Willingness-to-pay for CO₂ offsets: A large-scale field study on revealed preferences in the aviation industry

Sebastian Berger, Andreas Kilchenmann, Oliver Lenz, Francisco Schlöder

University of Bern, Switzerland

Author note

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Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Abstract

Studies assessing people's willingness-to-pay for carbon offsets are overwhelmingly grounded in hypothetical stated-preference approaches. Here, we report on a large-scale observational field study involving a final sample of 63,520 bookings made with a European airline, allowing us to gauge willingness-to-pay for offsets in a revealed-preference approach. Our pre-registered study shows that the median willingness-to-pay to voluntarily offset a ton of CO₂ from flight-related emissions is zero, with the mean willingness-to-pay being around 1 EUR. Neither prices of the offset nor airfares are predictive of offsetting behavior in a highly powered sample. Climate vulnerability of the destination has no significant impact on the compensation decision either. On the other hand, higher ancillary spending is associated with an increased likelihood to compensate, even though the effect size is low due to the general unwillingness to internalize flight-related emissions. Additionally, we find the choice of a vegetarian meal to be of similar predictive power (significant, but low in effect size given an overall low proportion of passengers choosing a vegetarian meal). Our results inform existing research on stated preferences as well as mitigation efforts relying on voluntary climate action.

Keywords: Voluntary climate action; carbon offsetting; aviation; revealed preferences

1. Introduction

Aviation contributes a substantial amount of greenhouse gas emissions and is therefore a key target of climate change mitigation efforts. In terms of carbon dioxide (CO₂), aviation accounted for an estimated 2.8% of global emissions before the Covid-19 pandemic began (Le Quéré et al., 2020), largely driven by the top 1% of polluters (Gössling & Humpe, 2020). Besides CO₂, aviation is responsible for other emissions, in particular nitrogen oxides (NO_x) and water (H₂O) emitted at flight altitude (Gössling et al., 2021). In sum, air transport causes 3.5% of the net anthropogenic effective radiative forcing in 2011 (Lee et al., 2021). Attempts to decarbonize aviation involve several regulatory measures. For example, European flights are already operated under the EU Emissions Trading Scheme (European Commission, 2021; Skelton, 2013) and other policy instruments such as mandatory feed-in quotas for sustainable aviation fuel are discussed (Gössling et al., 2021). Yet, under current legislation, voluntary climate action through corporate offsetting programs (Günther et al., 2020) continues to play a pivotal role. Voluntary climate action not only allows a glimpse into passengers' motivation to pay higher amounts in order to travel carbon neutral but offsetting flight-related emissions also marks an effort that can be used to assess people's individual willingness to contribute to humanity's mitigation efforts.

Next to research investigating willingness to forego flying (Whitmarsh et al., 2020), a large number of studies has been conducted in an effort to measure people's willingness to offset flight-related carbon emissions (e.g., Brouwer et al., 2008, Choi et al., 2018, MacKerron et al., 2009, Rotaris et al., 2020, Seetaram et al., 2018, and Sonnenschein & Smedby, 2019, see Table 1 for an overview of all identified studies). As a critical limitation, all identified studies relied uniquely on stated-preference approaches, therefore eliciting willingness-to-pay hypothetically, without actual financial consequences to passengers and without actual environmental consequences.

Table 1*Overview of studies on willingness-to-pay (WTP) for flight-related carbon compensation*

Study	Reference item	Place	Sample	WTP		
				Original	EUR	EUR/tonCO ₂ ²
Brouwer et al. (2008)	1 tonCO ₂	Amsterdam Schiphol airport	International passengers	25.00 EUR	25.00 EUR	25.00 EUR
MacKerron et al. (2009)	Flight (emitting exactly 1 tonCO ₂)	United Kingdom	General population	24.00 GBP	27.36 EUR	27.36 EUR
Lu & Shon (2012)	Flight to Western city	Taipei intl. airport	Taiwanese passengers	28.60 USD	23.74 EUR	N/A
Choi & Ritchie (2014)	1 tonCO ₂	Australia	General population	21.38 AUD	13.68 EUR	13.68 EUR
Jou & Chen (2015)	Flight to Hong Kong	Taipei intl. airport	Taiwanese passengers	39.05 TWD	1.13 EUR	13.81 EUR ^a
Cheung et al. (2015)	3 tonsCO ₂ , compensated with forest protection (other state)	Australia	General population	46.24 AUD	29.59 EUR	9.86 EUR
	3 tonsCO ₂ , compensated with forest protection (own state)	Australia	General population	77.39 AUD	49.53 EUR	16.51 EUR
	3 tonsCO ₂ , compensated with renewable energy project	Australia	General population	8.38 AUD	5.36 EUR	1.79 EUR
Fatihah & Rahim (2017)	Flight	Malaysia	Putrajaya residents	6.10 MYR	1.22 EUR	N/A
Seetaram et al. (2018)	Flight (economy, short-haul)	United Kingdom	General population	16,54 GBP	18.86 EUR	N/A
	Flight (business, short-haul)	United Kingdom	General population	24,12 GBP	27.49 EUR	N/A
	Flight (economy, medium-haul)	United Kingdom	General population	22,89 GBP	26.09 EUR	N/A
	Flight (business, medium-haul)	United Kingdom	General population	30,41 GBP	34.67 EUR	N/A
	Flight (economy, long-haul)	United Kingdom	General population	29,30 GBP	33.40 EUR	N/A
	Flight (business, medium-haul)	United Kingdom	General population	36,79 GBP	41.94 EUR	N/A
Choi et al. (2018)	1 tonCO ₂ (domestic flight) ^b	Australia	General population	12.27 AUD	7.85 EUR	7.85 EUR
	1 tonCO ₂ (international flight) ^b	Australia	General population	0.92 AUD	0.59 EUR	0.59 EUR
Sonnenschein & Mundaca (2019)	1 tonCO ₂ (tax for long-haul flights)	Sweden	General population	36.00 EUR	36.00 EUR	36.00 EUR
	1 tonCO ₂ (voluntary offsetting) ^c	Sweden	General population	14.00 EUR	14.00 EUR	14.00 EUR
Sonnenschein & Smedby (2019)	1 tonCO ₂ (long-haul flight)	Sweden	General population	295.00 SEK	29.21 EUR	29.21 EUR
	1 tonCO ₂ (short-haul flight)	Sweden	General population	495.00 SEK	49.01 EUR	49.01 EUR
Shaari et al. (2020)	Flight	Kuala Lumpur intl. airport	Malaysian travelers	86.00 MYR	18.43 EUR	N/A
Rotaris et al. (2020)	1 tonCO ₂ (no purpose mentioned, up to 1.2 tons)	Italy	Travelers	24.00 EUR	24.00 EUR	24.00 EUR
	1 tonCO ₂ (for technology improvement, up to 1.2 tons)	Italy	Travelers	27.00 EUR	27.00 EUR	27.00 EUR
	1 tonCO ₂ (for reforestation, up to 1.2 tons)	Italy	Travelers	38.00 EUR	38.00 EUR	38.00 EUR
	1 tonCO ₂ (no purpose mentioned, above 1.2 tons)	Italy	Travelers	12.00 EUR	12.00 EUR	12.00 EUR
	1 tonCO ₂ (for technology improvement, above 1.2 tons)	Italy	Travelers	16.00 EUR	16.00 EUR	16.00 EUR
	1 tonCO ₂ (for reforestation, up to 1.2 tons)	Italy	Travelers	26.00 EUR	26.00 EUR	26.00 EUR

Abbreviations: N/A: not available (e.g., due to missing reference to CO₂ impact of reference item)

Notes: ^a The authors make no reference to the CO₂ impact of a flight from Taipei to Hong. The amount per ton of CO₂ is calculated based on emissions of 82 kg for this leg (ICAO, 2016); ^b Both WTPs were elicited conditional on the Australian carbon tax policy being in place, hence these results are difficult to generalize; ^c As this study is focused on the differences in WTP attributable to the payment vehicle, it is difficult to compare to more general WTPs for voluntary offsetting.

Research on stated preferences has received criticism from various fields. Within environmental psychology, Lange and Dewitte (2019) as well as Berger and Wyss (2021) argue that pro-

environmental behavior research excessively focuses on self-reports, with detrimental consequences as self-reports are potentially biased by recall inaccuracy, social desirability, and other factors. Thus, it does not come as a surprise that a large portion of actual pro-environmental behavior remains unexplained by self-reports. In a meta-analysis, Kormos and Gifford (2014) examined the association between self-reports and objectively observable pro-environmental behavior and showed that 79% of the variance remains unexplained. Within environmental economics, Löschel et al. (2013) present controlled laboratory evidence on people's willingness to curb CO₂ emissions and show that median willingness to do so is zero. Hence, research seems to suggest that a strong discrepancy exists between self-reports of intentions (i.e., stated preferences) and actual behavior (i.e., revealed preferences). This discrepancy is commonly referred to as the environmental attitude-behavior gap (Carrington et al., 2014; Kollmuss & Agyeman, 2002).

In order to contribute to a more wholesome assessment of willingness-to-pay for flight-related carbon emission offsets, we report on a large-scale field study using a revealed-preference approach. To do so, we gauge willingness-to-pay for offsets using a dataset comprising 63,520 actual bookings made with a European airline. Thus, we are able to infer actual, consequential payments for offsets and complement existing stated-preference approaches. This contributes to a recent methodological debate within environmental behavioral research, calling for the study of more impactful behaviors to complement measures of intentions or environmental behaviors with relatively little climate impact (Lange & Dewitte, 2019; Nielsen et al., 2021).

2. The present research: Revealed preferences for offsetting flight-related emissions

In this study, we report on an observational field study that allows us to elicit the willingness-to-pay of airline passengers to compensate their flight-related carbon emissions. This section explains our open science practices, sampling, and dataset, as well as pre-registered hypothesis.

2.1. Open science and ethical statement

All materials, data, and code to replicate the statistical analyses are available on the Open Science Framework: [original link redacted for peer review, anonymized link:

https://osf.io/u3faz/?view_only=7f31d8f803d7421987200044450e7252]. The present research includes observational data, therefore no experimental conditions were assigned. All data exclusions follow the pre-registered protocol. The study's central hypotheses were pre-registered. We received access to the airline's data after pre-registration of our hypothesis. As this observational dataset did not contain any sensitive or personal data and was completely anonymized, analyzing the dataset and testing our hypotheses was exempt from ethical approval.

2.2. Sample and variables

This research is based on a dataset of passenger bookings of a European airline, collected between August 2019 and October 2020. The initial dataset contained all bookings made directly on the airline's website during the respective collection period. This corresponds to about 20% of all bookings with this airline, resulting in 74,216 bookings. As the airline is part of an international aviation company, most other bookings were made through a partner airline. Passenger characteristics are, however, comparable. All bookings have the same "first origin" and "second destination", which means that all passengers depart from the same airport, fly to one of 66 destinations, and return to the origin airport. Per pre-registered protocol, we excluded (a) open-jaw bookings (passengers flying from A to B and returning from C back to A) and (b) one-way bookings from the dataset. The final sample results in 63,520 bookings. Our dataset includes initial bookings as changes to bookings are processed in a different data warehouse. The large majority of bookings are never changed before a flight takes place.

All bookings include between one and nine passengers (adults and children, not including infants). Our variables consist of the following: information about the air fare (i.e., price of roundtrip, excluding ancillaries), travel class, destination (anonymized to protect the airline's data privacy), number of passengers (adults, children), number of infants, and ancillary services (e.g., additional bags, reserved seats, etc.). Our central variable of interest is the dichotomous decision whether to offset flight-related carbon emissions, for which we also obtain the cost to the passenger. The offsetting price is calculated by an external company and aims to be accurate for a passenger in a

given flight and booking class (i.e., offsetting cost take into account plane type, route, average fuel burn, number of passengers, etc.). This implies that travelers cannot choose how much they want to offset, but that they face a decision to bear the cost to offset their flight or to forego this opportunity.

2.3. Booking procedure

As stated, our dataset is restricted to bookings created on the airline's website. The booking process on the website consists of five parts: In a first step, individuals select the desired destination, the type of trip (i.e., round-trip, one-way, or open jaw) as well as the number of passengers. In a second step, the exact flight (flight number, date, and time), and the travel class are selected. Then, passengers are given the opportunity to opt for ancillary services, which also includes the opportunity to offset their flight-related carbon emissions.

2.4. Pre-registered hypotheses

To complement existing stated-preferences studies, our core interest is in the overall willingness to purchase carbon offsets during the flight booking, which consists of the descriptive probability to offset as well as the mean and median willingness-to-pay per ton of CO₂. In addition, our dataset allows testing of the following hypotheses.

First, we expect that the price of the offset itself has a relevant influence on the decision. In line with the low-cost hypothesis of pro-environmental behavior (Diekmann & Preisendörfer, 1998), the price to offset should be – ceteris paribus – negatively related to the probability to offset (Hypothesis 1, pre-registered).

Second, as carbon emissions positively correlate with flight distance, long flights could be considered the most important to be compensated, as these have the higher climate impact and tend to be not regulated by the EU-ETS (which applies to European flights). But compensation costs are also higher for longer flights and air fare as well as other ancillary fees tend to increase as well, which might reduce the willingness to offset. Existing research offers conflicting findings with respect to the association of air fare and offsetting behavior. First, Lu and Shon (2012) suggest that there

may be a positive relationship between airfare and willingness-to-pay for offsetting. MacKerron et al. (2009) as well as Rice et al. (2020) suggest negative effects. All three studies, however, used a hypothetical stated-preference approach. We use the more recent findings as a basis for our measurement of actual behavior and hypothesize that the likelihood of a voluntary compensation is negatively related to the airfare (Hypothesis 2, pre-registered).

Third, we look at the role of income. Research suggests that pro-environmental behavior increases with rising income levels (Blasch & Farsi, 2014; Choi, 2015; Denstadli & Veisten, 2020; Fatihah & Rahim, 2017; Jou & Chen, 2015; Rotaris et al., 2020; Seetaram et al., 2018; Shaari et al., 2020)¹. Conceptually, this can be related to the extension of the low-cost hypothesis (Diekmann & Preisendörfer, 1998) regarding income, i.e. the “low-income hypothesis”, introduced by Tutić et al. (2017). As our dataset is limited in terms of personal information, we have to use the best available proxy for income. As is often the case in today’s aviation industry, the basic airfare will be relatively low. Passengers can then choose to add ancillaries such as baggage, seat reservations, priority boarding, special meals, and travel insurances. Ancillary spending has been shown to depend on passengers’ income (Balcombe et al., 2009). Therefore, we use the amount of money spent on ancillaries as a proxy for income, which is the best approximation available in the current dataset. People who can afford to spend money on things like a seat reservation usually also have the financial resources to offset flight-related carbon emission. We therefore expect that the likelihood of voluntary compensation may be positively related to the ancillary spending (Hypothesis 3, pre-registered).

Fourth, environmental psychology has identified that people’s environmental behavior depends on incidental cues associated with the detrimental consequences of climate change. For example, people are more concerned about the climate after severe weather events (Sisco et al., 2017), if they experience hot days (Zaval et al., 2014) or have been exposed to nature disasters (Konisky et al., 2016). Based on this, exposure to the detrimental effects of climate change may motivate people’s willingness to curb CO₂. Up to date, evidence for this hypothesis uniquely stems from stated-

preference approaches, self-reported intentions, or behaviors with minimal cost to decision-makers. Our dataset allows us to test this idea in a more consequential context. If a destination is vulnerable to climate change and natural disasters, we expect people to be more motivated to offset flight-related carbon emission compared with a destination that is less vulnerable. Therefore, the likelihood of voluntary compensation is expected to be positively related to the climate vulnerability of the destination region, measured with the Climate Risk Index (Eckstein et al., 2020, Hypothesis 4, pre-registered).

3. Results

This section reports descriptive results and confirmatory test of all four pre-registered hypothesis. Additional, non-registered analyses are presented (and marked as exploratory). Overall, the willingness-to-pay elicited by a revealed-preference approach is low. Only 4.46% of bookings include a compensation. The median willingness-to-pay to offset 1 ton of CO₂ is therefore zero, the mean willingness-to-pay ranges between 0.95 and 1.27 EUR². This result is much lower than elicitation that relied on stated-preferences, as could be expected based on criticisms associated with hypothetical measures of intentions and the environmental attitude-behavior gap. In fact, a substantial share of the bookings in our sample could have been offset at a cost lower than the average willingness-to-pay elicited by recent hypothetical studies in countries with comparable purchasing power (at least 83% compared to the average of 30 EUR/tonCO₂ elicited by Rotaris et al., 2020, in Italy³, and by Seetaram et al., 2018, in the UK⁴, and 100% compared to 29 EUR/tonCO₂ for long-haul and 49 EUR/CO₂ for short-haul flights, respectively, elicited by Sonnenschein & Smedby, 2019, in Sweden⁵). Table 2 shows a detailed overview of the willingnesses-to-pay elicited in the three studies mentioned and which quantile they represent in our respective sample.

3.1. Tests of Hypothesis 1

Contrary to our prediction, the cost of the compensation has no significant effect on the decision to compensate (see Table 3). Although we observe a weakly significant negative effect ($p < 0.1$) in the basic model without controls, this effect vanishes when controlling for booking class, flight

length (long-haul vs. short-/medium-haul), and whether or not the booking included infants. The latter is important, because travelling with infants requires a small additional fare, but no additional compensation cost. There is also no effect within booking classes or flight length category (as shown by the Interaction Model in Table 3). Given that the average marginal effect of 1 SD increase in compensation cost even in the weakly significant Basic Model is below 0.01 (in absolute terms), we can conclude that the cost of the compensation seems to have no substantial influence on the decision to compensate one's flight-related emissions in our data.

Table 2

Comparison of compensation cost in our sample to willingness-to-pay (WTP) elicited by studies in geographies with similar purchasing power

Study	Our study's relevant sample		Average WTP	Quantile in sample (lower bound – upper bound) ^a
	Description	Size		
Seetaram et al. (2018) ^b	All	63,520 (100%)	30 EUR	82% - 96%
	Short-haul, economy class	16,156 (25%)	19 EUR	100% - 100%
	Short-haul, business class	925 (1%)	27 EUR	100% - 100%
	Medium-haul, economy class	25,133 (40%)	26 EUR	100% - 100%
	Medium-haul, business class	3,277 (5%)	35 EUR	100% - 100%
	Long-haul, economy class	16,439 (26%)	33 EUR	52% - 100%
	Long-haul, business class	1,590 (3%)	42 EUR	5% - 34%
Sonnenschein & Smedby (2019)	All ^c	63,520 (100%)	29 EUR	72% - 100%
	Long-haul	18,029 (28%)	29 EUR	100% - 100%
	Short-haul	45,491 (72%)	49 EUR	100% - 100%
Rotaris et al. (2020) ^d	All	63,520 (100%)	30 EUR	83% - 100%

Notes: ^a As we only have a range of potential exchange rates of dummy currency units to EUR, we calculated the quantiles with the highest and the lowest possible values; ^b Comparison to WTP per flight, as the authors only elicit WTP per flight without any reference to CO₂ impacts; ^c Compared to long-haul WTP, because we do not have any basis to average the 2 values; ^d Average of elicited WTPs for up to 1.2 tons of CO₂

Table 3

Mixed-effects logit regressions of decision to compensate on compensation without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.04	0.04 – 0.05	<0.001	0.05	0.04 – 0.06	<0.001	0.05	0.04 – 0.08	<0.001
Compensation cost	0.93	0.85 – 1.01	0.071	1.00	0.86 – 1.15	0.965	1.27	0.78 – 2.06	0.335
Long-haul				0.91	0.61 – 1.37	0.658	0.52	0.22 – 1.24	0.139
Business class				0.85	0.70 – 1.04	0.123	0.76	0.57 – 1.02	0.071
With infant				1.17	0.94 – 1.45	0.161	1.17	0.94 – 1.45	0.166
Compensation cost X long-haul							1.11	0.72 – 1.71	0.650
Compensation cost X business class							0.81	0.60 – 1.09	0.169
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.25 Destination			0.25 Destination			0.25 Destination	
ICC		0.07			0.07			0.07	
N		66 Destination			66 Destination			66 Destination	
Observations		63520			63520			63520	
Marginal R ² / Conditional R ²		0.002 / 0.073			0.001 / 0.072			0.003 / 0.072	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. Compensation cost (per passenger) has been centered and scaled to represent multiples of 1 standard deviation. Bold p-values indicate significance at the 0.05-level.

3.2. Tests of Hypothesis 2

Contrary to our prediction, the ticket price has no significant effect on the probability to compensate (see Table 4, Basic Model). When controlling for booking class, flight length (long-haul vs. short-/medium-haul) and whether the booking included infants the air fare shows a significant

effect, but in the opposite direction as stated in the hypothesis (see Table 4, Control Model). As the effect is rather small (the average marginal effect of 1 SD increase is below 0.003 in the Control Model) and only relevant for short- and medium-haul flights (see Table 4, Interaction Model), we conjecture that higher ticket prices in short- and medium-haul flights are not in itself the reason for higher uptake of carbon offsetting but rather coincide with other unobserved variables that positively impact compensation behavior.

Table 4

Mixed-effects logit regressions of decision to compensate on ticket price without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.04	0.04 – 0.05	<0.001	0.05	0.05 – 0.06	<0.001	0.05	0.05 – 0.07	<0.001
Ticket price	1.01	0.96 – 1.05	0.818	1.07	1.01 – 1.13	0.024	1.42	1.21 – 1.67	<0.001
Long-haul				0.83	0.62 – 1.12	0.220	0.74	0.54 – 1.00	0.052
Business class				0.76	0.64 – 0.91	0.002	0.67	0.55 – 0.82	<0.001
With infant				1.17	0.94 – 1.46	0.155	1.18	0.94 – 1.46	0.147
Ticket price X long-haul							0.76	0.62 – 0.93	0.008
Ticket price X business class							0.97	0.84 – 1.13	0.735
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.25 Destination			0.25 Destination			0.24 Destination	
ICC		0.07			0.07			0.07	
N		66 Destination			66 Destination			66 Destination	
Observations		63520			63520			63520	
Marginal R ² / Conditional R ²		0.000 / 0.071			0.002 / 0.072			0.004 / 0.072	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. Ticket price (per passenger, without infants) has been centered and scaled to represent multiples of 1 standard deviation. Bold p-values indicate significance at the 0.05-level.

3.3. Tests of Hypothesis 3

As predicted, the ancillary spending of passengers is associated with a higher likelihood of offsetting the flight's carbon emissions (see Table 5 – Basic Model). This finding is robust to controlling for booking class, flight length (long-haul vs. short-/medium-haul) and whether the booking included infants (see Table 5 – Control Model). When looking at the interactions with flight

length and booking class, we find that the effect is especially articulated in short- and medium-haul flights (see Table 5 – Interaction Model), whereas it does not seem to differ across booking classes. Figure 1 additionally shows that spending money on ancillaries is associated with a higher probability to compensate. Regressions corroborating this result are shown in Table S1 in the Supplementary Material. When looking at the individual items that make up the available ancillaries we find that making a seat reservation is the main driver of the association of ancillary spending and carbon offsetting, followed by the purchase of an insurance, which seems to increase the offsetting likelihood only on short- and medium-haul flights (see Table S2 in the Supplementary Material for the corresponding regression results). While all these results are highly significant, the effect sizes are rather small (the average marginal effect of 1 SD increase in ancillary spending is between 0.002 and 0.016, depending on the model). Hence, we can conclude that ancillary spending is a significant predictor of the probability to engage in carbon offsetting but the small effect size requires large differences in ancillary spending to observe a meaningful increase in offsetting probability.

Figure 1

Proportion of compensated bookings, differentiated by choice of ancillaries (with 95% confidence intervals)

Note: Stars indicate significance based on χ^2 -test of proportions, with * = $p < 0.10$, ** = $p < 0.05$ and *** = $p < 0.01$.

Table 5

Mixed-effects logit regressions of decision to compensate on ancillary spending without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.04	0.04 – 0.05	<0.001	0.05	0.04 – 0.06	<0.001	0.05	0.05 – 0.06	<0.001
Ancillary spending	1.10	1.06 – 1.14	<0.001	1.10	1.06 – 1.14	<0.001	1.80	1.55 – 2.10	<0.001
Long-haul				0.81	0.60 – 1.08	0.149	0.73	0.55 – 0.97	0.031
Business class				0.88	0.76 – 1.01	0.063	0.88	0.75 – 1.04	0.143
With infant				1.16	0.94 – 1.45	0.171	1.15	0.93 – 1.44	0.198
Ancillary spending X long-haul							0.59	0.51 – 0.70	<0.001
Ancillary spending X business class							0.89	0.66 – 1.20	0.457
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.26 Destination			0.25 Destination			0.24 Destination	
ICC		0.07			0.07			0.07	
N		66 Destination			66 Destination			66 Destination	
Observations		63520			63520			63520	
Marginal R ² / Conditional R ²		0.003 / 0.075			0.004 / 0.074			0.006 / 0.074	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. Ancillary spending (per booking) has been centered and scaled to represent multiples of 1 standard deviation. Bold p-values indicate significance at the 0.05-level.

3.4. Tests of Hypothesis 4

In contrast to our prediction, the climate-related vulnerability of the flight destination has no effect on the decision to compensate the CO₂ emissions of a flight (see Table 6). We used the climate risk index (CRI) reflecting a country's vulnerability in 2018 (Eckstein et al., 2020) expecting that the

current situation in the destination regions might be more salient to passengers. However, our results show that neither the index of 2018 nor the index taking into account the twenty-year period between 1999 and 2018 have any meaningful impact on the decision to compensate (Table S3 in the Supplementary Material shows the results using the long-term CRI score).

Table 6

Mixed-effects logit regressions of decision to compensate on CRI score (see Eckstein et al., 2020) without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.04	0.04 – 0.05	<0.001	0.05	0.04 – 0.05	<0.001	0.05	0.04 – 0.05	<0.001
CRI score	0.94	0.83 – 1.07	0.371	0.94	0.83 – 1.07	0.353	0.89	0.76 – 1.03	0.124
Long-haul				0.89	0.66 – 1.20	0.436	0.91	0.67 – 1.22	0.521
Business class				0.87	0.75 – 1.00	0.049	0.87	0.75 – 1.00	0.048
With infant				1.18	0.95 – 1.47	0.131	1.18	0.95 – 1.47	0.135
CRI score X long-haul							1.20	0.91 – 1.60	0.197
CRI score X business class							1.05	0.92 – 1.21	0.456
Random Effects									
σ^2	3.29			3.29			3.29		
τ_{00}	0.26	Destination		0.26	Destination		0.25	Destination	
ICC	0.07			0.07			0.07		
N	64	Destination		64	Destination		64	Destination	
Observations	62105			62105			62105		
Marginal R ² / Conditional R ²	0.001 / 0.073			0.003 / 0.075			0.005 / 0.074		

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. CRI score has been centered and scaled to represent multiples of 1 standard deviation. Bold p-values indicate significance at the 0.05-level.

3.5. Additional exploratory analyses

In addition to the four pre-registered hypotheses, we complement our research with an exploratory finding. It can be expected that the meal a person selected may – at least partially – relate to one's climate concern. For example, many vegetarians have shown to have higher environmental concern compared to non-vegetarians (Fan et al., 2019; Plohl & Stern, 2020) and, on top of that, being pro-environmentally minded leads to stricter adherence to a vegetarian diet (Krizanova et al., 2021). Furthermore, pro-environmental passengers with willingness-to-pay for carbon offsetting have been shown to also display willingness-to-pay for organic or vegan meals (Hinnen et al., 2017). Thus, we explored whether the ordered meal correlates with the probability to offset the flight. And in fact, even though only 2.21% of all passengers chose a vegetarian meal, we found a positive and meaningful effect of the choice of a vegetarian meal on the probability of compensation (see Figure 2). Regression analyses show that having chosen a vegetarian meal for the flight more than triples the odds of offsetting a flight's CO₂ emissions (see Table 7). The result is robust to controlling for flight length, booking class and travelling with infants (see Table 7, Control Model) and the effect does not differ among travel classes or flight lengths (see Table 7, Interaction Model).

Figure 2

Proportion of compensated bookings, differentiated by choice of vegetarian meal (with 95% confidence intervals)

Note: Stars indicate significance based on χ^2 -test of proportions, with * = $p < 0.10$, ** = $p < 0.05$ and

*** = $p < 0.01$.

Table 7

Mixed-effects logit regressions of decision to compensate on vegetarian meal choice without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.04	0.04 – 0.05	<0.001	0.05	0.04 – 0.05	<0.001	0.05	0.04 – 0.05	<0.001
Vegetarian meal	3.15	2.68 – 3.70	<0.001	3.14	2.68 – 3.69	<0.001	3.11	2.50 – 3.88	<0.001
Long-haul				0.88	0.67 – 1.17	0.385	0.88	0.66 – 1.17	0.378
Business class				0.85	0.74 – 0.98	0.025	0.86	0.74 – 0.99	0.039
With infant				1.14	0.91 – 1.41	0.252	1.14	0.91 – 1.41	0.256
Vegetarian meal X long-haul							1.05	0.75 – 1.46	0.793
Vegetarian meal X business class							0.90	0.49 – 1.67	0.737
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.24 Destination			0.24 Destination			0.24 Destination	
ICC		0.07			0.07			0.07	
N		66 Destination			66 Destination			66 Destination	
Observations		63520			63520			63520	
Marginal R ² / Conditional R ²		0.008 / 0.076			0.009 / 0.077			0.009 / 0.077	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. Bold p-values indicate significance at the 0.05-level.

4. Discussion

This study investigated the willingness-to-pay for flight-related carbon emissions by means of a revealed-preference approach in a large-scale field study in the aviation industry. The central result is an overall low willingness to offset flights, in line with the environmental attitude-behavior gap. Pro-environmental attitudes are high in Europe, but costly climate action is rather low in our sample,

with the median willingness-to-pay to curb emissions in our study being zero. This finding therefore qualifies stated-preference results that are suggestive of a substantially higher willingness-to-pay for CO₂ offsetting. Despite the differences to other (hypothetical) studies in the aviation industry, our results match other revealed-preference studies under controlled laboratory conditions (e.g., Lösschel et al., 2013).

Overall, we found little support for the pre-registered hypotheses that lower cost of compensation, lower ticket price, or higher climate vulnerability of the destination increase the likelihood of compensating carbon emissions. On the other hand, we found evidence in favor of the pre-registered hypothesis that higher ancillary spending is associated with a higher probability to offset. Additionally, we explored the relationship between the choice of a vegetarian meal and compensation behavior and found that people choosing a vegetarian meal are much more likely to offset. However, the low base rate of offsetting decisions casts doubts on the importance of these effects and the general message from the results is that voluntary climate action is low in our sample.

While our dataset reflects real behavior from actual airline passengers and is as such, also given its size, highly representative of European airline customers, an important shortcoming of our study is the lack of information related to the personality of the passengers. As we did not have direct access to the passengers – we only received the anonymized data from the airline – we had no opportunity to complement our research with additional surveys and potentially better understand the differences between those who decided to offset their flight-related emissions and those who did not. However, given the small number of passengers in our dataset who actually compensated their carbon emissions, if voluntary climate action is to play a significant role in global mitigation efforts, it is probably more relevant to find ways to motivate the vast majority of people to compensate their flight's carbon emissions instead of analyzing the characteristics of those who already do in detail. In sum, our revealed-preference results crucially complement existing work using hypothetical, stated-preference approaches to measure willingness-to-pay, not only with respect to curbing flight-related emissions, but also regarding other pro-environmental behaviors.

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Footnotes

¹ L. T. O. Cheung et al. (2019) find a negative relationship between income and likelihood to offset, but in their case high income coincided with higher booking class and thus c.p. higher price of offsetting. By using ancillary revenue as a proxy for higher income, we hope to disentangle the price effect and the income effect (at least to some degree).

² Due to data privacy concerns, the airline only provided us with figures in a dummy currency and a range instead of an exact exchange rate.

³ This is the average of all WTPs for offsetting up to 1.2 tons of CO₂. 72% of the bookings in our sample fulfilled this criterion.

⁴ The authors elicit willingness to pay for one flight without any reference to the CO₂ amount emitted. Given that most flights' emissions stay well below 1 ton of CO₂, the corresponding WTP for one flight-related ton of CO₂ is even higher than the 26.65 GBP (roughly equal to 30 EUR) used here. 26.65 GBP is the sample-size weighted average of the individual WTPs elicited in the study.

⁵ Using only the elicited WTP for long-haul flights for all our bookings leads to 72% of bookings below the WTP.

Supplementary Information

1. Supplementary Material 1: Robustness of ancillary-related findings (Table S1 andS2
Table S2)
2. Supplementary Material 2: Robustness check of long-term CRI (Table S3)S4

Supplementary Material 1: Robustness of ancillary-related findings

Table S1

Mixed-effects logit regressions of decision to compensate on ancillary dummy (1 = yes) without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.03	0.03 – 0.04	<0.001	0.04	0.03 – 0.04	<0.001	0.04	0.03 – 0.04	<0.001
Ancillaries (1 = yes)	1.61	1.49 – 1.74	<0.001	1.61	1.49 – 1.75	<0.001	1.67	1.52 – 1.84	<0.001
Long-haul				0.81	0.62 – 1.08	0.149	0.81	0.60 – 1.10	0.184
Business class				0.98	0.85 – 1.13	0.823	1.14	0.97 – 1.35	0.115
With infant				1.20	0.97 – 1.50	0.096	1.21	0.97 – 1.50	0.092
Ancillaries X long-haul							1.00	0.83 – 1.20	0.971
Ancillaries X business class							0.61	0.44 – 0.85	0.003
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.24 Destination			0.23 Destination			0.23 Destination	
ICC		0.07			0.07			0.07	
N		66 Destination			66 Destination			66 Destination	
Observations		63520			63520			63520	
Marginal R ² / Conditional R ²		0.016 / 0.082			0.016 / 0.081			0.017 / 0.081	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. Bold p-values indicate significance at the 0.05-level.

Table S2

Mixed-effects logit regressions of decision to compensate on individual ancillary item dummies (1 = yes) without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.03	0.03 – 0.04	<0.001	0.04	0.03 – 0.04	<0.001	0.04	0.03 – 0.04	<0.001
Seat reservation	1.58	1.46 – 1.70	<0.001	1.58	1.46 – 1.71	<0.001	1.62	1.47 – 1.78	<0.001
Additional bag	0.98	0.65 – 1.47	0.913	0.98	0.66 – 1.46	0.933	1.25	0.74 – 2.10	0.403
Insurance	1.47	1.22 – 1.77	<0.001	1.46	1.22 – 1.76	<0.001	1.83	1.47 – 2.28	<0.001
Long-haul				0.81	0.62 – 1.07	0.144	0.82	0.60 – 1.11	0.193
Business class				0.98	0.85 – 1.13	0.816	1.14	0.97 – 1.34	0.122
With infant				1.20	0.96 – 1.49	0.104	1.20	0.97 – 1.49	0.100
Seat res. X long-haul							1.04	0.86 – 1.25	0.675
Add. bag X long-haul							0.60	0.26 – 1.42	0.245
Insurance X long-haul							0.52	0.33 – 0.81	0.004
Seat res. X business class							0.63	0.45 – 0.88	0.006
Add. bag X business class							0.67	0.10 – 4.33	0.676
Insurance X business class							0.58	0.25 – 1.35	0.207
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.24 _{Destination}			0.23 _{Destination}			0.23 _{Destination}	
ICC		0.07			0.07			0.07	
N		66 _{Destination}			66 _{Destination}			66 _{Destination}	
Observations		63520			63520			63520	
Marginal R ² / Conditional R ²		0.016 / 0.083			0.016 / 0.081			0.018 / 0.082	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. Bold p-values indicate significance at the 0.05-level.

Supplementary Material 2: Robustness check of long-term CRI

Table S3

Mixed-effects logit regressions of decision to compensate on CRI score (1999 - 2018, see Eckstein et al., 2020) of the destination without (Basic Model) and with controls for travelling with infants, length of flight and booking class (Control Model) as well as with interactions (Interaction Model)

Variable	Basic Model			Control Model			Interaction Model		
	OR	CI	p	OR	CI	p	OR	CI	p
Intercept	0.04	0.04 – 0.05	<0.001	0.05	0.04 – 0.05	<0.001	0.05	0.04 – 0.05	<0.001
CRI score (long term)	1.05	0.92 – 1.19	0.492	1.05	0.92 – 1.19	0.470	0.95	0.82 – 1.12	0.561
Long-haul				0.89	0.66 – 1.21	0.466	0.87	0.65 – 1.17	0.354
Business class				0.87	0.75 – 1.00	0.046	0.86	0.75 – 0.99	0.035
With infant				1.18	0.95 – 1.47	0.134	1.18	0.95 – 1.47	0.138
CRI (long) X long-haul							1.26	0.97 – 1.63	0.080
CRI (long) X business class							1.09	0.97 – 1.24	0.148
Random Effects									
σ^2		3.29			3.29			3.29	
τ_{00}		0.26 Destination			0.26 Destination			0.24 Destination	
ICC		0.07			0.07			0.07	
N		64 Destination			64 Destination			64 Destination	
Observations		62105			62105			62105	
Marginal R ² / Conditional R ²		0.001 / 0.073			0.002 / 0.075			0.005 / 0.074	

Note: Table displays odds ratios (OR) with 95%-confidence intervals (CI) from mixed-effects logit regressions with decision to compensate as the dependent variable. CRI score has been centered and scaled to represent multiples of 1 standard deviation. Bold p-values indicate significance at the 0.05-level.