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Willingness-to-pay for carbon dioxide offsets: Field evidence on revealed preferences in the aviation industry

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ABSTRACT

Voluntary offsetting of flight-related emissions is an important cornerstone of passengers' individual efforts to contribute to climate change mitigation. Hence, many scientific studies have tried to assess people's willingness-to-pay to offset their own flight-related carbon emissions. Up-to-date, these studies are overwhelmingly grounded in hypothetical stated-preference approaches, with very limited knowledge about external validity. Here, we report on an observational field study involving a final sample of 63,520 bookings made with a European airline, allowing us to gauge actual willingness-to-pay for carbon dioxide compensation in a revealed-preference approach. Our pre-registered study shows that the median willingness-to-pay to voluntarily offset a ton of carbon dioxide from flight-related emissions is zero, with the mean willingness-to-pay being around 1 EUR. Aggregated voluntary willingness-to-pay thus dramatically falls short of current prices to offset carbon dioxide, for example through the EU-ETS. Our results thereby question the suitability of self-reported, hypothetical assessments of offsetting and raise caution about the effectiveness of offsetting schemes, which currently do not very successfully internalize flight-related cost of emissions.

1. Introduction

Aviation contributes a substantial amount of greenhouse gas emissions and is therefore a key target of humanity's efforts when it comes to the mitigation of climate change. In terms of carbon dioxide (CO_2), 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 and Humpe, 2020). Besides CO_2, aviation is responsible for other emissions, in particular nitrogen oxides (NO_x) and water (H_2O) emitted at flight altitude. In sum, air transport caused 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 role and many airlines offer their passengers the opportunity to do so individually and voluntarily. Therefore, research investigating the willingness of travelers to do so emerged as a viable research topic in environmental social science (e.g., Brouwer et al., 2008, Choi et al., 2018, MacKerron et al., 2009, Rotaris et al., 2020, Seetaram et al., 2018, and Sonnenschein and Smedby, 2019). In principle, voluntary offsetting of flight-related emissions not only allows a glimpse into passengers' motivation to pay higher prices in order to travel carbon–neutral, but also marks an effort that can be used to assess people's individual willingness to contribute to humanity's mitigation efforts. Despite these potential benefits, the research – to our knowledge – thus far uniquely relies on hypothetical assessments of willingness-to-pay and therefore remains mute on how much actual passengers are willing to pay to offset their actual flights. As no prior research has investigated real-world choices, it also remains unclear how structural elements surrounding the offsetting choice (i.e., airfare, compensation cost, etc.) affect people's decision-making.

To overcome this research gap, we present research based on a pre-registered observational field study involving actual passenger data and

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their actual willingness-to-pay to offset their flight-related emissions. Unlike the existing research, the present research analyzes revealed, not stated, preferences, and thereby complements the existing literature through a measure of actual behavior, rather than measurements of hypothetical behavior, intentions, or self-reports.

2. Literature review

A large number of studies has been conducted in an effort to measure people's willingness to offset flight-related carbon emissions. Table 1 provides a detailed overview of all the identified studies in a literature search that focused on the willingness-to-pay to offset flight-related emissions. Importantly, this search was restricted to offsetting *flights*, and therefore excluded willingness-to-pay to offset a given amount of CO_2 in general (e.g., laboratory research, Berger and Wyss, 2021, and Löschel et al., 2013) or offsets from other industries (e.g., conference travel, Araña and León, 2013, or long-distance bus travel, Kesternich et al., 2019).

From the existing research, the estimated willingness-to-pay for offsetting a ton of CO_2 ranges between low amounts of below 1 EUR (e.

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
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 and Shon (2012)	Flight to Western city	Taipei Intl. Airport	Taiwanese passengers	28.60 USD	23.74 EUR	N/A
Choi and Ritchie (2014)	1 tonCO_2	Australia	General population	21.38 AUD	13.68 EUR	13.68 EUR
Jou and 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 through forest protection (other state)	Australia	General population	46.24 AUD	29.59 EUR	9.86 EUR
	3 tonsCO_2, compensated through forest protection (own state)	Australia	General population	77.39 AUD	49.53 EUR	16.51 EUR
	3 tonsCO_2, compensated through renewable energy project	Australia	General population	8.38 AUD	5.36 EUR	1.79 EUR
Fatihah and 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 and 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 and 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 CO_2 impact of reference item).
Notes: [a] The authors make no reference to the CO_2 impact of a flight from Taipei to Hong Kong. The amount per ton of CO_2 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.

g., Choi et al., 2018) to rather high amounts of nearly 50 EUR (e.g., Sonnenschein and Smedby, 2019). The most noteworthy observation from the published literature on offsetting flight-related emissions, however, is the fact that no single study has used *actual* willingness-to-pay as their dependent variable. Rather, all studies merely relied on *hypothetical* assessments of willingness-to-pay (i.e. "stated" preferences). The existing literature thereby elicits willingness-to-pay largely without actual financial consequences to passengers and without actual environmental impact. Typical dependent measures include questions referring to people's intentions ("Would you pay *X* EUR to offset a flight from origin *A* to destination *B*?" or "How much would you pay to offset the emissions resulting from a flight between origin *C* to destination *D*?") or their self-reported past behavior ("Have you ever offset a flight?").

Although this approach may result in interesting early insights into passengers' motivation to offset, it is clear that measurements of *actual* behavior are crucial to evaluate *a)* the degree to which voluntary offsetting may actually work in the field and *b)* how situational (i.e., structural) elements surrounding the decision affect people's behavior. It is obvious that research *uniquely* grounded in hypothetical scenarios should only very carefully inform climate policy or corporate strategy.

Research on stated preferences has already 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. This excessive reliance may come at a cost as self-reported measures may potentially be biased by recall inaccuracy, social desirability, or other factors. And in fact, Kormos and Gifford (2014) examined the association between self-reports and objectively observable pro-environmental behavior in a *meta*-study and showed that 79% of the variance remains unexplained. Besides this psychological research, environmental economic research also provides evidence that actual pro-environmental behavior is lower than one could expect based on self-reports. For example, Löschel et al. (2013) present controlled laboratory evidence on people's revealed-preference to curb CO_2 emissions and show that median willingness to do so is zero. Hence, research seems to suggest that a strong discrepancy exists between intended behaviors (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 and Agyeman, 2002) and highlights the discrepancy between "talking the talk" and "walking the talk" (Carrington et al., 2010). Hence, a considerable research gap remains in our knowledge about people's actual willingness-to-pay to offset flight-related emissions. Our study aims at filling this gap.

3. Hypothesis development

To complement existing stated-preferences studies, we measures airline passengers' actual willingness-to-pay for carbon offsets. First, we explore passengers' mean and median willingness-to-pay to offset one ton of CO_2. Next, we study the degree to which structural variables affect offsetting behavior. In particular, we can test in how air fares, compensation cost, and an (imperfect) proxy for income affect decision-making.

Among the structural variables, we pre-registered a hypothesis assessing the cost-sensitivity of pro-environmental behavior (i.e., offsetting). The low-cost hypothesis of pro-environmental behavior (Diekmann and Preisendörfer, 1998) argues that pro-environmental behavior should depend on the associated cost of action. The low-cost hypothesis has received much empirical support in various behavioral paradigms (e.g., Berger and Wyss, 2021, and Lange et al., 2018), but has not yet been tested in the context of offsetting flight-related emissions. Hence, the price to offset could 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 given their higher climate impact and lack of regulation by the EU-ETS (which applies to European flights only). In contrast, compensation costs as well as air fares are also higher for longer flights, which might reduce the willingness to offset. Existing research offers conflicting findings with respect to the association of airfares 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), on the other hand, suggest negative effects. All three studies, however, used a hypothetical stated-preference approach. We expect that the likelihood of a voluntary compensation is negatively related to the airfare as the total cost to passengers is higher (Hypothesis 2, pre-registered).

Third, research suggests that pro-environmental behavior increases with rising income levels (Blasch and Farsi, 2014; Choi, 2015; Denstadli and Veisten, 2020; Fatihah and Rahim, 2017; Jou and Chen, 2015; Rotaris et al., 2020; Seetaram et al., 2018; Shaari et al., 2020). Conceptually, this observation extends the low-cost hypothesis (Diekmann and Preisendörfer, 1998) to the "low-income hypothesis" (Tutić et al., 2017). As a low income limits people's total spending potential, having little income may undermine their ability to engage in pro-environmental behavior. As our dataset is limited in terms of personal information, we rely on our best available proxy for passenger income – their ancillary spending. Ancillary spending (e.g., additional baggage, food, priority treatment) has been shown to be robustly associated with a passenger's income (Balcombe et al., 2009), allowing us to approximate income indirectly by means of total money spent for ancillaries. We expect that the likelihood of voluntary compensation is 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). Thus, exposure to the detrimental effects of climate change may motivate people's willingness to curb CO_2. 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, one could expect people to be more motivated to offset flight-related carbon emissions compared to a destination that is less vulnerable. Therefore, the likelihood of voluntary compensation could 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).

4. The present research: Sample and methodology

In order to contribute to a more wholesome assessment of willingness-to-pay for flight-related carbon emission offsets, we report on an observational 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.

4.1. Open science and ethical statement

All materials, data, and code to replicate the statistical analyses are available on the Open Science Framework (https://osf.io/u3faz). 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 hypotheses. As this observational dataset did not contain any sensitive or personal data, analyzing the dataset and testing our hypotheses was exempt from formal ethical approval by the researchers' home institutions.

4.2. Sample and variables

The data stem from passenger bookings of a Swiss 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 partner airlines. Passenger characteristics are, however, comparable. The airline operates out of a large Swiss international airport and serves destinations around the globe. Therefore, all bookings have the same "first origin" and "second destination", which means that all passengers departed from the same airport, flew to one of 66 destinations, and returned to the origin airport. Because the airline serves the leisure market, flights in our sample are private trips paid for by the passengers themselves. The airline targets a premium segment, hence the passengers have medium to high income levels. Very price-conscious passengers would likely choose low-cost carriers instead, which also operate from the same airport. More than 80% of the passengers of the airline are residents or passport holders from Switzerland. 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 resulted in 63,520 bookings. Our dataset includes only initial bookings. Any subsequent changes to flights (re-bookings, cancellations, etc.) are processed in a different data warehouse. However, the large majority of passengers does not change their bookings and sticks to initial travel plans.

All bookings included between one and nine passengers (i.e., excluding infants without their own seat). Our variables are the following: information about the airfare (i.e., price of roundtrip, excluding ancillaries), travel class, destination (anonymized in the accompanying dataset 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 offsetting decision, 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 on a given flight and booking class. This implies that offsetting costs take into account plane type, route, average fuel burn, number of passengers, among other factors. Travelers thus could not choose how much they wanted to pay for offsetting, but faced a decision to bear the cost to offset their flight's emissions or to forego this opportunity.

4.3. Booking procedure

As described above, our dataset is restricted to bookings made directly on the airline's website. The booking process on the website consists of three main steps: In the 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 included the opportunity to offset their flight-related carbon emissions. Fig. 1 illustrates the booking procedure in more detail.

5. Results

This section reports descriptive results and confirmatory tests of all four pre-registered hypotheses. Additionally, non-registered analyses are presented and labeled as *exploratory*. Overall, the willingness-to-pay elicited by our revealed-preference approach is low. Only 4.46% of bookings include a compensation. The median willingness-to-pay to offset 1 ton of CO_2 is therefore zero, the mean willingness-to-pay ranges between 0.95 and 1.27 EUR. This result is much lower than elicitations that relied on stated preferences, as could be expected based on criticisms associated with hypothetical measures of intentions and the environmental attitude-behavior gap.

Noteworthy, 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. This means that at least 83% of flights could have been offset based on the average of 30 EUR/tonCO_2 elicited by Rotaris et al. (2020). 82% of flights could have been offset based on the 30 EUR/

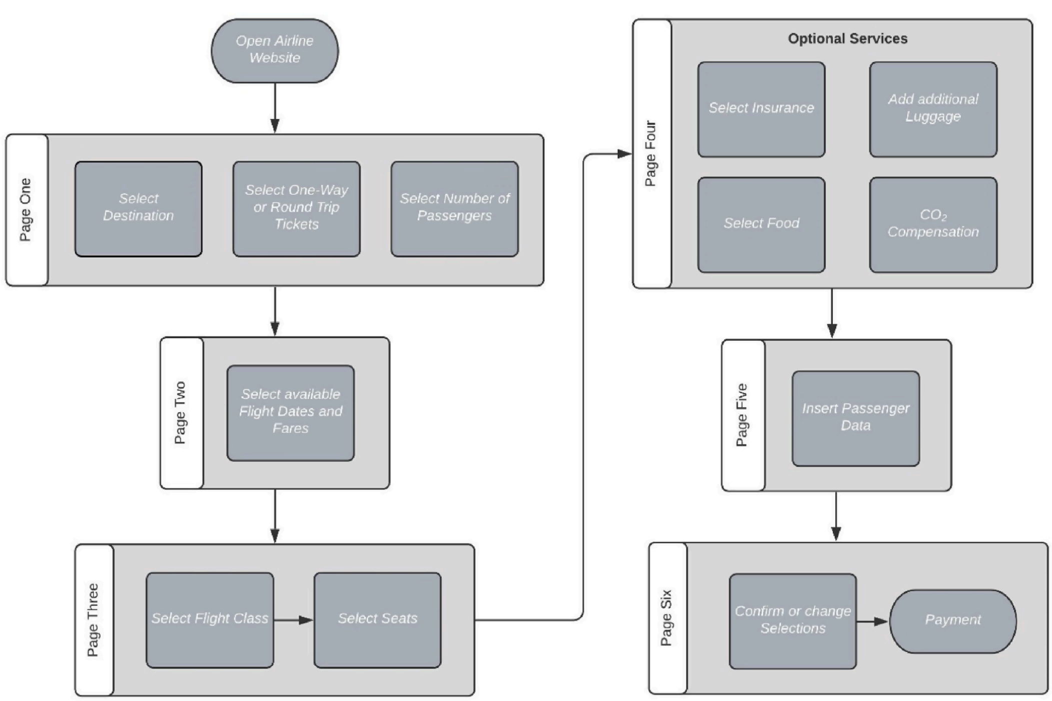

Fig. 1. Process map of online flight booking.

flight elicited by Seetaram et al. (2018). Finally, 100% of flights and could have been offset based on the assessments of willingness-to-pay by Sonnenschein and Smedby (2019; 29 EUR/tCO_2 for long-haul and 49 EUR/tCO_2 for short-haul flights). Table 2 shows a detailed overview of the respective willingness-to-pay elicited in the three studies mentioned and which quantile they represent in our respective (sub)samples.

5.1. Tests of hypothesis 1

Contrary to the predictions based on the low-cost hypothesis of pro-environmental behavior, the cost of the compensation did not have a 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 control variable was included as travelling with infants requires a small additional fare, but no additional compensation cost. Neither booking classes nor flight length category are predictive of offsetting (as shown in the Interaction Model in Table 3). Given that the average marginal effect of 1 SD increase in compensation cost is below 0.01 (in absolute terms), we can conclude that the cost of the compensation has no meaningful influence on the decision to compensate one's flight-related emissions in our data.

5.2. 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 practical implication of the effect is likely not strong. Specifically, the average marginal effect of 1 SD increase is below 0.003 in the Control Model and driven by short- and medium-haul flights (see Table 4, Interaction Model).

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 and 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 CO_2 impacts; [c] Compared to long-haul (i.e., lower) 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 CO_2.

5.3. Tests of hypothesis 3

As predicted, passengers' ancillary spending is associated with a higher likelihood to offset 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), or whether the booking included infants (see Table 5 – Control Model). In addition, we find that this effect is especially articulated in short- and medium-haul flights (see Table 5 – Interaction Model). Regressions corroborating this result are shown in Table S1 in the Supplementary Material. Table S2 of the Supplementary Material shows that this effect is particularly driven by specific ancillaries, namely making a seat reservation and insurance purchases. Whereas all these results are highly significant in statistical terms, the related 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.

5.4. Tests of hypothesis 4

In contrast to our prediction, climate vulnerability of the destination measures by a 2018 climate risk index (Eckstein et al., 2020) does not predict compensation behavior. Neither the index of 2018 alone (see Table 6) nor the 20-year index taking into account the period between 1999 and 2018 (Table S3 in the Supplementary Material) have any meaningful impact on the decision to compensate.

5.5. Additional exploratory analyses

In addition to the four pre-registered hypotheses, we present an exploratory finding. We explored whether the ordered meal correlated with the probability to offset the flight. In fact, although only 2.95% of the 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 Table 7). Regression analyses show that having chosen a vegetarian meal for the flight increased the odds of offsetting by factor 3 (see Table 7, all models). The result was robust to controlling for flight length, booking class, or travelling with infants (see Table 7, Control Model). Furthermore, the effect did not differ between travel class or flight length (see Table 7, Interaction Model).

Future research could qualify this exploratory finding with confirmatory research. Previous research has already shown that vegetarians report higher environmental concern compared to non-vegetarians (Fan et al., 2019; Ploll and Stern, 2020). Likewise, pro-environmental behavior has been linked to a stricter adherence to a vegetarian diet (Krizanova et al., 2021). In terms of airline passengers, research has shown that pro-environmental passengers with willingness-to-pay for carbon offsetting also display willingness-to-pay for organic or vegan meals (Hinnen et al., 2017).

6. Discussion

This study investigated the willingness-to-pay for flight-related carbon emissions by means of a revealed-preference approach in an observational study in the aviation industry. The central result is an overall low willingness to offset flights, in line with the environmental attitude-behavior gap and in contrast to the findings of offsetting-behavior based on hypothetical research paradigms. 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 raises the question about the reliability of stated-preference results that are suggestive of a substantially higher willingness-to-pay for CO_2 offsetting.

Table 3
Mixed-effects logit regressions of decision to compensate on compensation cost 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).

	Basic Model			Control Model			Interaction Model		
Variable	*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	63,520			63,520			63,520		
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.

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).

	Basic Model			Control Model			Interaction Model		
Variable	*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	63,520			63,520			63,520		
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.

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).

	Basic Model			Control Model			Interaction Model		
Variable	*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	63,520			63,520			63,520		
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.

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).

	Basic Model			Control Model			Interaction Model		
Variable	*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 $_{\text{Destination}}$			0.26 $_{\text{Destination}}$			0.25 $_{\text{Destination}}$		
ICC	0.07			0.07			0.07		
N	64 $_{\text{Destination}}$			64 $_{\text{Destination}}$			64 $_{\text{Destination}}$		
Observations	62,105			62,105			62,105		
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.

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).

	Basic Model			Control Model			Interaction Model		
Variable	*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 – 0.06	**<0.001**
Vegetarian meal	3.15	2.68 – 3.70	**<0.001**	3.13	2.66 – 3.68	**<0.001**	3.09	2.48 – 3.83	**<0.001**
Long-haul				0.84	0.64 – 1.10	0.199	0.83	0.63 – 1.10	0.192
Business class				0.83	0.71 – 0.96	**0.012**	0.83	0.72 – 0.97	**0.017**
With infant				1.25	0.97 – 1.60	0.084	1.25	0.97 – 1.60	0.082
Vegetarian meal X long-haul							1.05	0.76 – 1.46	0.752
Vegetarian meal X business class							0.92	0.51 – 1.66	0.770
Random Effects									
σ^2	3.29			3.29			3.29		
τ_{00}	0.20 $_{\text{Destination}}$			0.19 $_{\text{Destination}}$			0.19 $_{\text{Destination}}$		
ICC	0.06			0.05			0.05		
N	66 $_{\text{Destination}}$			66 $_{\text{Destination}}$			66 $_{\text{Destination}}$		
Observations	47,690			47,690			47,690		
Marginal R^2 / Conditional R^2	0.011 / 0.066			0.014 / 0.068			0.014 / 0.068		

Note: Table displays odds ratios (*OR*) with 95%-confidence intervals (*CI*) from mixed-effects logit regressions with decision to compensate as the dependent variable. Only bookings where vegetarian meal choice was possible are considered. Bold *p*-values indicate significance at the 0.05-level.

Despite the strong differences to other (hypothetical) studies in the aviation industry, our results match revealed-preference studies under controlled laboratory conditions (e.g., Löschel et al., 2013). Based on our data, one could question the contribution of voluntary climate action on the aviation sector's decarbonization strategy.

Overall, we found no support for the pre-registered hypotheses that lower cost of compensation and lower ticket price increase the likelihood of compensating carbon emissions. One important cause for this inexistence of any meaningful correlation between cost and willingness to offset is the overall low rate of offsetting decisions. Due to our large sample size, however, we would have been able to detect even small effects. Hence, we can conclude that cost-sensitivity is not a relevant driver of offsetting behavior for passengers in our sample.

Higher climate vulnerability of the destination neither has a statistically significant impact on the decision to offset. One potential reason – besides passengers' general unwillingness to compensate – may lie in the fact that climate vulnerability is not very salient to passengers. In addition, even if people have a specific perception regarding the vulnerability of a certain region, this does not necessarily need to match this region's CRI score (Eckstein et al., 2020).

On the other hand, we found support 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, one potential 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 consumer surveys. This could have helped to better understand the differences between those who decided to offset their flight-related emissions and those who did not. At the same time, the low proportion of passengers in our dataset who compensated their carbon emissions calls the importance of such analyses into question. Importantly, research has found that characteristics obtained through surveys are not good predictors of high-impact behaviors. Correlations found for low-cost sustainable behaviors such as recycling often do not emerge in high-cost behaviors such as flying (Alcock et al., 2017).

Future research could address the degree to which behavioral design – broadly speaking – could contribute to a larger revealed preference to contribute to climate change mitigation. Evidence from other sectors (e.g., long-distance bus travel, Kesternich et al., 2019) has shown that directing people to make an active choice about offsetting can strongly increase uptake behavior.

Generally, the fact that offsetting decisions are potentially prone to aspects of behavioral design could lead to the conclusion that preferences to offset (or not) are rather weak. In the present context, the behavioral design does not systematically prevent offsetting (i.e., it is placed equally prominently on the choice menu as other ancillaries), and people can easily update their choice before proceeding to the payment. This – together with laboratory research finding low compensation willingness (e.g., Löschel et al., 2013) – may suggest that the overall willingness to compensate for flight-related emissions is indeed low.

7. Conclusion and implications

The present research investigated the willingness-to-pay for voluntary carbon offsets using a revealed preference approach based on a highly powered sample of airline customers. The central finding is that passengers are largely unwilling to offset their flights, in contrast to many studies that rely on hypothetical behavior. Our research has various key implications for the theory and practice of offsetting.

First, our results raise skepticism about the degree to which voluntary offsetting works from a consumer perspective. Quite obviously, our data allow the conclusion that adequately offsetting one's own emissions does not seem a behavioral priority for most passengers. This naturally raises the question about the contribution carbon offsetting programs have on climate change mitigation. Clearly, average willingness-to-pay drastically falls short of the true cost of carbon. Whereas in our sample of airline passengers the mean willingness-to-pay to offset a ton of carbon is merely 1 EUR, the carbon price in the EU-ETS has reached more than 90 EUR in December 2021, and the "true cost of carbon" may even exceed this number. This extreme difference between voluntary payments and actual carbon prices shows how such voluntary offsets are likely not a meaningful element to internalize the cost resulting from pollution.

Thereby, our results contribute to research that is critical of carbon offsets. This research has already pointed out that offsetting may be problematic for a plethora of reasons, among them lack of additionality or permance, problematic double counting, or leakage effects. For example, recent economic research (Calel et al., 2021) has suggested that 52% of approved carbon offsets under the Clean Development Mechanism did not lead to additional offsets. Our research complements these findings by showing that passengers are largely unwilling to offset, with the implication being that even offsetting schemes that do not suffer from above mentioned problems may be ineffective because of low behavioral uptake. An an alternative, research into the willingness to *forego* flights may be a more fruitful endeavor (as done by Whitmarsh et al., 2020).

Second, the striking difference of actual willingness-to-pay and hypothetical willingness-to-pay elicited from stated-preference studies should caution researchers to rely on such self-reported measures when trying to capture willingness-to-pay for climate action. It seems important to not rely uniquely on hypothetical dependent variables when analyzing pro-environmental behaviors.

In sum, our revealed-preference study suggests that voluntary climate action falls dramatically short of what is necessary and our work crucially complements existing work using hypothetical, stated-preference approaches to measure willingness-to-pay. Whereas the present study focused on aviation, the results may also translate to other fields and other pro-environmental behaviors. Thus, we suggest that environmental social science increasingly shift their focus away from mere measures of self-reports or intentions in favor of measurement of consequential behavior, particular in areas of high environmental impact (Brick et al., 2021).

CRediT authorship contribution statement

Sebastian Berger: Conceptualization, Formal analysis, Writing – original draft, Writing - review & editing, Supervision, Funding acquisition. **Andreas Kilchenmann:** Conceptualization, Writing - review & editing. **Oliver Lenz:** Conceptualization, Writing – review & editing. **Francisco Schlöder:** Conceptualization, Formal analysis, Writing - original draft, Writing – review & editing.

Declaration of Competing Interest

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2022.102470.

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