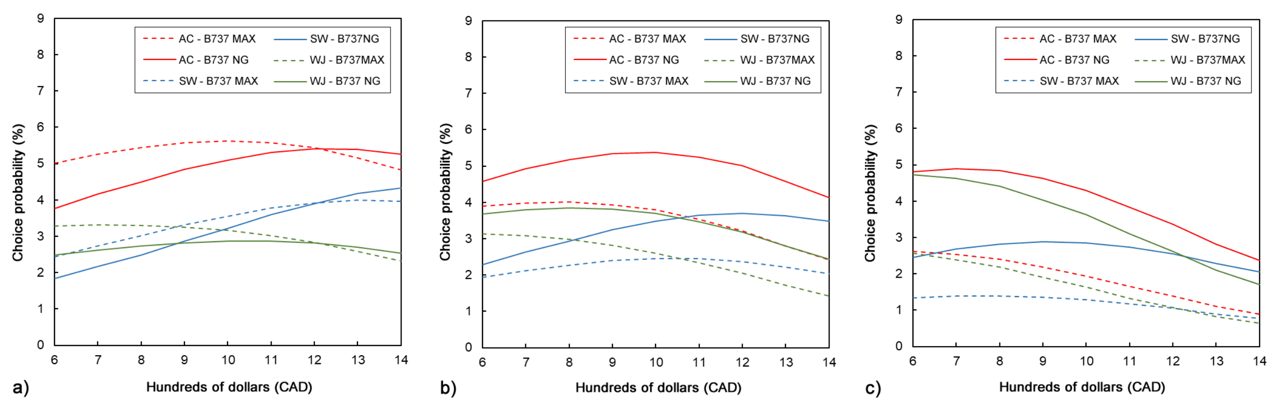

FIGURE 8 BOEING 737 AIRCRAFT FAMILY PREFERENCE INFLUENCED BY CARRIER AND PRICE: A) LOW FOF, B) INTERMEDIATE FOF AND C) HIGH FOF

The choice probabilities observed in **Figure 8c** differ significantly from those in **Figure 8a**. In the first figure, there seems to be some indifference between the two Boeing models. However, when the FoF is high, at all price points, the B737NG is preferred over the B737 MAX, regardless of the airline. Preference for the B737 MAX is lowest at the high end of the price scale. For passengers with a low FoF, the most important decision seems to be the choice of airline, and AC is preferred. For passengers with a high FoF, the choice of aircraft is more important, and the B737NG is preferred. These results demonstrate that, although Boeing as a whole has an outstanding reputation of producing high-quality trustful airplanes, the mediatization of accidents and grounding of the B737 MAX had effects on the population causing an avoidance from this version that is directly proportional to the FoF level.

This fact is very unfortunate because the engines of the MAX version produce significantly less pollution overall.

Figure 9 compares the two Embraer models. Interestingly, the Embraer models are affected by fear of flight and airline preference in the same way as the Boeing models are, but with a few important differences. For the choice between the E190 and the E190-E2, the choice probability of the original E190 is higher at all price points, regardless of the airline, at all levels of FoF. At intermediate and high FoF levels, the choice probability of the E190-E2 is very low. For the choice between one of the three airlines on an Embraer aircraft, AC has the highest choice probability, regardless of the FoF level, at all price points. Nonetheless, although the E190 is a somewhat popular option, people tend to avoid the ticket when it is offered by SW airlines. This outcome is most visible in the high FoF scenario at the low end of price. In this case, the preference for WJ or AC is the same with an approximately 7% choice probability, but for the SW option, the choice probability drops to 3.6% perhaps because this combination makes the more exotic option of Embraer less familiar than Airbus/Boeing in terms of aircraft and SW less familiar than AC/SW in terms of airline to the North American public.

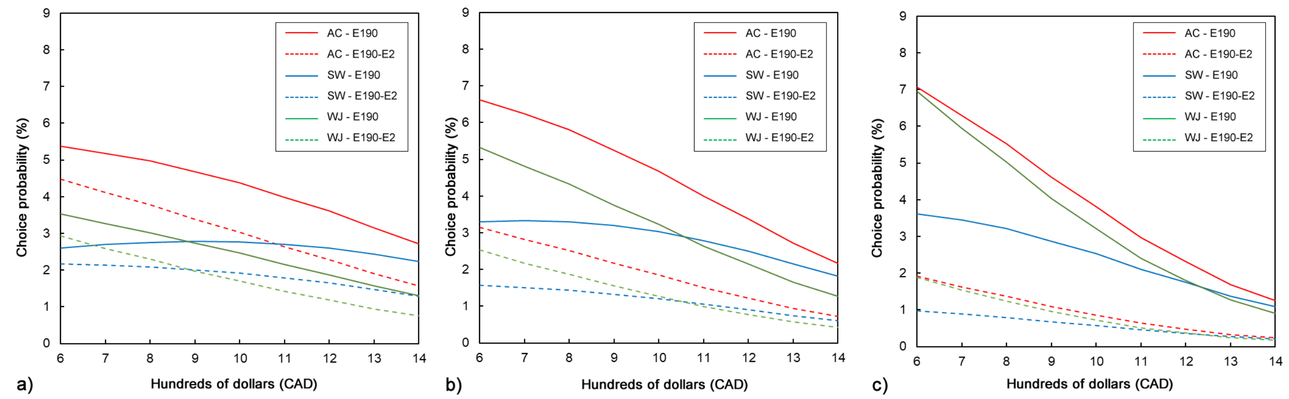

FIGURE 9 EMBRAER E190 AIRCRAFT FAMILY PREFERENCE INFLUENCED BY CARRIER AND PRICE: A) LOW FOF, B) INTERMEDIATE FOF AND C) HIGH FOF

The choice probability of the E190-E2 model for passengers with an intermediate or a high FoF monotonically decreases with price, being lower than 0.5% at the high end of the price scale for high-FoF passengers, regardless of the airline. This is surprising since the E190-E2 model has not suffered any reputation-damaging events such as grounding. Therefore, this phenomenon cannot be attributed to the new motorization; the low preference might be due to the North American public's lack of familiarity with this newest Embraer aircraft. This fact is again very unfortunate because the engines of the E2 are much more environmentally friendly than the previous generation, producing substantially less CO_2 per trip. As in the case of the Boeing models, for passengers with a low FoF, the most important decision seems to be the choice of airline, and AC is usually preferred. For high-FoF passengers, the choice of aircraft is more important, and at the high end of the price scale, the choice probability for each of the three airlines is approximately the same.

A comparison of the aircraft in the Airbus A320 family leads to different observations. Once again, Air Canada tickets lead with greater choice probabilities, but the similarities end there, as shown in **Figure 10**. For low FoF levels, the preference for the A320 model decreases with price increases, while the preference for the A320neo is increasing, or its slope is less negative. For all carriers and all fear levels, the choice probability for the A320 is higher than that for the A320neo at the low end of the price scale, but that preference switches at some point near the low end of the price scale, and the A320neo becomes the preferred model for most of the price scale. That switchover occurs at approximately Can$750 or Can$800 for low and intermediate FoF levels and at approximately Can$900 for a high FoF. For passengers with a high FoF, **Figure 10c** shows that the choice probability difference between Air Canada and WestJet is immaterial, regardless of the aircraft model, along the whole price scale.

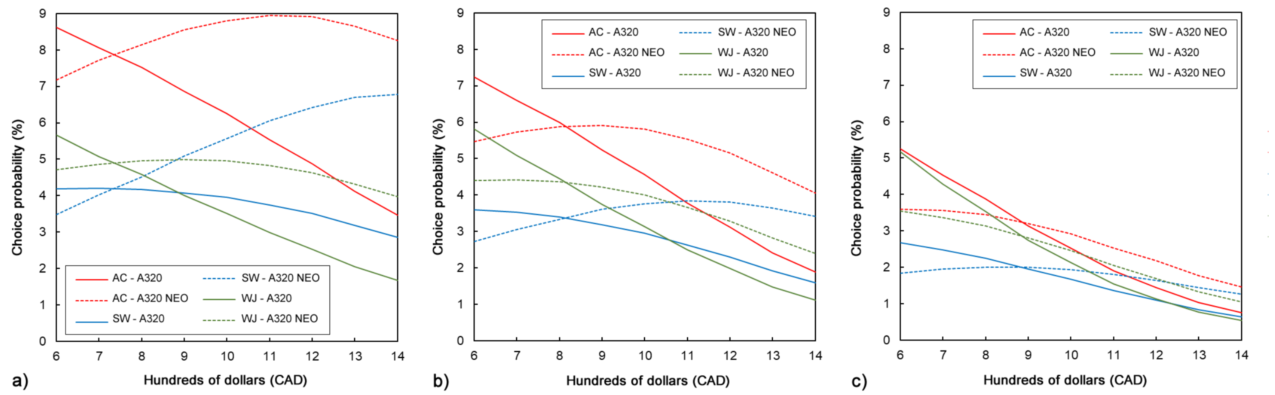

FIGURE 10 AIRBUS A320 AIRCRAFT FAMILY PREFERENCE INFLUENCED BY CARRIER AND PRICE: A) LOW FOF, B) INTERMEDIATE FOF AND C) HIGH FOF

It is not the simple fact of offering customers an air ticket option that has an equivalent aircraft but also a newer, more modern and more environmentally friendly version that will naturally cause passengers to migrate to ecological choices. Passengers feel at ease with newer models that are more economical and environmentally friendly only when it comes to certain price ranges of the A320 family. This phenomenon is likely due to the combination of Airbus' strong presence, marketing capacity, and public familiarity (which is not the case for Embraer and its E2 family) coupled with the absence of fateful and heavily mediatized events (which is not the case for Boeing and its B737 MAX family). Any of these discomforts could invalidate efforts to lead passengers to opt for less polluting aircraft alternatives in terms of CO_2. In this case, proactive marketing measures would be recommended to raise additional awareness that tickets with newer aircraft options are not only greener but also more comfortable and safer and thus a better choice overall.

5. CONCLUSIONS

This article analyzes the results of a model to determine passengers' preferences in terms of airlines and aircraft models for vacation flight tickets and the ways in which these air ticket features interact with ticket prices and passengers' inherent fear of flying. Nine aircraft were considered in this study. Among them, four have recently been designed to incorporate new motorization and light materials to support reduced noise and lower fuel consumption, which enable lower CO_2 emissions.

It was observed that under general conditions, AC is passengers' favorite carrier at every price point. WJ and SW have similar choice probability levels between them; however, WJ is preferred over SW at lower prices, which is in line with the WJ business proposition as a low-cost carrier. SW is preferred at higher prices, probably because the company is associated with taking its passengers to exotic and expensive holidays in resorts abroad, where customers might be less price sensitive. In general, the FoF has little influence on the behavior of passengers in terms of choosing one company over another, and AC's leadership seems to decrease slightly only at higher FoF levels.

In a comparison of the aircraft, wide-body aircraft attract the clear preference of high-FoF passengers. In fact, the only twin-aisle aircraft in the study, the B777, has a higher choice probability level than all of the single-aisle aircraft combined when the price is higher than Can$1302 for passengers with an intermediate FoF level or when the price is higher than Can$979 for passengers with a high FoF. This choice concentration on the Boeing 777 for high-priced tickets among high-FoF passengers is surprising, given the large number of more modern and convenient alternatives. This is probably due to the idea that large airplanes are safer and less sensitive to turbulence.

In a comparison of brands, models outside the Airbus-Boeing duopoly have low preference. Perhaps this is because the new entrants, Embraer and Sukhoi, are headquartered in developing countries, which may cause some passengers to question the quality of their products. If we compare the two leaders, Boeing seems to command higher prices for passengers with a high FoF, but Airbus has a much higher choice probability at all price levels among passengers with a low FoF. This is the opposite of what one would expect after the accidents that grounded the B737 MAX. It seems that these accidents affected the image of that particular aircraft but not of the Boeing brand overall.

Considering all charts in **Figures 8-10**, it is worth noting that the A320neo is the only aircraft with modern motorization that has a choice probability consistently higher than that of the traditional version of the same aircraft; passengers prefer the B737NG over its younger sibling the B737 MAX, and they prefer the E190 instead of the newer E190-E2. It is not difficult to explain why the E190-E2 or B737 MAX might not be the first choice for most passengers with high FoF levels. However, this is a setback in the effort to reduce the environmental impact of commercial air travel, considering that significant improvements depend on the adoption of these newer and more efficient aircraft with lower emission levels. Further studies should be performed once the Boeing 737 MAX has its safety record reestablished to evaluate whether travelers become more confident in that new airframe.

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ABOUT AUTHORS

Alencar Bravo

Université du Québec à Trois-Rivières, Canada

Alencar Bravo holds a PhD in engineering from the Université du Québec à Trois-Rivières (Canada), and he is a professor of project management at the same university. He also holds two professional master's degrees in mechanical engineering from the National Institute of Applied Sciences in Lyon (France) and the Technical University of Catalonia (Spain). He has significant experience in the field of industrial research and in development projects of high technical complexity, especially in the automotive and aeronautical fields. Other areas of research interest include eco-design tools, techniques and methods; life cycle management and total cost of ownership; uncertainty and risk management; customer behavior; and management and support systems in projects.

Darli Rodrigues Vieira

Université du Québec à Trois-Rivières, Canada

Darli Rodrigues Vieira, PhD, is a full professor of Project Management at the University of Quebec in Trois-Rivières (UQTR). He is currently the Director of the Master program in Project Management at this university. His current research focuses on project management, defense projects, product lifecycle management, new product development, supply chain management, strategy and management of operations, and management of MRO (Maintenance, Repair & Overhaul). He has over 25 years of professional experience in a variaty of roles and industries. Also, he was the holder of the Research Chair in Management of Aeronautical Projects (2013 – 2019) and Head of the Management Department (2018-2021).

Geraldo Ferrer

Naval Postgraduate School, United States

Supply Chain Management Professor Geraldo Ferrer is an expert in the areas of global operations, supply chain management, sustainable technologies, product stewardship, reverse logistics and remanufacturing. He has studied the reverse logistics required in recycling and remanufacturing operations, and inventory problems affecting products made in small batches for frequent deliveries. He has presented his research in national and international conferences in four continents, and in invited seminars in various academic institutions.Dr. Ferrer has consulted for companies in the United States and abroad on process improvement, waste reduction and reverse logistics issue.

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