Adding Carbon to the Equation in Online Flight Search

February 2020

A Research Report from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation

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16. Abstract

This study explores the potential to promote lower-emissions air travel by providing consumers with information about the carbon emissions of alternative flight choices in the context of online flight search and booking. Researchers surveyed over 450 UC Davis faculty, researchers, and staff, asking them to choose among hypothetical flight options for university-related business trips. Emissions estimates for flight alternatives were prominently displayed alongside cost, layovers and airport, and the lowest-emissions flight was labeled "Greenest Flight". The researchers found an impressive rate of willingness to pay for lower-emissions flights: around $200/ton of CO_2E saved, a magnitude higher than that seen in carbon offsets programs. They also found that displaying carbon information encouraged Davis employees to choose nonstop (lower-emissions) flights, when available, from a more distant airport over indirect flights from their preferred airport for medium-distance flights. In a second step of analysis, they estimated the carbon and cost impacts for UC Davis business travel if the university were to adopt a flight-search interface that prioritizes carbon emissions information and displays alternatives from multiple regional airports in their employee travel-booking portal. Based on the choice models from the survey data, a year's worth of actual employee air travel data, and data collected on flight alternatives with respect to the flights chosen by employees, they estimated potential annual savings of more than 79 tons of CO_2E, and a more impressive $56,000 reduction in airfare costs, due to an increased willingness of travelers to take advantage of cheaper (often nonstop) flight options out of SFO. Broader university policies encouraging lower-emissions flights and enhanced public transportation within the multi-airport mega-region would likely support much greater carbon savings. Institutionalizing this "nudge" within organizations with large travel budgets, like the UC system, could have an industry-wide impact in aviation.

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NCST

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February 2020

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EXECUTIVE SUMMARY

Different flight itineraries with the same origin and destination can vary greatly in terms of their carbon emissions, depending mainly on the number and location of connections and aircraft type (Jardine 2009). Taking advantage of the potential savings of lower-emissions flights is an appealing approach to air travel emissions reductions (Lee et al. 2009, Carmichael 2019). This study explores the potential to promote lower-emissions air travel by providing consumers with information about the carbon emissions of alternative flight choices in the context of online flight search and booking.

We surveyed over 450 faculty, researchers, and staff at the University of California, Davis, and asked them to choose among hypothetical flight options for domestic and international university-related business trips. Emissions estimates for different flight alternatives were presented prominently alongside price, with the lowest-emissions option labeled "greenest flight." We based the survey's hypothetical flight choice scenarios (destinations, costs and carbon levels) on an analysis of one year's worth of UC Davis employee travel data. The survey data were analyzed using discrete choice modeling, yielding an estimate of participants' willingness to pay for lower-emissions flights.

We found an impressive rate of willingness to pay to reduce the carbon impact of flying: around \$200/ton of CO_2E saved. This rate is much higher than that seen in carbon offsets programs (Brower 2008; Lu et al. 2012; van Birgelen et al. 2011). Note that we use willingness to pay as a measure of the value of reducing emissions to our research subjects; it is *not* the potential cost to the university for the emissions savings.

Davis employees fly out of both Sacramento and Bay Area airports, with about 90% of our survey respondents preferring to fly out of Sacramento. Travelers at other UCs face similar choices, e.g., San Jose vs SFO, Orange County vs LAX, etc., and in general departing from multi-airport regions is quite common across the U.S. (Van Dender 2006). Our survey offered flights out of both Sacramento and San Francisco in order to study the effect of emissions information on travelers' valuation of a nonstop (generally lower-emissions) flight out of a more distant airport versus an indirect flight from a closer airport. When holding carbon emissions constant across flight options, we found that these two alternatives were nearly equally desirable. Emissions information can "break the tie" in this situation, encouraging travelers to choose the nonstop flight.

In a second step of analysis, we estimated the effect that changing the flight-search interface and showing alternative departure airports could have on the emissions and costs of business-related air travel at UC Davis. We used our survey-based models of UC Davis employees' willingness to pay for lower-emissions flights, and the actual employee travel data. We also used another dataset that we collected, on the flight options available for the most frequent UC Davis employee air travel destinations and emissions estimates for each of these options.

Based on this analysis, we estimate potential annual savings for Davis of more than 79 tons of CO_2E (or 4% of emissions associated with all air travel booked on the university portal) if employees could see emissions information prominently. While this estimate of the potential for emissions savings might be disappointing, we found that it was combined with a $56,000 ***reduction*** in airfare costs, due to an increased willingness of travelers to take advantage of cheaper (often also nonstop) flight options out of SFO when incentivized with reduced emissions. The UC system has an overall goal of reducing transportation emissions, including those of business travel, by 20% from 2010 levels by 2020 (Annual Report on Sustainable Practices, 2018). In this context, an easily achieved 4% emissions savings for air travel is clearly worthwhile. Broader University policies encouraging the use of lower-emissions flights, as well as enhanced public transportation within the SFO–SMF multi-airport mega-region, would likely support much greater carbon savings.

Institutionalizing this “nudge” within organizations with large travel budgets, like the UC system, could have an industry-wide impact in aviation. Many consumers making lower-carbon flight choices would encourage airlines to invest in more efficient aircraft and biofuels. Highlighting emissions information during flight search also has an educational benefit and may increase personal awareness of air travel emissions, which could reduce the total number of trips. Increasing public awareness of the environmental costs of air travel could also ultimately influence government regulation and public investment in transportation. These could include better regional transportation options to alternative airports, the use of biofuels, and the optimization of airline schedules and routes to further prioritize fuel efficiency.

Introduction

Air travel is estimated to contribute as much as 2.5% of worldwide greenhouse gas emissions (EPA 2016), and this proportion is expected to grow (Lee et al. 2009). Furthermore, for those of us who fly, air travel makes up a significant proportion of our individual carbon footprint. Annual greenhouse gas emissions in the U.S. are about 20 tons per person, and a single round-trip coach flight from San Francisco to Miami is responsible for about one ton of emissions. This makes reducing emissions due to air travel an important goal.

Although generally high relative to other travel modes, emissions for different flight itineraries with the same origin and destination can vary greatly, depending mainly on the number and location of connections and on aircraft type (Jardine 2009). For example, different itineraries for the San Francisco–Miami trip can vary by 0.7 tons of carbon dioxide equivalent (CO_2E; aircraft emissions are measured in CO_2E, which takes into account the environmental impact of all emitted greenhouse gasses in terms of the equivalent weight of CO2 only). Taking advantage of these potential savings is an appealing approach to air travel emissions reductions (Lee et al. 2009), and the focus of this project.

Specific and relevant information provided at the purchase decision point has been suggested as the most effective strategy to help consumers to make environmentally beneficial choices (Fogg 2009). Online flight searching presents an excellent opportunity to promote lower-emissions flights at the point of purchase. Someone making an air travel purchase is already carefully examining a website that presents detailed information on many possible itineraries, and choosing a flight based on a variety of factors (cost, number and length of layovers, airline, etc.). Displaying a CO_2E emissions estimate for each flight would allow the consumer to consider emissions among these other factors.

If online travel agencies (e.g., Expedia, Kayak, Google Flights) adopted this practice, they could enable or even encourage consumers to choose lower-emissions flights. Corporations and institutions could further leverage these tools by requiring or encouraging their employees to use them for booking flights for business trips. Business travel is responsible for a large fraction (25–65%) of airline emissions (Coogan 2000), and accounts for most frequent flyers. Influencing business-related air travel could thus have large impacts on air travel emissions.

In an earlier project, we developed GreenFLY, a demonstration flight search website that emphasizes emissions (Figure 1). GreenFLY's design attempts to make emissions information both salient and persuasive (Figure 2). By default, the output sorts flight options by emissions (lowest to highest) and provides contextual information for the magnitude of the potential emissions savings—specifically, a CO_2E emissions range summary meter at the top of the flight search output page, indicating the minimum, maximum, and average emissions of the available flight options. The meter uses a gradient of yellow-orange-red to imply that higher emissions is negative and undesirable. A green dot on the far left of the meter marks the flight option(s) with the lowest emissions. Lowest emissions flight(s) are also labeled as "Your GreenFLY" in green text, with the emissions number also in green text to imply that these are the most positive and desirable flights.

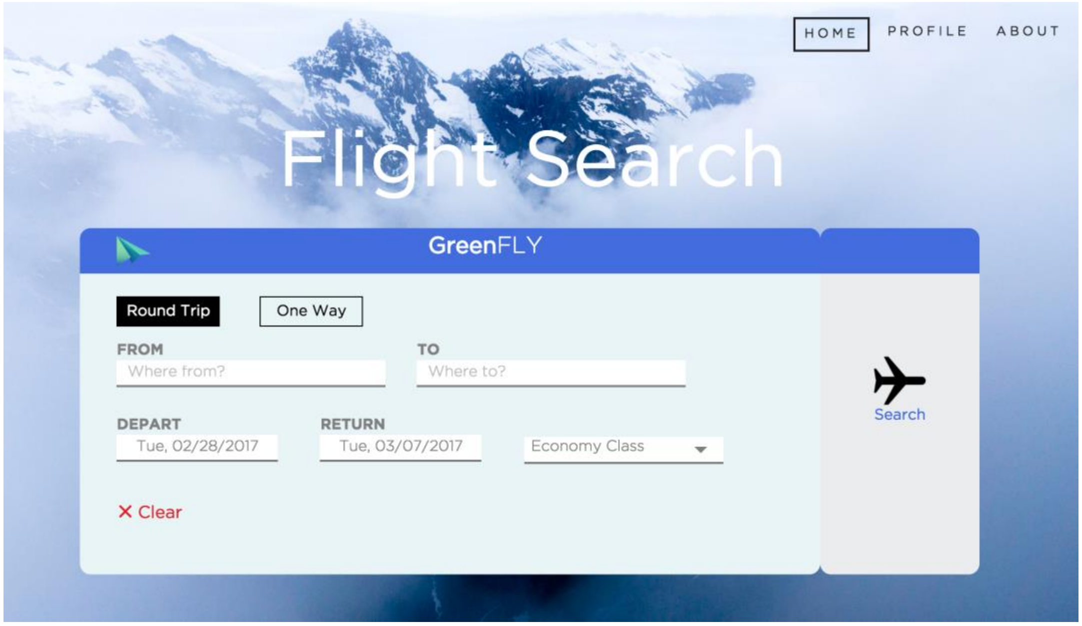

Figure 1. The query interface for flight search in GreenFLY. The background is meant to suggest cleanliness and nature as well as flight, while the form resembles a ticket.

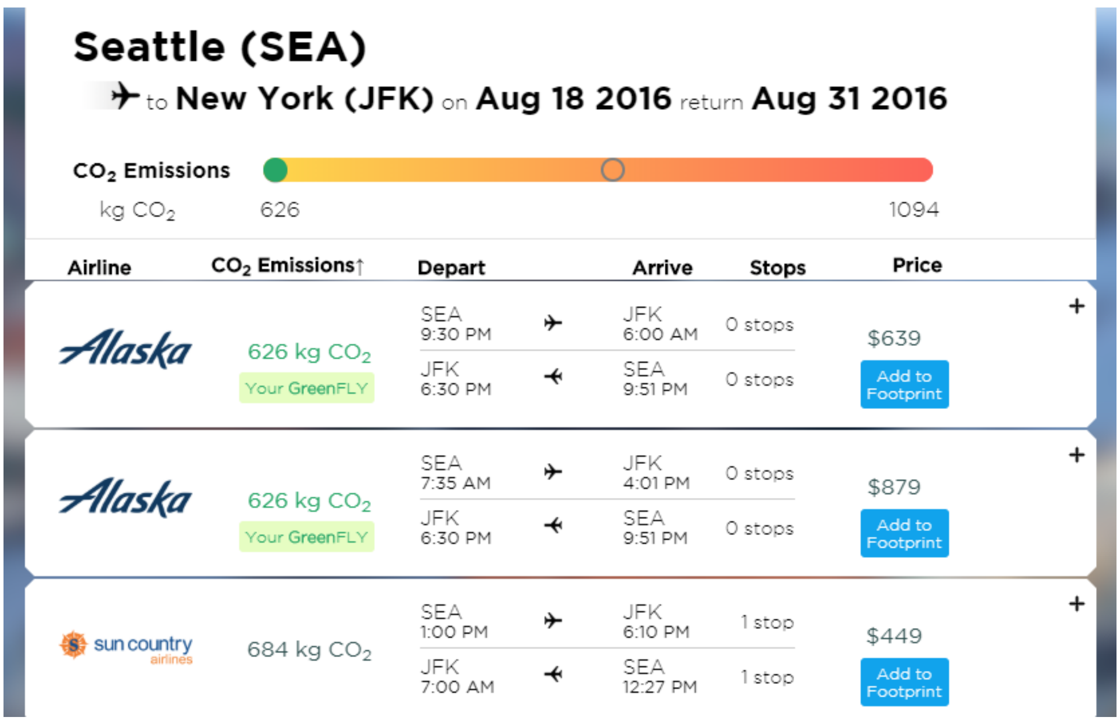

Figure 2. Flight results in GreenFLY. Emissions estimates appear on the left, and price on the right; flights can be expanded to show details.

We then embarked on a research program to measure the degree to which a GreenFLY-style interface (i.e., prominently displaying and comparing emissions information for flight alternatives) could influence consumer flight choices. The present research is the second study in a series of online discrete choice experiments. In these experiments, participants choose among hypothetical flight alternatives presented in GreenFLY-style. Our first study (Sanguinetti et al. 2017) involved a convenience sample of over 1,400 U.S. citizens recruited via Amazon Mechanical Turk. Based on their hypothetical flight choices among alternatives that varied in terms of carbon emissions, cost, and number of layovers, participants demonstrated a willingness to pay more for lower-emissions flights at a rate of $192/ton of CO_2E saved.

The present research extended our prior work in several ways. First, we studied flight choice in the context of business travel, which is responsible for a large fraction of airline emissions and accounts for most frequent flyers. Influencing business-related air travel could thus have large impacts on air travel emissions. If large institutions required or encouraged the use of GreenFLY-style travel booking sites it could potentially substantially reduce the carbon footprint of their business travelers.

Specifically, we surveyed University of California, Davis, employees and asked them to choose among hypothetical flight alternatives for business travel. We calculated their willingness to pay for lower-emissions flights, also taking into consideration airport choice and nonstop versus indirect options. Based on the results and actual historical travel data for UC Davis employees we modeled the potential aggregate emissions and cost implications for the university if they adopted GreenFLY-style interface in their employee travel-booking site. Before presenting our study, we provide background on the concept of providing emissions information in the context of online flight searching, and summarize relevant literature on consumer flight choice and carbon valuation.

Background

The idea of displaying greenhouse gas emissions estimates during flight search was pioneered, as far as we know, by a company called Brighter Planet, whose main business was carbon accounting for industrial and institutional clients. They developed an air travel emissions calculator, and a plug-in, Careplane, that worked with the major web browsers. Careplane could be downloaded and used in conjunction with Expedia, Orbitz, Kayak, and a few other online travel sites, decorating them with emissions estimates during flight search. Unfortunately, when Brighter Planet went out of business neither their calculator nor the plug-ins were supported, so they no longer give correct results.

Calasi, a later start-up, has a business model in which they market an emissions calculator and information on other flight details, such as in-flight entertainment options, to online travel agencies. Unfortunately, we are not aware of any sites currently using their emissions data. Calasi also developed a browser plug-in, but again maintenance is a problem. A site called Glooby offered “sustainable travel” including links to low-emissions flights, but they also do not appear to be maintained.

Flight search is a competitive, low-margin industry. Flight search engines, services which provide the data on flight schedules, prices and availability, are expensive, so it is difficult to build a profitable custom flight search website based on a commercial flight search engine.

While Web plug-ins do not incur the cost of a flight search engine, they are difficult to build and even more difficult to maintain, since both browsers and flight search websites change frequently. In addition, decorating existing flight search pages can add clutter instead of providing a sense of consistency, clarity and purpose, and plug-ins do not allow for more complex functions (e.g., allowing the user to sort flights by carbon emissions).

While a stand-alone emissions-centric flight-search site like GreenFLY might not be commercially viable, there are market niches where a similar approach might work well. In particular, institutions committed to reducing emissions could highlight emissions in their in-house flight search portals. As an example, the University of California (UC) system (our employer) provides a travel-booking service through a portal called ConnexUC (formerly Connexxus). The portal is provided and supported by two companies: SAP Concur and BCD Travel. The University of California is also committed to becoming carbon neutral by 2025.

At UC Davis, the ConnexUC portal currently allows users to sort by emissions (Figure 3); this was not the case when we began the GreenFLY project or this study. However, it is the last option on a menu that may not be well-used, rather than the default output organization. Furthermore, sorting by emissions does not add any other cues to help guide the user in selecting the lowest emissions flights; for example, GreenFLY labels all of the lowest emissions flights and provides a summary of the range of emissions for all flight alternatives at the top of the output. In ConnexUC, emissions information for each flight alternative remains hidden in the initial output and is revealed (sometimes) when the user clicks a link to see “More fares/details” (for one flight alternative at a time). It is to the university’s credit that emissions information is included at all, since most popular online travel-booking sites do not include it. However, it is unlikely that this format is effective in nudging users to consider emissions.

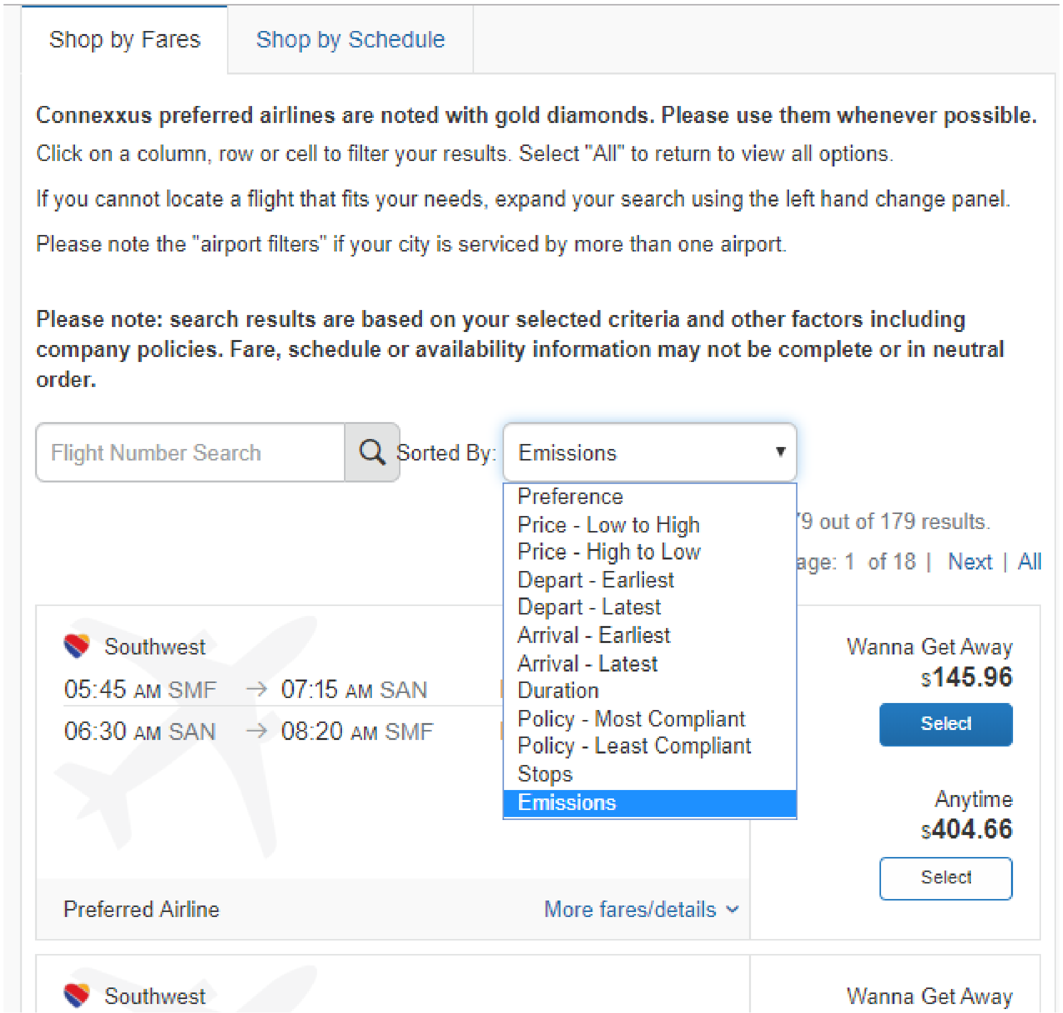

Figure 3. Flight results in ConnexUC.

Economic valuation of carbon offsets

There have been a number of studies attempting to quantify air travelers' willingness to pay (WTP) for carbon offsets for their flights (Brouwer, Brander, & Van Beukering 2008, Choi & Ritchie 2014, Lu & Shon 2012, MacKerron, Egerton, Gaskell, Parpia, & Mourato 2009, van Birgelen, Semeijn, & Behrens 2011). The purchase of carbon offsets is distinct from the goals of GreenFLY and similar tools that integrate emissions information into online flight searching. Carbon offsets provide the consumer with an opportunity to pay for activities that combat climate change in order to offset the carbon they are responsible for producing with their air travel. In contrast, the idea behind GreenFLY and similar tools is to provide the consumer with an opportunity to avoid some emissions entirely. To our knowledge, our studies (the present study and Sanguinetti et al. 2017, which found a WTP of $192 per ton of CO_2E saved) are the first to focus on consumer WTP for carbon in this context. However, previous studies on WTP for carbon offsets are relevant as a point of comparison.

Brouwer et al. (2008) recruited 400 air travelers (mostly European) at Amsterdam Schiphol Airport in 2006 to participate in a contingent valuation (CV) study of WTP for carbon offsets. After receiving an explanation of the concept of a carbon tax, participants were asked if, in general, they were willing to pay such a tax on their plane ticket. Those who said yes (75%) were then asked if they were willing to pay a specific amount of money for that tax. Using the CV method, if the response was no, the interviewer asked about a second amount that was lower; if the initial response was yes, the interviewer asked about a second amount that was higher. This process continues until an interval is reached between an amount the consumer is willing to pay and an amount they are not willing to pay. Mean WTP for a flight carbon tax was 23.1 Euros (equivalent to 25 Euros per ton of CO_2E).

Similar CV studies were subsequently conducted by Jou and Chen (2015), Lu and Shon (2012), and MacKerron et al. (2009). MacKerron et al. asked 321 UK adults aged 18–34 to imagine flying from New York to London and having the opportunity to purchase a carbon offset for the flight. Mean WTP was GBP £24. Lu and Shon interviewed 1,339 air travelers at Taoyuan International Airport in Taiwan. They found that passengers flying to China, Northeast Asia, Southeast Asia, and western countries were willing to pay $5, $8.80, $10.80, and $28.60, respectively, to offset their flight carbon emissions (amounting to 1–1.5% of participant flight cost).

Overall, studies have shown that most air travelers say they are willing to pay some amount to offset flight carbon emissions, and often at rates higher than standard carbon offset prices. However, as Jou and Chen (2015) caution, stated valuation is an easier commitment than actually making the donation. In Brouwer et al. (2008), when participants were asked how likely they would be to pay their stated WTP amount if it were a voluntary tax, only 37% percent of North American participants, 47% of European participants, and 50% of Asian participants said they were likely to pay. In Choi and Ritchie (2014), most participants agreed that voluntary offset payments must be “a convenient thing to do”, and they talked about the importance of the position of the offset option during online booking as well as convenient payment procedures. Providing salient information in a flight search tool about the range of carbon emissions for flight alternatives could be the most convenient strategy, as users could simply purchase a lower emissions flight without any additional donation and payment procedure.

Valuation of other flight attributes

There is also a literature on understanding consumer preferences for flight choices based on the variety of attributes generally presented in the context of a purchase decision, e.g., on travel-booking sites. These attributes include the airfare, airport and airline, and timing considerations such as flight durations, departure and arrival times, and number and length of layovers. Most of these studies are stated preference (SP) experiments using discrete choice analysis, in which participants are presented with a set of flight alternatives that vary in terms of the different attributes and are asked to choose which they would hypothetically purchase. The analyses typically focus on establishing the value of the different attributes in terms of cost, called the willingness to pay (WTP) metric (e.g., WTP higher purchase price to avoid a layover, take preferred airline, etc.). Choice experiments enable the researcher to examine whether and to what degree specific attributes, or attribute combinations, influence the value of an economic good, i.e., the consumers' willingness to pay for those attributes (Louviere et al. 2000). Discrete choice is a common method in marketing research as it resembles real purchase situations. Revealed preference (RP) studies, in which actual flight purchases are analyzed in order to infer the preferences of consumers, have also been conducted—sometimes in conjunction with SP work.

Although some SP flight choice studies consider the potential influence of attributes that are less commonly provided in reservation and ticketing services (such as on-time performance; Adler, Falzarano & Spitz 2005), none that we could find, besides our own earlier study (Sanguinetti et al. 2017) considered the value of carbon emissions. Although carbon emissions information has not been considered as a factor in these studies, a brief review of this research provides some context for the possible value of carbon emissions information as another choice attribute in the flight purchase decision.

Overall, past SP studies tell us that airfare is typically the most important determinant of flight choice (e.g., Hess, Adler, & Polak 2007), and confirm all the above-named factors as influential. However, no one attribute outweighs all others (Ishii, Jun, & Ven Dender 2009); thus, there tend to be trade-offs consumers are willing to make between attributes. Particularly relevant to the present research are trade-offs between cost and layovers, since number of layovers for an itinerary is highly positively correlated with emissions. A recent report from the MIT International Center for Air Transportation (Ennen, Florian Allroggen, & Malina, 2019) found that in general consumers are willing to pay $140 more to avoid a layover, and $168 more for the most convenient nonstop flight compared to the most convenient flight with a layover.

Our prior research showed a much lower rate of willingness to pay (WTP) to avoid a layover: $51 without carbon emissions in the model and $83 with carbon included. This finding was taken to suggest that consumers will pay more to avoid a layover when information that the nonstop flight is also less carbon intensive is presented. The discrepancy between our earlier finding on WTP and that of Ennen et al. (2019) might be partly attributable to the lower income of our convenience sample of participants from Amazon Mechanical Turk. The present study replicates the WTP evaluation for UC Davis employees, and we indeed found a higher WTP, comparable to Ennen et al.

Prior research also highlights the importance of airport as a factor in flight choice, with consumers showing a strong preference for airports with faster access time (generally those closest to them). Understanding this factor is particularly relevant for multi-airport regions, in which consumers may choose between multiple reasonably accessible airports. Van Dender (2007) reported that 40% of U.S. flight passengers depart from multi-airport regions, and that number is likely higher now with disproportionate population growth in urban cores. Furthermore, airport access time seems to be more important for business travel compared to leisure (Hess & Polak 2005, Koster, Kroes, & Verhoef 2011).

The findings regarding airport preference are relevant to the present stated preference study, which focuses on business travel and includes flight options from Sacramento International Airport (SMF) and San Francisco International Airport (SFO). Davis is located in a multi-airport region, or perhaps more accurately a multi-airport mega-region (Hess, Ryley, Davison, & Adler, 2013): SMF is 22 miles away and SFO is 85 miles away; Oakland International Airport is 82 miles away.

SFO offers nonstop flights to many destinations for which SMF only offers indirect flights. This might nudge some employees toward choosing an SFO flight even though they prefer SMF (if they value nonstop flights more than their preferred airport; e.g., Blackstone, Buck, and Hakim 2006). Furthermore, a nonstop flight from SFO will in many cases be less carbon intensive than a flight with layovers from SMF, even after taking ground transportation into account. For example, the 170-mile roundtrip drive between Davis and SFO in an efficient vehicle (30 mpg) produces about 40kg CO_2E, much less than the typical difference between a nonstop flight and a flight with a layover. Granted, some travelers will take more efficient and some less efficient modes to the airport. We hypothesized that prominently displaying emissions information may nudge some employees toward choosing SFO flights even though they prefer SMF.

Present Research

Our primary research question was:

1. Are UC Davis employees willing to pay (i.e., allocate from university funding sources) more to take a flight with lower emissions, and if so at what rate?

As in our earlier study, this issue is complicated by the fact that itineraries with fewer layovers typically have significantly lower emissions, and many consumers will pay more for a flight with fewer layovers, regardless of emissions. Therefore, a second question is:

2. What additional encouragement (i.e., value) do emission reductions contribute to choosing a flight with fewer layovers?

We also wanted to consider access to airport since it is an important factor in flight choice, particularly for business travel. SFO, though further from Davis, offers nonstop flights to many destinations for which SMF only offers flights with layovers. Even accounting for emissions from ground transportation to and from SFO, a nonstop flight from SFO will typically be more efficient than an indirect flight from SMF. Thus, our third question was:

3. What additional encouragement (i.e., value) do emission reductions contribute to choosing a roundtrip direct flight out of SFO over a flight with layovers out of SMF?

Finally, we wanted to extrapolate from the study findings to estimate the impact that adopting a GreenFLY-like interface in the UC Davis travel portal might have on the University's Scope 3 GHG emissions and at what financial cost:

4. How much CO_2E might be spared campus-wide by prioritizing emissions information in the campus travel portal and at what, if any, additional cost?

Flight Choice Experiment

The first three research questions were addressed through a stated preference choice experiment, similar to those reviewed in the Background section of this paper, and similar to our earlier study (Sanguinetti et al., 2017).

Methodology

The flight choice experiment involved an online survey in which UC Davis employees were asked to make a series of discrete choices between roundtrip flight alternatives, that varied in terms of cost, carbon emissions, layovers (0 or 2: one layover each way), and airport (SMF or SFO), for hypothetical UC Davis-related business trips. We based these hypothetical scenarios (trip destinations and attribute levels of flight alternatives) on data about actual UC Davis employee air travel. This was intended to increase the social and statistical validity of the resultant choice models by making the scenarios seem realistic to participants, and by building the models in the range in which they would be applied (rather than extrapolating to untested contexts). The following sections describe the use of actual travel data, the experimental design and survey instrument, and survey recruitment and participants.

Using historical employee travel data to create realistic trip scenarios

UC Davis Accounting and Financial Services (AFS) shared data with us for one complete year (2017) of UC Davis business travel booked through the university travel portal (hereafter called the *AFS History* dataset). According to AFS, roughly 50% of reimbursed air travel is booked though the university portal, and thus represented in the AFS History dataset. The AFS History dataset includes 7,593 trips, both roundtrip and one-way, to over 300 different destinations. For each flight leg, data include origin and destination city and airport, airline and ticket class; and at the trip level: cost, distance, and emissions estimates (computed in ConnexUC).

Our first task with these data was to identify common business trip destinations that represent a significant portion of total air travel emissions for UC Davis employee travel, to inform the hypothetical trip destinations in the choice experiment. We focused on roundtrip and one-way flights originating from SMF and SFO (65%), omitting one-way flights into SMF or SFO, flights from Oakland, and flights between two other cities. We divided the resulting flights into short (up to 1,400 miles roundtrip), medium (1,400 to 6,000 miles), and long trips (more than 6,000 miles). Figure 4 shows the contributions of each group to total emissions. While there are many short trips, their impact on emissions is small. Medium-length trips account for most of the emissions, and long trips have a disproportionately large impact given their low frequency. For this reason, we decided to include two hypothetical trip scenarios in our choice experiment: one medium-length (domestic) and one long (international) trip.

Ordered by total emissions for all trips to each destination city (regardless of specific airport), Washington, DC and London were the most frequent domestic and international destinations. It was also important that each of these destinations were reasonably accessible by each SMF and SFO since we planned to vary the choices on those two airports. The top 23 destinations departing from Sacramento (SMF) were all domestic, followed by London, while the top seven destinations departing from SFO were all international, followed by Washington, DC Thus, although SMF is more popular among UCD employees for domestic flights, flights to London are not uncommon. Similarly, although international flights are most common out of SFO, flights to DC are not uncommon. Based on this, the two hypothetical trips in the choice experiment were to Washington DC and London.

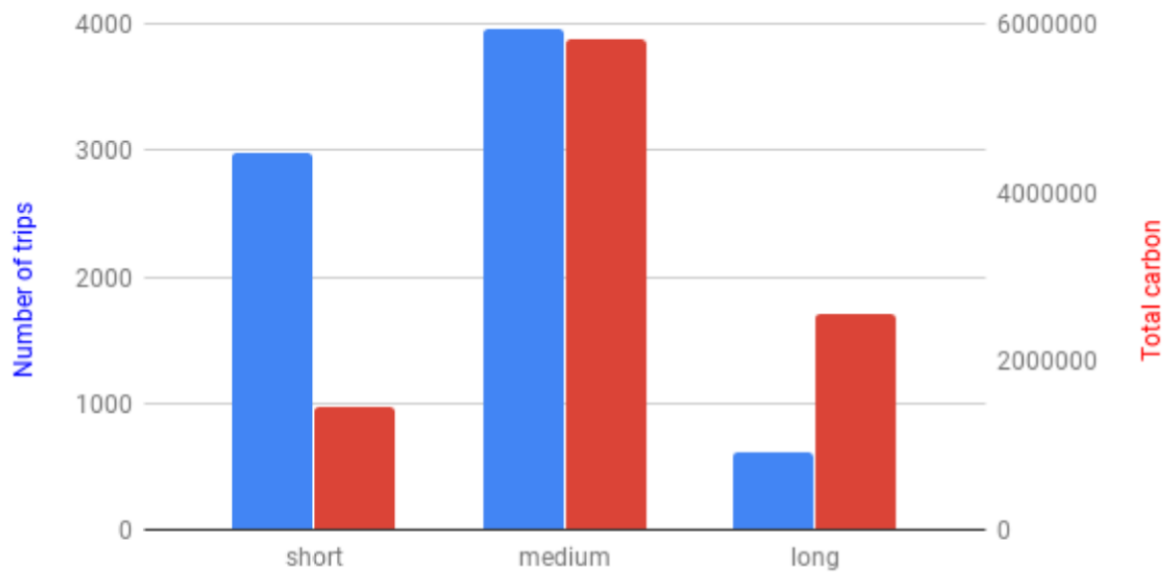

Figure 4. AFS History trip summary by distance, frequency and total carbon impact. Medium distance is between 700–3000 miles from Sacramento to the destination city, so it includes all destinations on the North American continent.

We also used the AFS history data to determine realistic cost and carbon levels for flight alternatives in the choice experiment. This was done by analyzing the distributions of cost and emissions for employees' roundtrip flights to each Washington, DC and London in 2017. For cost, we calculated the mean and standard deviation for each city (Table 1). There were a few very expensive flights to each destination, which we removed as outliers (over $100 more than the next most expensive flight). For carbon, we calculated the mean and standard deviation separately for nonstop flights and flights with layovers. Emissions for nonstop flights did not vary much at all.

Table 1. Distributions of cost and carbon emissions for DC and London flights in AFS history.

Destination	Cost mean (sd)	Emissions, layover mean (sd)	Emissions, nonstop mean
Washington, DC	$502 ($109)	2127lbs (204lbs)	1645
London	$1135 ($375)	4084lbs (165lbs)	3638

For layover flights to both destinations, we selected four price levels and four carbon levels. We distributed the prices from –1 standard deviation below the mean to .5 standard deviation above the mean, each separated by half a standard deviation. We distributed the four carbon emissions levels around (but not including) the mean, also separated by half a standard deviation. We wanted nonstop flights to be more expensive in our hypothetical choices, to give respondents the opportunity to demonstrate WTP for nonstop. We assigned four price levels by increasing each of the four layover price levels by .25 standard deviations, and used the single mean emissions value since there was little variation.

Experimental design and survey instrument

With four price levels, four carbon levels, two airport levels (SMF or SFO) and two layover levels (0 or 2: one layover each way), there were too many possible combinations to include and compare all possible flights in the choice experiment. Instead of randomly sampling from all possible attribute combinations, we chose a set of flight alternatives, and then a set of pairs of flight alternatives for the choice questions, which would sample the part of the hypothesis space in which we expected our model to fall. The literature reviewed above, our own previous survey work, and common sense tells us that respondents will prefer nonstop to layover flights, cheaper to more expensive flights, and flights with lower emissions, and that most of our respondents would prefer to leave out of SMF rather than SFO. We designed specific flight alternatives, and questions pairing flight alternatives, to explore the trade-offs between these different benefits, and to avoid questions for which the response was "obvious".

For the layover flight alternatives, we created eight possible cost-carbon combinations, using each cost level and each carbon level twice, and not repeating any pairing. There are many ways to do this, and we chose one which tended to pair high cost with low carbon, to create trade-offs. Our eight layover flights from SMF to London appear in Table 2. The same cost-carbon pairings were used for layover flight alternatives from SFO.

Table 2. Hypothetical layover flights from SMF to London used in questionnaire.

	F1	F2	F3	F4	F5	F6	F7	F8
Carbon	4331	4331	4167	4167	4002	4002	3837	3837
Cost	$761	$948	$948	$1322	$761	$1135	$1322	$1135

We also created four nonstop flights from each departure airport, with the four nonstop prices and the single nonstop emissions level. This gave us 12 possible flights from SMF and 12 from SFO, for a total of 24 possible flights to London. Using the same methods, we created 24 possible flights to Washington, DC.

We organized the flight alternatives into sets of two for the choice experiment questions. We chose to do questions based on pairs rather than, say, triples, since more, cognitively easier questions seemed more likely to produce good data than fewer, more difficult choices. Criteria for pairing flight alternatives were as follows:

1. Every flight alternative should appear the same number of times in the survey,
2. The distribution in the questions of pairs of flights (eg. layover out of SFO vs layover out of SMF) should match the distribution of all possible pairs,
3. Avoid questions in which the two flights had the same cost, or the same carbon, and
4. Focus on pairs that might have competitive utility (e.g., an alternative that is lower cost, lower carbon, nonstop and out of SMF is likely to be selected in most cases, so not as useful for understanding potential trade-offs).

With these criteria, we developed a solution of organizing questions into seven buckets for each of the two destinations (14 buckets total), representing different kinds of questions (Table 3). Each respondent was asked a randomly chosen question from each bucket. Due to a survey programming error, one DC flight bucket was omitted (at random) for each participant. Thus, each participant received six questions with DC flight choices and seven questions with London flight choices. The full list of questions is included as an Appendix.

Table 3. Logic of flight choice question "buckets".

Bucket	Flight Alternative A	Flight Alternative B (relative to A)	No. of Items
1	SMF layover	SMF layover (lower carbon, higher cost)	8
2	SFO layover	SFO layover (lower carbon, higher cost)	8
3	SMF layover	SFO layover (mixed carbon and cost)	8
4	SFO layover	SMF layover (mixed carbon and cost)	8
5	SMF or SFO nonstop	Opposite airport layover (higher carbon, mostly lower cost)	8
6	SMF or SFO nonstop	Same airport layover (higher carbon, lower cost)	8
7	SMF nonstop	SFO nonstop (same carbon, mixed cost)	2

The choice experiment was conducted using an online survey instrument programmed in Qualtrics survey software. Prior to the choice questions, the survey asked four questions to get participants thinking about business-related air travel and their experience with both SMF and SFO:

1. How do you typically arrange flights for UCD-related work travel?
2. What airport do you prefer to use for your business travel?
3. When flying out of Sacramento International Airport (SMF), how would you typically get to the airport and back home? (select all that apply)
4. When flying out of San Francisco International Airport (SFO), how would you typically get to the airport and back home? (select all that apply)

Following these questions, a prompt to consider the DC trip scenario preceded the seven questions for DC flight choices, and then a similar prompt followed by the seven London flight choice questions. The DC prompt read: “Imagine you are searching for a flight to Washington, DC for UCD business (perhaps a conference or training). The flight will be paid for from a University account. You will be shown a series of flight alternatives, with different prices and levels of carbon emissions. Some depart from Sacramento and some from San Francisco, and some have layovers while others are nonstop. Each time, please pick the one you would choose if you were actually taking this trip.”

The flight choice questions were programmed with image files as the response options, to mimic the look of a flight-search interface, but with prominent information about emissions (Figure 5).

Figure 5. Example of flight choice question response options, with prompt: “Which flight would you choose?”

At the end of the survey, two questions asked participants if they would be interested in seeing more prominent carbon emissions information about flight alternatives when they search for flights, and how seeing that information might affect their choices. Some basic demographic information (age, position on campus) and frequency of air travel, generally and work-related air travel in particular, were also collected at the end of the survey.

Survey recruitment and participants

The survey was deployed from June–August 2019. We collected contact information for administration (department chairs and coordinators) at each university department and research center we could identify from university website searches. The final list of contacts included at least one email address for 90 different departments. A mailmerge email was generated to these contacts with a request to forward a survey participation invitation to faculty, staff, post-docs, and graduate students in their respective departments. Participants had the option to enter their email address at the end of the survey to be entered in a raffle to win a $250 Amazon gift card.

The survey had a 92% completion rate; 488 people initiated and 447 completed it. Of these, 40% were grad students, 33% were faculty, 17% were staff, and were 9% post-docs (a few were undergraduate researchers). Participants ranged in age from 20 to 80, with a mean age of 38 (standard deviation = 13 years). Participants reported a range of recent air travel (in the past 12 months), from 0 to more than 10 of each work-related and other trips, with a mean of 2.3 work trips (sd = 2.6) and 2.8(2.3) other trips (more than 10 trips counted as 11 for mean calculations).

About one-third (31%) reported that they typically use the university portal (AggieTravel) to book their work-related air travel; Google Flights was also popular (21%); 12% reported they book directly from airlines; 9% each Expedia and Kayak; 5% said their administrative staff arranges. Others named Skyscraper, Orbitz, Travelocity, Hipmunk, and other sites, with some noting that they use multiple tools—like searching on one site and buying on another. About 90% of participants reported that SMF was their preferred airport for business trips; 8% preferred SFO and 2% preferred Oakland. Driving to the airport in one's own private car was the most common mode for both SMF (55%) and SFO (41%) access, however taxi/ride-hailing was also common for SMF (53%), and using AMTRAK + BART (31%) and/or airport shuttle services (23%) was relatively common for SFO (another 17% reported driving or being driven to BART).

Results

Following the standard discrete choice model (e.g., Louvier et al., 2000), we used the survey data to compute a utility model of traveler behavior. Our utility model is a linear formula of the form:

$$\text{utility} = a * \text{carbon} + b * \text{cost} + c * \text{nonstop} + d * \text{airport}$$

Here, "utility" is a function that describes the desirability of a particular itinerary. We assume that given a choice between itineraries, the traveler will choose the one of greatest utility. "Carbon" is an estimate of CO_2 equivalent emissions in pounds, and "nonstop" is equal to 1 for a nonstop flight and 0 for a flight with a layover. The "airport" variable is equal to 1 if the flight leaves from the traveler's preferred airport, and 0 if it leaves from the other airport. Recall that we asked participants which airport they preferred, and that 90% of respondents preferred flying out of Sacramento; the 2% who preferred Oakland were treated as if they preferred San Francisco.

We computed these models in R, using the *mlogit* package for logistic regression of discrete choice data. This package is based on the assumption that the probability that a flight will be chosen from some set of alternatives is proportional to exp[utility(A)]; that is, flights with greater utility are exponentially more likely to be chosen. Given the empirical probabilities with which one flight is chosen over another, the software "works backwards" to the best coefficients for the utility function using a maximum likelihood optimization procedure.

We computed several different pairs of D.C. and London models from the survey data. Separate models were created for the two trips because combining them in a single model would not make sense (if the traveler is going to London, the utility of a Washington flight is zero, and visa versa). We computed a pair of models with emissions as a factor and another excluding the emissions factor, in order to compare the difference. We also computed normalized versions of the models with all factors, to give some idea of the relative importance of the different factors to the respondents.

All models appear in Table 4. A row in the table represents a utility function supported by the data. The coefficients (a, b, c, d) in the utility equation on the previous page are the columns Carbon, Cost, Nonstop and Airport. WTP is the willingness-to-pay to save one ton of CO_2E, according to the model (calculated as 2000*Carbon/Cost). The *mlogit* software provides both a log-likelihood score for each model, as well as a p-value on every coefficient; the coefficient p-values on the other input variables were all vanishingly small.

Table 4. Models of utility computed from survey data

	Carbon	Cost	Non-stop	Airport	WTP	Log-Likelihood	p-val carbon
Washington	-.0012	-.013	1.54	1.60	$184	-1086	$3xe^{-9}$
London	-.00064	-.0051	1.76	1.33	$250	-1218	$7xe^{-3}$
Washington no emissions		-.010	1.87	1.48		-1104	
London no emissions		-.0048	1.94	1.28		-1221	
Washington normalized	-1.25	-4.56	1.54	1.60		-1086	$3xe^{-9}$
London normalized	-0.65	-1.79	1.76	1.33		-1218	$7xe^{-3}$

We see that traveler's behavior is significantly different for the two destinations, with respondents strongly preferring nonstop flights to London while taking cost and the departure airport into account more strongly for the Washington trip.

In addition to WTP to avoid emissions, we can also use the models to get a sense of how willing travelers were to avoid layovers, and how strongly they preferred one departure airport over another. The model for Washington predicts as WTP of $115 to avoid a layover and $123 to fly from the preferred airport, while the model for London predicts $352 to avoid a layover, and $255 to fly out of the preferred airport. These larger numbers, as well as the larger WTP to avoid emissions on the London trip, are probably just a function of the overall higher prices on the London options.

The WTP to avoid CO_2E emissions in this context is surprisingly large; typical carbon offset costs are $20–$25 per ton. To check and make sure that it is not biased by the strong correlation between nonstop flights and low emissions (both in reality and in the scenarios we presented in the survey), we computed models based only on the questions involving two layover flights. From those models, we found a similar WTP of $187 for the flight to Washington and $325 for the flight to London. This very large WTP to reduce emissions on the London flight shows that, if anything, the lower emissions on the nonstop flights makes the London model over-value a nonstop, rather than nonstops making it over-value the emissions savings.

We can also use these models to predict how much showing emissions information for alternative flights during flight search could encourage travelers to use a less-convenient airport to avoid a layover. We can see from the similarities of the coefficients on "nonstop" and "airport" that there is a near-tie between a flight from the preferred airport with a layover as opposed to a nonstop flight from the less desirable airport. This gives an opportunity for lower cost and lower emissions to change traveler's behavior. For a flight to Washington, the layover flight from the preferred airport is more desirable, but a savings of only $8, or 87 lbs of carbon emissions, tips the balance the other way. For the trip to London, the nonstop is already the preferred option (we also found in the AFS History data that UCD employees often go to SFO to get nonstop flights to London); according to the model, employees are willing to pay $97 more for a nonstop from their non-preferred airport over a layover flight from their preferred airport. According to the AFS history data, the real difference in emissions between a layover flight and a nonstop is about 450 lbs, for which the model predicts a $56 difference in willingness to pay (at $0.125/lb of carbon for London). That is, when shown the emissions estimates, a traveler who likes to fly out of SMF will prefer a nonstop from SFO even if a layover flight from SMF is $97+$56 = $153 cheaper. The main point here is that for either trip, the emissions savings of a nonstop flight are sufficient to encourage travelers to use a less convenient airport (typically, departing from SFO instead of SMF).

To get a rough sense of the relative importance of the factors in travelers' decisions, we can normalize the carbon and cost variables so that the mean is zero and one standard deviation each way falls at –1 and 1. This kind of estimate involves the somewhat arbitrary rescaling, especially relative to the 0–1 variables, and is less favored by statisticians than describing tradeoffs using WTP. That said, the two "normalized" models in the table illustrate the importance of nonstops to the London travelers, and the lower (but still significant) importance that they attach to emissions.

To test the significance of carbon emissions in these models, and to be able to predict the difference in consumer behavior when booking flights on a website interface that emphasizes emissions compared to a standard one that does not, we also computed models that do not use carbon emissions as a prediction variable. Since the models are computed using maximum likelihood, we can measure how much including the carbon emissions variable improves the model by comparing the likelihoods of the models with and without emissions as an input. For Washington, the difference between the model without emissions (noELL - no-emissions log likelihood) and the model considering emissions (ELL) is:

$$\text{Log-likelihood ratio} = 2(\text{ELL} - \text{noELL})$$

For the D.C. models in Table 4, this calculation is 2*(1104-1086) = 36. For adding one variable, standard tables indicate that a log-likelihood ratio of 7.85 or higher is at the 99.5% confidence level for stating that the factor in question adds to the model. The value of 36 in this case means the carbon emissions factor unequivocally adds to the model. For London, the ratio is 7.2, which is still significant but less so; this is probably due to the already strong preference for nonstop flights to very distant locations.

Participants' direct assessment of the importance of air travel emissions information

At the end of the survey, we asked participants if they would be interested in seeing more prominent carbon emissions information about flight alternatives when they search for flights, and how seeing that information might affect their choices. A majority (75%) said yes, they would be interested in seeing emissions information. Most participants indicated that seeing the information would have some impact on their choices, but few said it would be among the most important factors. Price, then layovers and airport, were most often cited as being more important, but many also mentioned the importance of trip timing (time of day and duration). The most common theme by far was that carbon emissions would be a consideration if other more important factors were comparable between options, e.g.:

> *Would try to do greener flights if other factors not too different.*
>
> *When convenience and prices are similar, I would definitely choose the more efficient flight.*
>
> *It's not the ultimate deciding factor for me, but it is useful when the other factors I take into consideration make two choices roughly equal. It's like calories on a menu, it's helpful to know when making your final decision.*

Some participants also mentioned the influence of university as payer. There were two contrary camps. Much less prevalent of the two was the idea that price mattered less since the university was paying. In contrast, many reported that price is a primary concern particularly for business travel because of limited funding, i.e., obligation, need or requirement to take the cheapest flight due to shared and/or constrained budgets. Many participants suggested that changes in university policy could support their desire to take lower-emissions flights:

> *I would take carbon emissions into account when booking for personal trips. However, until the UC makes it a policy that they prioritize lower carbon emissions over lower costs, I will continue to take the lower cost flight for business purposes.*
>
> *I am in favor of reducing carbon emissions but I still have to travel on a budget. If the lower carbon emissions flight were more expensive but the campus offered some rebate/credit to my accounts for taking a lower carbon emission flight, that would make choosing the lower carbon emissions flight more attractive.*
>
> *UC gives faculty a flat amount of travel funds plus access to one, flat rate travel grant per year. That means that I always prioritize the following things: cost, closest airport (SFO for me), and nonstop flights. Therefore, carbon emissions do not factor into my decision. If the UC would compensate extra to make up for the*

expense of the low-emission flight, I would then be willing to wiggle on airport location and nonstop, but not when I have to nickel-and-dime myself to avoid debt for work travel.

It would give those with the financial flexibility the option to choose the less carbon intensive option. Although at this point in my life I don't have that flexibility, if it were university policy to choose the more carbon light option and it were being paid for with university funds, I would choose the greener option. We are typically meant to choose the most cost effective way to spend public funds, so this gets into bigger issues of what is the most "responsible" use of public money. Thanks for the survey. This is very interesting.

It would certainly play a role in my decision making, especially if that was supported by the university and some extra intramural funds to cover cost differences, within a certain range.

I worry about the amount I travel and the footprint this has. It would be great if UCD can incentivize the price difference if there is a greener flight. I am now sometimes asked to accept flights with extra layovers that are almost always more miles and more takeoff/landings and therefore more carbon emissions. This is usually cost driven.

In this survey, I always selected the cheapest option. Some departments do not have the luxury of a well-padded budget to select more expensive flights, even if that means lower CO2 emissions. As a private citizen, seeing the CO2 emissions would actually help me select flights and be more mindful about my travel. I could see myself selecting flights that are slightly higher in price but lower in CO2 emissions. … Anyway, if departments supported the purchase of flights that had lower CO2 emissions but were more expensive then I would definitely take that route (no pun intended!).

Unfortunately, the limited startup and grant funding allocated for traveling "forces" most faculty to fly as cheap as possible. If there were any incentives or state/campus support available to support the low carbon emission flights, I am sure that all faculty would consider it.

When flying on grant money, I sacrifice a lot to keep the price down. Carbon emissions are a tertiary priority behind price and convenience. Unless there is encouragement or incentive, I am unlikely to significantly alter my flight choices based on carbon emissions. But it never hurts to have more information, especially should there be several roughly equivalent choices.

We also learned from open-ended comments that simply highlighting the lowest-emissions flight will not be enough to sway some travelers to choose an SFO nonstop over an SMF indirect because there is not enough information about net emissions including ground transportation:

If the carbon emissions are significantly higher one one flight vs another, I would pay a bit more to keep the carbon emissions down. But I probably wouldn't choose *to go to SFO instead of SMF because it takes more carbon emissions to get to SFO and significantly more time.*

Would also like CO2 for taxi from Davis–SFO & Davis–SMF shown.

It would make more sense to avoid adding car travel to air travel.

It would be helpful to know what the average carbon emissions are for ground travel options to get from UCD to SFO.

I would also have to know what additional carbon emissions it would be to get to SFO compared to SMF.

A broader theme along these lines was that consumers need more contextual information to interpret, and trust, the emissions estimates and potential impact of choosing a flight with lower emissions:

I might choose the lower carbon option if it was only slightly more expensive. The problem with the options you showed me now is that I didn't understand how the calculation was being done (so whether to trust it) or what a difference of 100 lb CO2 actually means (is that a big difference?)

I honestly have no idea what those CO2 LBS emissions really mean. If a flight was within $10 to $40 I might consider a more "green" flight but having direct flights and lowest cost are my #1 priorities by far.

I don't fully understand the exact impact a flight with a few hundred less lbs of emissions has on the environment so it would be more meaningful if there was also more information.

If it's a significant difference, it might be worth paying up to approximately 10% more, as long as the travel time, nonstop, etc., aren't changed. Would also be more meaningful if there is some analogy to give the emissions numbers in layperson terms.

It would only affect my flight choices if they were accurate. For example, it's not clear if the choices in this survey reflected the CO2 emissions of driving to SFO vs SMF. So unless some methodology would be provided to tell us how it was determined that a flight was "greener" (does airline use biofuels? Is the aircraft more fuel efficient? Does taking off at a specific airport require more fuel due to topology?), I am not sure if I would believe or use that information.

Would want to see lbs CO2 per $, not calculate the differences myself.

Finally, there were several noteworthy comments that reflect some deeper issues to consider, like conveying to consumers how their collective choices could influence airlines, i.e.:

[Emissions information] won't [affect my choices] until there is the development of truly low-carbon flights (i.e., electric, etc.).

It would play a factor in my decision. I'm not entirely sure how I would rank it next to convenience and cost. I also don't really understand enough about the economics of this to really know if choosing a lower carbon flight actually stops the other flight from occurring...can't we assume that the other presented alternatives would also happen regardless? That's probably why I would generally select SIA over SFO. At least I'm burning less carbon to get to the airport. Also assuming direct flights out of SIA are probably the lowest carbon footprint; using SIA creates demand, which creates more of these options in the future??

I think it would make sense to implement a personal internalized version of a carbon tax in terms of consumer preference. The values I usually see for carbon taxes are in the area of $20–50 / ton, which is why I'm relatively insensitive to differences of a couple hundred lbs CO2—if the carbon can be mitigated for cheaper than the difference in flight costs, then choosing a more expensive greener flight is a suboptimal decision for the environment. Carbon pricing schemes often price emissions between $10 and $100 / ton. On this logic, the cheaper flight usually makes more sense. The 'greenest' action would be to purchase the cheaper flight and donate the saved funds to a carbon mitigation effort.

At this point, only saving time and money concern me. I am all for environment, but airlines themselves should figure out how to cut back on carbon emissions.

Modeling Potential Carbon and Cost Impacts

For our fourth and final research question, we wanted to estimate the potential emissions savings and costs if the UC Davis travel portal prominently displayed carbon emissions while users were searching for flights. We triangulated the models of UC Davis employee traveler behavior reported above with the AFS History data, and another dataset we created, which we call the Flight Options dataset. These potential campus-wide impacts depend on the distribution of UCD traveler destinations, which we gleaned from the AFS History data, and also on the array of options from which travelers made their selections (options that varied in terms of cost and carbon, among other factors). We collected the latter data in what we refer to as the Flight Options dataset.

Methodology

To create the Flight Options dataset, we first identified the most common destinations in the AFS History dataset (including both SMF and SFO departures, but excluding flights originating elsewhere). We chose the top 70 destinations in order to account for a majority (86%) of all 2017 flights out of SMF and SFO. For each of these, we collected a large number of possible flights by using a web-scraping script on the Google Flights website (using a Web scraping tool called DataMiner). We searched for roundtrip flights, departing on a Thursday and returning on a Sunday, a couple of months in the future, to get reasonable price estimates. We found a broad range of alternatives for the different destinations, with a minimum of 1 option to a maximum of 250 (SFO to Singapore) flights. The data collected for each flight included the airline, price, duration, number of layovers, and the aircraft used on each flight leg.

For each flight leg collected, we used a second web-scraping script to collect accurate carbon emissions estimates, using the specified aircraft, from the website of a German offset company, Atmosfair (https://co2offset.atmosfair.de/co2offset?p=1#/flight?locale=en). Atmosfair was often more specific about aircraft models than Google Flights. We used Wikipedia to select the most likely aircraft model given the information from Google Flights, for instance "Airbus 330–300" for "Airbus 330". For most aircraft, this "best guess" for the specific aircraft model was consistent across the industry. For the Boeing 737, there are many models, with significantly different emissions, in use, and the specific mix differs between airlines, so for the 737 we also took the airline into account when guessing the specific aircraft model.

Finally, we discarded any flights whose duration was more than twice that of the quickest flight, and any with more than one layover each way. We also discarded a small number of flights for which there was no aircraft information, or for which the aircraft was completely unknown to Atmosfair. This eliminated three of our original set of 70 destinations. The resulting collection of possible flights to each remaining destination formed the Flight Options Dataset.

In our predictions of potential emissions savings and costs, we assumed SMF was the preferred airport. We used the Washington, DC model for all domestic destinations and the London model for all foreign destinations (including Mexico and Canada). We added 30lbs of additional carbon to the SFO flights to account for the emissions of the trip to the airport. Emissions estimates from Atmosfair were more than twice those given in the AFS History data, mainly because they assume a larger RFI (radiative forcing index), a "fudge factor" in emissions estimates that covers emissions other than CO2, the fact that emissions take place in the upper atmosphere, and other factors that are difficult to account for. We scaled numbers from Atmosfair by 1.0478, converting from kilograms to pounds while simultaneously scaling the RFI down; that number is the ratio of the two estimates (AFS and Atmosfair) of emissions from Sacramento to Washington, DC.

For each destination, we used the two appropriate models (using and not using emissions) to compute utility, and then the probability that each flight would be chosen under each model. Using the probability of each flight, we computed the expected cost and expected emissions for each destination, and the probability that a traveler would choose SFO as the departure airport.

Results

We see in Figure 6 that UC Davis employees' most frequent air travel destinations are dominated by short- and medium-distance trips. Our models predict that travelers will use SFO as the departure airport more often for nonstop flights if they see emissions values during flight search, particularly for medium-distance flights. On short flights, less than a quarter of trips will originate in SFO in either model. A closer look at the data shows that many of these frequent short flights are inexpensive nonstops, on Southwest, from SMF. On medium-distance trips, however, 50% of trips originate in SFO under the model where the traveler sees emissions, while only 39% do under the model in which the traveler does not. Many of these flights are on major airlines, and nonstops are available from SFO but not from SMF. For long-distance trips, most flights originate in SFO under either model.

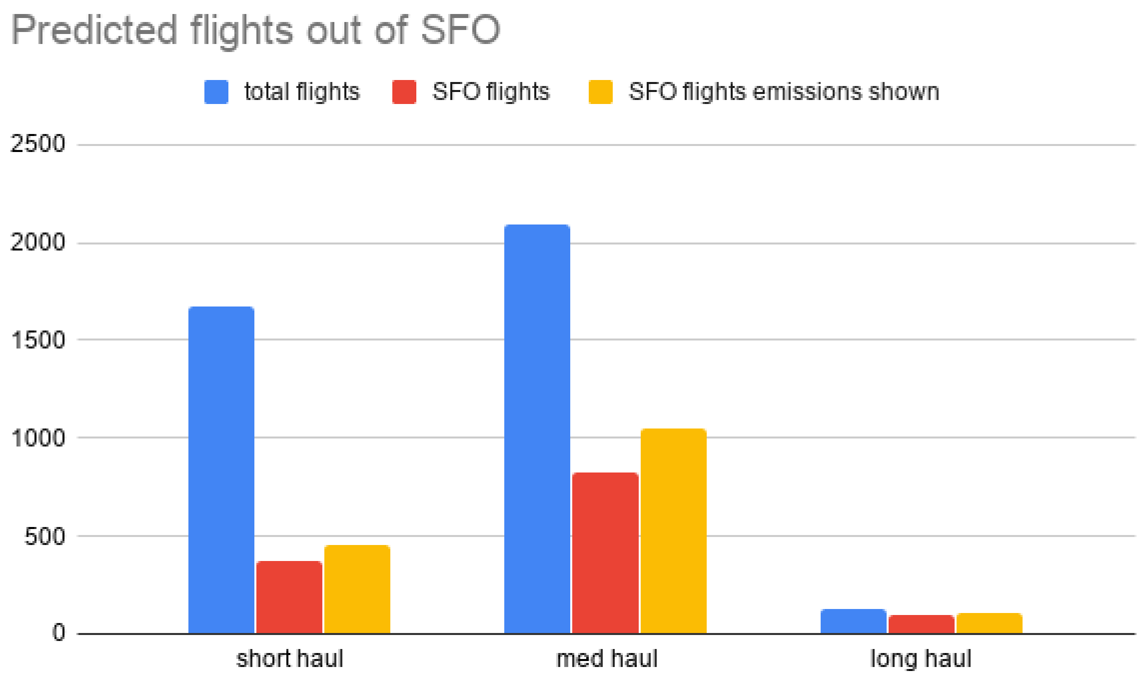

Figure 6. Showing emissions savings during flight search (yellow) encourages travelers to fly out of SFO instead of Sacramento, often to get a nonstop instead of a layover flight. Most travelers already leave from SFO for long-distance flights (right). Prediction models are based on a survey of 447 UC Davis employees, applied to a distribution of trips to 67 popular destinations derived from institutional accounting data.

This change in flight choices leads to lower emissions overall, as seen in Figure 7. There is virtually no change in emissions from the short-distance flights; they are already about as efficient as they can be. Changes in both the medium- and long-distance flights are responsible for virtually all the emissions savings. Long-distance flights are under-represented in our Flight Options dataset since it only includes the most popular destinations.

Figure 7. The predicted change in behavior from Figure 6 corresponds to a modest emissions savings of 3.8%, mostly on medium- and long-distance flights.

Based on this analysis, we estimated potential annual savings for UC Davis of more than 79 tons of CO_2E if employees could see emissions information prominently on the university travel portal, out of a total of 2099 tons (3.8%) for the 67 popular destinations. This modest emissions reduction was combined with a $56,000 reduction in airfare costs, due to an increased willingness of travelers to take advantage of cheaper (often also nonstop) flight options out of SFO when incentivized with reduced emissions. That is, while employees are willing to pay more to avoid emissions, on the existing mix of travel destinations, showing them emissions information while searching for flights would ***reduce, rather than increase***, costs.

Discussion

In a flight choice experiment given hypothetical business trip scenarios, UC Davis employees demonstrated a willingness to pay (WTP) for lower-emissions flights at a rate of $184 per ton for a domestic trip and $250 per ton for an international trip. This is an order of magnitude more than the typical carbon price used in offsetting schemes. It is also consistent with the WTP that we found in our earlier experiment using Amazon Mechanical Turk ($192 per ton; Sanguinetti et al., 2017).

Furthermore, the presence of emissions information and highlighting the greener option makes nonstop flights even more desirable than they already are. Because of this, it encourages travelers to take a nonstop from SFO instead of a layover flight from SMF. Based on the distribution of flights available to UCD travelers, these trade-offs mostly occur for medium-distance flights. These findings demonstrate behavioral plasticity in this range, suggesting that better public transportation to regional hub airports would further encourage the use of nonstop flights.

Principles of choice architecture may explain these impressive findings. Choice architecture refers to ways a choice is presented that influence what a decision-maker chooses (Johnson et al., 2012). Subtle features of a choice scenario can predictably influence behavior, for example, by increasing the salience of a particular choice attribute that might otherwise be overlooked (such as carbon emissions in flight choice). Attribute parsimony is one strategy to increase salience, by simplifying of a choice attribute so that it is easier for consumers to evaluate. Translating highly quantitative information, especially in an unfamiliar domain (such as carbon emissions, for many consumers), into simple categories (e.g., "greenest flight") enables quick affective reactions and a shortcut in cognitive processing, particularly for less numerate consumers (Peters et al., 2007, 2009; Peters, 2012). This kind of "attribute translation" into evaluative labels can also have a signpost effect, which activates otherwise dormant objectives, such as pro-environmental values, and promotes choices aligned with those objectives (Ungemach et al., 2018). The few survey respondents who reported actually processing the difference in carbon emission quantities in relation to knowledge of offset costs recognized that they were being asked to pay at a significantly higher rate for reduced emissions, but most participants were probably influenced by these aspects of choice architecture.

Based on the choice models derived from our UC Davis employee survey, historical UCD air travel data, and a dataset of flight options for common UCD business travel destinations, we estimated that UC Davis could save more than 79 tons of CO_2E (or 3.8% of total emissions from air travel booked on the UCD portal) if a GreenFLY-like interface were adopted in the university travel-booking portal. While this estimate of the potential for emissions savings is disappointing, we found that it was combined with a $56,000 ***reduction*** in airfare costs, due to an increased willingness of travelers to take advantage of cheaper (often also nonstop) flight options out of SFO when incentivized with reduced emissions. The UC system has an overall goal of reducing transportation emissions, including those of business travel, by 20% from 2010 levels by 2020 (Annual Report on Sustainable Practices, 2018). In this context, an easily achieved 4% emissions savings is clearly worthwhile.

Based on the open-ended comments when we directly asked participants how seeing emissions information would influence their decisions, WTP for lower-emissions flights would likely be much higher than we found if university policy somehow supported or subsidized purchase of lower-emissions flight options. Further research is required to develop promising policies that maximize emissions savings and balance costs to the university. The potential annual savings of $56,000 should be considered when developing policies since it could fund some kind of incentive or subsidy program. Incentivizing the lower-emissions flight choice could both increase WTP to pay to reduce carbon and drive more traffic to the university travel portal since currently only about half of estimated UCD air travel is booked through the site. Driving traffic to the portal would increase carbon savings even more since more employees would be exposed to the emissions estimates when making their air travel decisions.

Other insights from survey-takers' open-ended comments include that contextual information could help make the emissions information more interpretable, trustworthy and meaningful. For example, some distrusted or were uncertain about the emissions estimates because they did not know how they were calculated and whether the estimates factored in ground transportation. Including information about carbon calculations is relatively easy; for example; GreenFLY has an About page that describes our carbon calculator. Enabling consumers to factor in ground transportation emissions to and from any destination is more complicated, but it would be relatively easy to add information to the UCD portal about typical emissions rates for different ground transportation modes in the context of the SFO–SMF comparison specifically.

Some respondents asked for more information to help them interpret the magnitude and relative impacts of different levels of carbon emissions and potential savings. Our solution for this in GreenFLY includes showing the range of emissions for all possible flight alternatives in the flight search output, as well as providing information about the average American's annual transportation carbon footprint for reference. Another option is to translate flight emissions estimates and/or potential savings into meaningful equivalent metrics (Ahmed & Sanguinetti, 2015), such as trees required to absorb the amount of carbon, or miles driven in a car with average fuel economy. However, even within the same comments, respondents both reported a WTP for lower-emissions flights and requested this kind of contextual information, indicating they are willing to pay more despite a lack of clarity. The one participant whose comments indicated familiarity with carbon offset pricing was not impressed by the magnitudes of potential savings in the trip scenarios. In our prior experiment, we found a comparable WTP despite some key differences in the message framing of emissions information: We primed participants, recruited through Amazon Mechanical Turk, by showing them information about the average American's annual carbon footprint (overall and for transportation in particular), and we presented emissions estimates in kilograms rather than pounds. Together, these findings suggest that WTP in this context may be mediated by emotional response to elements of the choice architecture (Thaler & Sunstein, 2009) such as labelling the greenest flight and relative differences between flight alternatives more than by rational considerations. The much higher WTP for lower-emissions rate for international compared to domestic flights is further evidence of this.

Limitations

Our estimates of potential emissions savings and airfare costs are very rough, because of limitations both with our survey-based models and with the distribution of flights to which they are applied.

One important limitation of our model is that our survey did not include some of the many factors important in flight search, such as airline, flight duration and how well the itinerary fits the traveler's schedule. Earlier research (e.g., Hess and Adler, 2011) indicates that flight duration is somewhat less important to travelers than airport choice, and that frequent flyer programs have a large impact, which we did not account for. This might inflate the potential effect of emissions estimates on behavior, at least for some travelers. Another issue is that in a stated preference study like this one, respondents might overestimate their responsiveness to emissions information. Finally, it seems likely that people interested in reducing emissions would have been more likely to agree to answer the survey in the first place. All of these uncertainties suggest that we may be overestimating traveler's responsiveness to emissions information.

The Flight Options dataset accounts for only the most common destinations (making up ~80% of all air travel booked on the UCD portal). Long-distance trips make up a greater proportion of the remaining flights, which include destinations with only 1-9 trips per year. Many far-flung destinations, such as Addis Ababa, Moskow, Tegucigalpa, and Vientiane, are each visited by one or two UC Davis employees each year. While estimating emissions for these long flights is complicated, it would be worthwhile since the potential carbon savings per trip are also large.

One more issue is that we use a lower estimate for the radiative forcing index (RFI) in our emissions calculations; choosing a larger RFI would effectively double the estimated emissions avoided, although leaving them unchanged as a percentage of the total.

We only considered travel booked on the University's own flight-search portal. Data on the destinations, costs, and estimated emissions of travel not booked through the portal is much more difficult, or in some cases impossible, to access. Since only an estimated half of UCD employee air travel is booked via the campus portal, these data might not represent the total distribution of all UCD employee air travel. If policies were implemented to increase use of the portal, the actual impacts of a GreenFLY-like interface could differ. Conversely, our models represent both employees that use the university portal and those who do not. Any systematic differences between the two groups are confounding variables not accounted for in this study (e.g., employees in certain departments, who may think alike in ways that affect their WTP for carbo, may tend to mostly use or mostly not use the portal).

Our stated choice experiment results are limited in generalizability since university employees, on average, have higher income and education than the general population, and higher education is associated with more liberal political ideology, thus this population is likely also more concerned about climate change than the general population. They also appear to be more frugal than typical business travelers, who in other studies have been shown to be willing to pay twice as much as leisure travelers to, for instance, avoid a layover. The WTP rate we found here is comparable to that found in our previous study with participants recruited on Amazon Mechanical Turk, who are typically lower income than the general population and who were instructed to consider a self-funded trip.

Our findings regarding WTP for lower-emissions in conjunction with a less-preferred airport should not be generalized directly to other multi-airport regions since the different travel times and transit options in other regions will influence the relative desirability of airport alternatives.

Conclusions and Research Opportunities

At the individual level, a GreenFLY-like travel-booking site identifies opportunities for emissions savings, such as avoiding a layover by flying out of less convenient airport. This study shows a potentially significant effect on behavior from highlighting emissions during flight search. How exactly emissions should be displayed to encourage behavior change, and what additional context information is helpful, could be studied easily on a platform such as Mechanical Turk. Since emissions information encourages travelers to think carefully about their carbon footprint when planning a trip, we believe that it could also encourage them to take fewer flights. This is a very interesting direction for future research, but more difficult.

At an institutional level, this study shows that adopting a GreenFLY-style flight search portal could both reduce emissions and save money in the short term, especially where travelers have a choice of airports. Governments and large corporations with sustainability goals, as well as universities, run internal flight-search portals and could adopt this approach with minimal effort. The obvious research opportunity here would be a live trial of a flight-search interface showing emissions, so that we can test the idea in a setting where travelers are spending real (if not their own) money. Ideally from a research perspective, one should do an A/B test, randomly showing the traveler either the interface showing emissions or an interface without emissions.

On a larger scale, significant adoption of emissions-aware flight search could encourage a real reduction in aviation emissions. The remarkable willingness-to-pay of travelers to avoid emissions that we have shown in our studies might allow air carriers to charge slightly more for especially fuel-efficient flights, making it possible to invest in more efficient aircraft more quickly. Rather than paying more, travelers might be willing to fly at less convenient times, or (as we have shown) from less convenient airports, opening up opportunities to change flight schedules to reduce emissions. Applying models such as ours to the design of flight schedules is a very interesting research direction. For example, where would travelers taking emissions into account promote more direct flights between smaller airports, and where would it promote the use of hubs, if the hubs can draw travelers from larger geographic areas? Finally, biofuels have the potential to provide very significant emissions savings, and highlighting these savings during flight search could encourage much faster adoption. User-interface research on highlighting biofuels in flight search would be very interesting.

Finally, improving ground-transportation access to hub airports from larger geographic regions could also encourage people to take more efficient flights. There are many interesting research opportunities here, including interactions with public transportation planning and commercial ridesharing. The many interconnected systems involved make this a very difficult question; for example emissions due to highway congestion near large hubs might increase, service to smaller airports may no longer be viable thus reducing access for some travelers, emissions per seat from planes from smaller airports might increase because of lower occupancy or more use of regional jets, and so on.

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Data Management

Products of Research

We collected three datasets for this study:

1. Employee Survey: A survey of UC Davis employees
2. AFS History: Data shared with us by UC Davis Accounting and Financial Services on one year of flights booked from the AggieTravel portal.
3. Flight Options: A dataset of flight information scraped from Google Flights and Southwest Airlines website and merged with emissions estimates from Atmosfair for flight alternative offered to most common destinations in AFS History.

Data Format and Content

1. Employee Survey: Survey data are anonymized and stored in a csv file. They include information about the flight options presented to participants and their flight selections, as well as participant preferences, reported travel behavior, and comments about the usefulness of emissions information in the context of online flight searching and booking.
2. AFS History: These data are in an Excel spreadsheet. They are not going to be shared publicly as they are not originally ours to share. They were shared with us by UC Davis Accounting and Financial Services, and it would be easy to figure out information that travelers assume would be private. We do share, with Dataset 3, a summary file showing frequent destinations and how often each trip is made in aggregate.
3. Flight Options: These data are stored in a csv file; they include the following data on flight alternatives: price, layovers, airport, airline, emissions, and flight duration (long flights were excluded).

Data Access and Sharing

Datasets 1 and 3 are archived in the Dryad data repository and can be accessed via DOI https://doi.org/10.25338/B81S5M and https://doi.org/10.25338/B8FS5B, respectively.

Reuse and Redistribution

Data can be reused and redistributed with credit to this report and referencing the above DOIs. Adaptations of the data should credit the following sources as well, and explicitly note procedures for changes, transformations, omissions or additions. Recommended citations:

Amenta, Annamaria; Sanguinetti, Angela (2019), Employee airline travel preferences survey data, UC Davis GreenFLY project, v2, UC Davis, Dataset, https://doi.org/10.25338/B81S5M

Amenta, Annamaria; Sanguinetti, Angela (2019), Popular flight costs and emissions data, UC Davis, Dataset, https://doi.org/10.25338/B8FS5B

Appendix

All flight choice survey questions are provided here. Cost-carbon combinations are color-coded. Each flight alternative (i.e., cost-carbon-airport-layover combination) is presented equally, with the exception of the nonstop flights, which are slightly overrepresented.

DC Bucket 1: SMF Layovers and SMF Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SMF	layover	2433	392	1821	502	SMF	layover
SMF	layover	2433	447	2229	556	SMF	layover
SMF	layover	2229	447	2025	502	SMF	layover
SMF	layover	2229	556	2433	392	SMF	layover
SMF	layover	2025	392	1821	556	SMF	layover
SMF	layover	2025	502	2433	447	SMF	layover
SMF	layover	1821	556	2229	447	SMF	layover
SMF	layover	1821	502	2025	392	SMF	layover

DC Bucket 2: SFO Layovers and SFO Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SFO	layover	2433	392	1821	502	SFO	layover
SFO	layover	2433	447	2229	556	SFO	layover
SFO	layover	2229	447	2025	502	SFO	layover
SFO	layover	2229	556	2433	392	SFO	layover
SFO	layover	2025	392	1821	556	SFO	layover
SFO	layover	2025	502	2433	447	SFO	layover
SFO	layover	1821	556	2229	447	SFO	layover
SFO	layover	1821	502	2025	392	SFO	layover

DC Bucket 3: SMF Layovers and SFO Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SMF	layover	2433	392	2229	447	SFO	layover
SMF	layover	2433	447	2025	502	SFO	layover
SMF	layover	2229	447	1821	556	SFO	layover
SMF	layover	2229	556	1821	502	SFO	layover
SMF	layover	2025	392	2433	447	SFO	layover
SMF	layover	2025	502	2433	392	SFO	layover
SMF	layover	1821	556	2025	392	SFO	layover
SMF	layover	1821	502	2229	556	SFO	layover

DC Bucket 4: SMF Layovers and SFO Layovers							
Flight Alternative A				Flight Alternative B			
Airport	**Layovers**	**Carbon**	**Cost**	**Carbon**	**Cost**	**Airport**	**Layovers**
SMF	layover	2229	447	2433	392	SFO	layover
SMF	layover	2025	502	2433	447	SFO	layover
SMF	layover	1821	556	2229	447	SFO	layover
SMF	layover	1821	502	2229	556	SFO	layover
SMF	layover	2433	447	2025	392	SFO	layover
SMF	layover	2433	392	2025	502	SFO	layover
SMF	layover	2025	392	1821	556	SFO	layover
SMF	layover	2229	556	1821	502	SFO	layover

DC Bucket 5: Layover in One Airport, Nonstop in the Other							
Flight Alternative A				Flight Alternative B			
Airport	**Layovers**	**Carbon**	**Cost**	**Carbon**	**Cost**	**Airport**	**Layovers**
SFO	layover	2433	392	1645	638	SMF	nonstop
SMF	layover	2433	447	1645	474	SFO	nonstop
SFO	layover	2229	447	1645	529	SMF	nonstop
SMF	layover	2229	556	1645	583	SFO	nonstop
SFO	layover	2025	392	1645	583	SMF	nonstop
SMF	layover	2025	502	1645	638	SFO	nonstop
SFO	layover	1821	556	1645	529	SMF	nonstop
SMF	layover	1821	502	1645	474	SFO	nonstop

DC Bucket 6: Same airport, Nonstop vs Layover							
Flight Alternative A				Flight Alternative B			
Airport	**Layovers**	**Carbon**	**Cost**	**Carbon**	**Cost**	**Airport**	**Layovers**
SFO	layover	2433	392	1645	638	SFO	nonstop
SMF	layover	2433	447	1645	474	SMF	nonstop
SFO	layover	2229	447	1645	529	SFO	nonstop
SMF	layover	2229	556	1645	583	SMF	nonstop
SFO	layover	2025	392	1645	474	SFO	nonstop
SMF	layover	2025	502	1645	529	SMF	nonstop
SFO	layover	1821	556	1645	638	SFO	nonstop
SMF	layover	1821	502	1645	583	SMF	nonstop

DC Bucket 7: Nonstop Opposite Airports							
Flight Alternative A				Flight Alternative B			
Airport	**Layovers**	**Carbon**	**Cost**	**Carbon**	**Cost**	**Airport**	**Layovers**
SFO	nonstop	1645	474	1645	529	SMF	nonstop
SFO	nonstop	1645	638	1645	583	SMF	nonstop

London Bucket 1: SMF Layovers and SMF Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SMF	layover	4331	761	3837	1135	SMF	layover
SMF	layover	4331	948	4167	1322	SMF	layover
SMF	layover	4167	948	4002	1135	SMF	layover
SMF	layover	4167	1322	4331	761	SMF	layover
SMF	layover	4002	761	3837	1322	SMF	layover
SMF	layover	4002	1135	4331	948	SMF	layover
SMF	layover	3837	1322	4167	948	SMF	layover
SMF	layover	3837	1135	4002	761	SMF	layover

London Bucket 2: SFO Layovers and SFO Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SFO	layover	4331	761	3837	1135	SFO	layover
SFO	layover	4331	948	4167	1322	SFO	layover
SFO	layover	4167	948	4002	1135	SFO	layover
SFO	layover	4167	1322	4331	761	SFO	layover
SFO	layover	4002	761	3837	1322	SFO	layover
SFO	layover	4002	1135	4331	948	SFO	layover
SFO	layover	3837	1322	4167	948	SFO	layover
SFO	layover	3837	1135	4002	761	SFO	layover

London Bucket 3: SMF Layovers and SFO Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SMF	layover	4331	761	4167	948	SFO	layover
SMF	layover	4331	948	4002	1135	SFO	layover
SMF	layover	4167	948	3837	1322	SFO	layover
SMF	layover	4167	1322	3837	1135	SFO	layover
SMF	layover	4002	761	4331	948	SFO	layover
SMF	layover	4002	1135	4331	761	SFO	layover
SMF	layover	3837	1322	4002	761	SFO	layover
SMF	layover	3837	1135	4167	1322	SFO	layover

London Bucket 4: SMF Layovers and SFO Layovers							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SMF	layover	4167	948	4331	761	SFO	layover
SMF	layover	4002	1135	4331	948	SFO	layover
SMF	layover	3837	1322	4167	948	SFO	layover
SMF	layover	3837	1135	4167	1322	SFO	layover
SMF	layover	4331	948	4002	761	SFO	layover
SMF	layover	4331	761	4002	1135	SFO	layover
SMF	layover	4002	761	3837	1322	SFO	layover
SMF	layover	4167	1322	3837	1135	SFO	layover

London Bucket 5: Layover in One Airport, Nonstop in the Other							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SFO	layover	4331	761	3638	1603	SMF	nonstop
SMF	layover	4331	948	3638	1042	SFO	nonstop
SFO	layover	4167	948	3638	1229	SMF	nonstop
SMF	layover	4167	1322	3638	1416	SFO	nonstop
SFO	layover	4002	761	3638	1416	SMF	nonstop
SMF	layover	4002	1135	3638	1603	SFO	nonstop
SFO	layover	3837	1322	3638	1229	SMF	nonstop
SMF	layover	3837	1135	3638	1042	SFO	nonstop

London Bucket 6: Same Airport, Nonstop vs Layover							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SFO	layover	4331	761	3638	1603	SFO	nonstop
SMF	layover	4331	948	3638	1042	SMF	nonstop
SFO	layover	4167	948	3638	1229	SFO	nonstop
SMF	layover	4167	1322	3638	1416	SMF	nonstop
SFO	layover	4002	761	3638	1042	SFO	nonstop
SMF	layover	4002	1135	3638	1229	SMF	nonstop
SFO	layover	3837	1322	3638	1603	SFO	nonstop
SMF	layover	3837	1135	3638	1416	SMF	nonstop

London Bucket 7: Nonstop Opposite Airports							
Flight Alternative A				Flight Alternative B			
Airport	Layovers	Carbon	Cost	Carbon	Cost	Airport	Layovers
SFO	nonstop	3638	1042	3638	1229	SMF	nonstop
SFO	nonstop	3638	1603	3638	1416	SMF	nonstop