Estimating carbon emissions from university air travel

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As part of an effort by the University of Washington to curb its impact on the environment, UW President Mark Emmert has signed onto the American College & University Presidents' Climate Commitment[2] (ACUPCC), a pledge to reduce UW's carbon footprint. Toward this end, UW conducted a greenhouse gas inventory[3] and finalized a Climate Action Plan[4] in September 2009.

Among the emissions considered in these documents is the CO_2 produced by university-related air travel to meetings, conferences, sporting events, etc. As noted in the ACUPCC Implementation Guide[5] "few campuses currently track air miles traveled, and doing so can be challenging… [so until a tracking system is in place] signatories may approximate their total air travel miles by dividing the total amount spent on air travel by a factor of $0.25 per passenger air mile" (p. 15).

This figure of $0.25 per passenger mile is cited in the UW Climate Action Plan (p. 47) and in the UW greenhouse gas inventory (p. 33, n5), which cites the ACUPCC Implementation Guide but also notes the following:

> The U.S. Bureau of Transportation Statistics maintains a national average revenue per passenger-mile, which was 12.22¢/passenger-mile in 2003, the most recent year available… However, the national figure is strongly influenced by budget and recreational travel that is atypical of the professional travel induced by a university.

Where does the $0.25 factor come from? The ACUPCC Implementation Guide cites a working paper (Huang 2000[6]) entitled "An Analysis of Air Passenger Average Trip Lengths and Fare Levels in US Domestic Markets." In this working paper, the author compiles various data from 1998—including the average cost per mile of different ranges of trips—but we cannot find any statement or suggestion that the overall average cost per passenger mile in 1998 was in fact $0.25. (According to the US Bureau of Transportation Statistics, the average cost per passenger mile in 1998 was $0.141 per mile.[7])

Because of this uncertainty, we decided to directly estimate average cost per passenger mile for the University of Washington from budget data.

Data, methods, and results

The samples for our study were drawn from a UW air travel activity report.[8] This document provides details (traveler's name, purchase price, flight origin and destination for each leg, and dates of travel) on $1.6 million spent by the University of Washington on air travel between June 2007 and June 2009. This sample is less than 5% of total air travel expenditures at UW during this period, but we believe that it is a random sample.[9]

With assistance from students in a summer 2009 Introduction to Environmental Economics course, 234 random dollar figures between zero and the $1.6 million total expenditure amount were generated. Students tracked each of these dollar figures to a particular trip in the air travel activity report, used an online distance calculator[10] to determine the miles flown for each trip, and then divided this mileage figure by the purchase price to determine the miles per dollar for that particular trip. (We excluded 5 of the 234 trips because they produced implausible large estimates of over 30 miles per dollar figures.) Details about our somewhat-complicated sampling procedure are available in Appendix 1.

We calculated a sample mean of 7.44 miles per dollar with a standard deviation of 4.21. Our 95% confidence interval is 7.44 +/- 0.55, i.e., between 6.89 and 7.99 miles per dollar. (Statistical details are in Appendix 2; using the entire sample of 234 trips instead of the restricted sample of 229 trips produced a sample mean of 8.21 miles per dollar with a standard deviation of 6.89.)

We used our sample mean in two hypothesis tests. First we tested the figure from the ACUPCC Implementation Guide, using a null hypothesis of $\mu = 4$ miles per dollar (i.e., $0.25 per mile) and an alternative hypothesis of $\mu \neq 4$ miles per dollar. Our t-score was 12.36 ($p<0.0001$), so we rejected the null hypothesis.[11] Then we tested the BTS figure, using a null hypothesis of $\mu = 7.69$ miles per dollar (i.e., $0.13 per mile) and an alternative hypothesis of $\mu \neq 7.69$ miles per dollar. Our t-score was -0.90 ($p>0.37$), so we fail to reject the null hypothesis.

Conclusion

The UW Climate Action Plan estimates total greenhouse gas emissions in 2007 of about 200,000 metric tonnes of CO_2-equivalent, including about 20,000 metric tonnes from air travel. This estimate is based on UW air travel expenditures and on the ACUPCC Implementation Guide figure of $0.25 per mile for air travel. Our estimate—one that must be considered preliminary because, e.g., we did not sample from the entire data set—is that UW air travel actually averages 7.44 miles per dollar, i.e., $0.13 per mile; this dollar-per-mile figure is much lower than the Implementation Guide figure, indicating that a given dollar amount corresponds to more travel and therefore more carbon emissions than previously thought.

Using our estimate of $0.13 per mile instead of the ACUPCC figure of $0.25 per mile increases UW air travel emissions by 87%. The ACUPCC methodology yields UW air travel emissions in 2007 of about 20,000 metric tonnes, or approximately 10% of total UW emissions of 200,000 metric tonnes. Using our methodology instead yields UW air travel emissions in 2007 of about 37,000 metric tonnes, or approximately 17% of total UW emissions of 217,000 metric tonnes.

We hope that our methodology will be used to estimate cost per passenger mile at other institutions and to track changes over time in this figure at UW and elsewhere. But we also want to emphasize that our estimate is statistically indistinguishable from the most recent (2007) BTS national average of $0.13 per mile. We therefore recommend that UW and other ACUPCC signatories use figures from the BTS national average if they are unable to conduct an analysis similar to ours in order to determine their own cost per mile. Either of these approaches will yield an estimate that is more firmly based in evidence than the $0.25 per mile figure currently recommended in the ACUPCC Implementation Guide.

Appendix 1: Sampling methodology

Our raw data set included entries such as those that appear in the first 5 columns of the table below; the first two rows below the header correspond to a simple one-way trip of 2,402 miles for $500, the next five rows to a multi-city trip totaling 11,628 miles for $1,300, and the last row to a travel agent charge of $80 that was billed separately from the affiliated flight and consequently has a mileage total of zero. To this raw data we added a sixth column for cumulative cost—to be explained shortly—and a seventh and final column indicating the mileage for each leg of each trip. (Again, the travel agent charge corresponds to a "trip" of zero miles.)

The fact that some entries took up more rows than others made it impossible to randomly sample by trip, so we randomly sampled by dollar amount instead. We did this by creating a column for cumulative cost—as in the 6th column in the example, where the total cost for all three entries is $1,880—and then generating random numbers between 0 and the total cost to select trips for our sample. In our example, a random number less than 500 would correspond to the first trip, a random number between 500 and 1800 would correspond to the second trip, and a random number greater than 1800 would correspond to the third trip (i.e, the travel agent charge). We then determined miles per dollar for each of the randomly selected trips, and then calculated the average of these to get an estimate of the population mean.

What this process does is randomly select trips in proportion to their cost, which is exactly what we want. To confirm this, note that our example involves total costs of $1,880 and total mileage of 14,030 miles, for a population average of 7.46 miles per dollar. If we calculate the expected value of miles-per-dollar for a trip randomly selected with our method then we get the same figure:

(500/1880)*(2402/500) + (1300/1880)*(11628/1300) + (80/1880)*0 = 7.46.

Another way to think about our methodology is that we are breaking the data set into trips that are each $1: the data set in our example would have 300 trips going 4.80 miles per dollar, 1300 trips going 8.94 miles per dollar, and 80 trips going 0 miles per dollar. We then select a random sample of these $1 trips and calculate the average miles per dollar.

Name	Date	Flight from	Flight to	Cost	Cumulative Cost	Mileage
Doe, Jane	3/9/09			$500	$500	
		SEA	EWR		$500	2402
Doe, Jane	7/19/08			$1,300	$1,800	
		TXL	AMS		$1,800	360
		AMS	SEA		$1,800	4886
		SEA	EWR		$1,800	2402
		EWR	TXL		$1,800	3980
Doe, John	3/5/09	XAA	XAO	$80.00	$1,880	0

Appendix 2: Statistics

After calculating the sample mean of 7.44 miles per dollar, we used $\sqrt{\frac{\sum (x-\bar{x})^2}{(n-1)}}$ to calculate the standard deviation of S = 4.21. (Here $\bar{x}$ is the sample mean and n=229 is the sample size. These figures were then used to calculate the 95% confidence interval via $\bar{X} \pm t^* \frac{S}{\sqrt{N}}$ where (t*) is the upper critical value for the t-distribution with (n-1) degrees of freedom. Our 95% confidence interval is 7.44 +/- 0.55, i.e., between 6.89 and 7.99 miles per dollar.

We then used a one-sample t-test to compare our estimate with the ACUPCC Implementation Guide figure ($0.25 per mile, i.e., 4 miles per dollar) and with the most recent estimate from the U.S. Bureau of Transportation Statistics ($0.130 per mile, i.e., 7.69 miles per dollar, based on 2007 data). We calculated a t-score via $\frac{(\bar{x}-M)}{s/\sqrt{n}}$, where (M) is the hypothesized population mean and (s) is the standard deviation of the sample.

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[2] http://www.presidentsclimatecommitment.org/
[3] http://www.washington.edu/facilities/files/documents/UW_GHG_Inventory_2005_Final_PDF.pdf
[4] http://f2.washington.edu/oess/draft-uw-climate-action-plan
[5] http://www.presidentsclimatecommitment.org/pdf/ACUPCC_IG_Final.pdf
[6] http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1005&context=its
[7] http://www.bts.gov/publications/national_transportation_statistics/html/table_03_16.html
[8] Tom Phillips, Fiscal Data Analyst, Financial Services, personal communication. The air travel activity report is dated June 19, 2009, and is available upon request by email or for those with UW Net IDs from https://catalysttools.washington.edu/workspace/yoram/5940#view=30351.
[9] According to the UW Climate Action Plan [p. 47], total air travel expenditures at UW in 2008 were $25.6 million. Our data set comes from a JP Morgan Chase report; we are not sure why it includes only a fraction of total UW air travel, but we have no reason to believe that it is not a random sample.
[10] http://www.wolframalpha.com/
[11] http://www.danielsoper.com/statcalc/calc08.aspx