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A panel analysis of change in personal air travel behaviour in England between 2012 and 2019

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Abstract
Decarbonizing aviation is challenging as few scalable technological alternatives exist, and travel activity is increasing rapidly. It is thus essential to better understand the drivers of air travel behaviour. Previous cross-sectional research has identified a range of factors associated with individual air travel frequency. There is, however, a lack of longitudinal studies identifying the factors associated with *change* in air travel frequency on the individual level. This is in contrast with research on daily travel and car use, where 'mobility biographies' studies have identified the life-course factors associated with travel behaviour change. Our study contributes to filling this gap. We investigate the determinants of change in air travel frequency using data from two waves of the UK Household Longitudinal Survey (2012–2013 and 2018–2019), combined with geographical information at the neighbourhood level. With regression models, we assess the impact of changes in a wide range of factors including socio-demographic and economic situation; residential location; spatial dispersion of social networks; migration status; car ownership; and environmental attitudes. We find significant effects for several variables, including e.g., a negative effect of having children on air travel frequency, and a reduction in the number of flights in the first few years after migrating to the UK. We conclude by discussing how the findings can inform debates on: i) the impact of life-course events on travel behaviour; ii) the causal drivers of air travel frequency; iii) the drivers of air travel growth, and related implications in terms of inequality and 'institutionalisation' of air travel.

Keywords Aviation · Mobility biographies · Panel · UK · Key events · Long-distance travel

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Introduction

Reaching 'net-zero' greenhouse gas emissions is currently a high priority of many governments. Meeting this goal will be particularly challenging in the transport sector as it will require not just technological substitution, but demand-side measures, including travel demand management as well (Creutzig et al. 2022; ITF 2023). This is even more pronounced in the aviation sector, where emissions have increased rapidly, as booming travel activity has more than offset technological and operational efficiency improvements to date (Lee et al. 2021). This is likely to continue in the future, unless unprecedented levels of both technological substitution and travel demand management are achieved (Bergero et al. 2023; Gössling et al. 2021; Graver et al. 2022). Given the limited scope for technological decarbonisation of the aviation sector in the medium term, future trends in air travel activity will be a key determinant of emission trends in this sector (Eurocontrol 2023; Sacchi et al. 2023).

It is thus essential to better understand the drivers of (growing) air travel demand to inform transport policy in this area. Previous multivariate quantitative research, overwhelmingly cross-sectional in nature, has identified several factors associated with individual air travel activity. Studies typically found higher levels of air travel among people in employment, with higher education and higher income, as well as associations with other factors such as migration background and urbanity. We review this research in section "Literature review".

To the best of our knowledge, to date no longitudinal multivariate study has investigated the factors associated with change in air travel activity for individuals. This lack of longitudinal evidence has been lamented by several authors (e.g., Árnadóttir et al. 2021; Oswald and Ernst 2020; Schmidt et al. 2023). It is also in stark contrast with research on car use and daily travel, where in the last twenty years an increasing number of 'mobility biographies' studies have identified the life-course factors associated with travel behaviour change (for a review see Müggenburg et al. 2015). This strand of research has identified several 'key events' that are associated with changes in daily travel behaviour such as childbirth (e.g., McCarthy et al. 2020), residential relocation (e.g., Schouten 2022), entry into the labour market (e.g., Scheiner 2014), and relationship dissolution (Oakil et al. 2018). For example, Whittle et al. (2022), using the same UK dataset as in this study, found that residential relocation and parenthood are associated with significant changes in the frequency of car, bus, train and bicycle use. A similar understanding of what drives change in long-distance travel, and notably air travel behaviour, remains largely to be developed (Mattioli 2020).

Our study fills this gap by providing longitudinal evidence on the impact of changes in individuals' socio-economic situation, residential location, pro-environmental attitudes, and other relevant factors on the frequency of air travel for private purposes, based on two waves from a large representative panel survey of English residents. Longitudinal evidence is valuable on three accounts. First in and of itself, as evidence of how travel behaviour changes through the life course. Second, longitudinal analysis provides better evidence of causality than cross-sectional analysis, as it is less affected by issues of spurious association and self-selection. Comparing our findings to those of previous cross-sectional studies could thus help discern which of the statistical associations identified to date are more likely to reflect a causal effect. Third, in a context where air travel activity is rapidly increasing, longitudinal analysis can help shed light on which social groups and societal trends are driving this growth. This is particularly interesting as participation in air travel is rather

unequally distributed (Czepkiewicz et al. 2019; Hopkinson and Cairns 2021; Shaw et al. 2024), which raises the question of whether these inequalities are closing or widening over time (Büchs and Mattioli 2021; Demoli and Dobruszkes 2024). It could also inform debates on the ongoing 'institutionalisation' of high levels of long-distance and air travel in our societies (Cass 2022; Frändberg 2006; Guillen-Royo et al. 2024; Mattioli 2020; Mattioli et al. 2022; Schmidt et al. 2023, 2024).

The remainder of the paper is structured as follows. We start by reviewing existing evidence on the determinants of air travel (section "Literature review"). We then provide information on the case study context (section "Case study context") and data and analysis approach (section "Data and analysis approach"). We then present (section "Results") and discuss (section "Discussion") the results of the analysis and conclude by discussing implications for future research and policy (section "Conclusion") and the limitations of our study section "Limitations").

Literature review

In recent years, several multivariate cross-sectional studies have investigated the factors associated with air travel behaviour. Here, we review their findings, to provide the background against which to interpret our results. The review covers multivariate regression studies where the dependent variable is participation in air travel, frequency of air travel, air travel distance or greenhouse gas emissions from air travel (Alcock et al. 2017; Bruderer Enzler 2017; Büchs and Mattioli 2021, 2024; Czepkiewicz et al. 2020a, b; Demoli and Subtil 2019; Dütschke et al. 2022; Falk and Hagsten 2021a, b; Kim and Mokhtarian 2021; Klein and Taconet 2024; Mattioli et al. 2021; Mattioli and Scheiner 2022; 2024; Reichert and Holz-Rau 2015; Schleich et al. 2024; Schubert et al. 2020). We further include studies where the dependent variable refers to international travel from Iceland and Norway, where most international travel is by plane (Czepkiewicz et al. 2019; Czepkiewicz et al. 2020a, b; Scheffler & Heinein 2024). It must be noted that all studies refer to European countries, except Kim and Mokhtarian (2021) which is based on US data. Also note that most studies focus on flights for private purposes only, with only few considering business travel as well (Büchs and Mattioli 2021; Demoli and Subtil 2019; Falk and Hagsten 2021b; Klein and Taconet 2024; Reichert and Holz-Rau 2015). We comment on differences between studies that include or exclude business travel as appropriate below.

We first consider the effect of socio-economic characteristics. Evidence on the impact of certain factors is robust. Studies consistently find a positive net association between income and air travel, and a negative association with disability. Higher levels of education are consistently associated with more air travel, although Scheffler and Heinen (2024) find that this applies only to 'intercontinental holiday trips' and not to other international holiday trips of Norwegians. Regarding household composition, larger household size is associated with less air travel in most studies, although Bruderer Enzler (2017) finds no statistically significant association. Being married or in a cohabiting relationship is associated with more flights in most studies, although Scheffler and Heinen (2024) find that Norwegian singles report more 'city trips in Europe'. The presence of children in the household is generally associated with less air travel, although Scheffler and Heinen (2024) find a positive association between being single parent and reporting 'mediterranean sea trips'. Most studies

find a positive association between employment and air travel, although Czepkiewicz et al. (2020a, b) find no association among younger adults in Iceland, and Falk and Hagsten (2021a) find a negative association for holiday flights in Austria.

The findings for the impact of age are mixed, although most studies find a negative association with older age (Alcock et al. 2021; Demoli and Subtil 2019; Klein and Taconet 2024; Mattioli and Scheiner 2022) and/or a positive association with being a young adult (Falk and Hagsten 2021a, b; Mattioli et al. 2021; Büchs and Mattioli 2021; Schubert et al. 2020). Scheffler and Heinen (2024) find a positive association between young age and the 'city trips in Europe' of Norwegians, but also a positive association between older age and 'mediterranean seaside trips'.

There are mixed findings concerning the impact of gender as well. Many regression models considering air travel for private purposes find a positive net association with female gender (Kim and Mokhtarian 2021; Schubert et al. 2020; Schleich et al. 2024), notably when the presence of children in the household is controlled for (Alcock et al. 2017; Czepkiewicz et al. 2020a, b; Falk and Hagsten 2021a, b; Mattioli et al. 2021), but other models find no statistically significant association (Alcock et al. 2017; Klein and Taconet 2024; Mattioli and Scheiner 2022). Büchs and Mattioli (2021) find a negative association between the household representative person being a woman and the number of flights reported by household members. Mattioli & Scheiner (2024) find a negative association between female gender and the number of flights among people living in a cohabiting relationship in the UK. Scheffler and Heinen (2024) find a positive association between female gender and the number of 'mediterranean seaside holiday trips' of Norwegians'. Studies that consider flights for all purposes, including business travel, mostly show a negative association between female gender and air travel (Demoli and Subtil 2019; Klein and Taconet 2024; Reichert and Holz-Rau 2015), as do studies that model air business travel separately (Falk and Hagsten 2021b; Reichert and Holz-Rau 2015). Overall, it appears that women tend to fly more than men for private purposes, but less than men for business, when other factors are controlled for.

Spatial characteristics of the residential location also appear to impact on air travel activity. Most studies find a positive net association between urbanity and/or population density and air travel, with the greatest magnitude for large cities such as London, UK (Mattioli et al. 2021). This reflects the broader, well-established net association between urbanity and long-distance travel (Czepkiewicz et al. 2018). Klein and Taconet (2024) find a positive association between urbanity and air travel when considering flights for private purposes, but not when business trips are included. Scheffler and Heinen (2024) find this association holds only for the 'intercontinental holiday trips' of Norwegians, but not for other types of international holiday trips. Only a few studies have considered accessibility to airports (Bruderer Enzler 2017; Kim and Mokhtarian 2021; Mattioli et al. 2021) but they all find a positive net association with air travel. Mattioli et al. (2021) find that better accessibility to airports accounts for part, but not all of the association between London residence and more air travel.

All studies that consider migration background, defined in terms of citizenship, place of birth, or language chosen to fill out the survey (Bruderer Enzler 2017; Büchs and Mattioli 2024; Czepkiewicz et al. 2020a; Demoli and Subtil 2019; Mattioli and Scheiner 2022; 2024; Mattioli et al. 2021), find a positive net association with air travel, which holds also when business travel is included (Klein and Taconet 2024). This effect is more pronounced for first-generation migrants (i.e., those born abroad) and for those among them who have

not been in the country for long. To date, the ethnicity of respondents has only been considered in studies from the UK, which have delivered mixed findings (Büchs and Mattioli 2021, 2024; Mattioli and Scheiner 2022; 2024; Mattioli et al. 2021). Overall, the evidence suggests that identifying as non-white is negatively associated with flight frequency, while identifying as non-British white is positively associated. The same UK studies have considered the dispersion of the respondents' social networks, and this appears to be an important determinant of air travel behaviour. Having close friends and/or relatives abroad is positively associated with air travel activity, as is having many friends outside of the local area. Mattioli & Scheiner (2024) find that even cohabiting with a partner with friends abroad is associated with more flights for the respondent.

Most multivariate studies that include car ownership among the predictors find a positive net association with air travel activity (Czepkiewictz et al., 2019; Mattioli et al. 2021; Mattioli & Scheiner, 2024; Reichert and Holz-Rau 2015). The findings of Klein and Taconet (2024) suggest that this association is weakened when business travel is included in the analysis.

Regarding socio-psychological factors, several studies investigated the association between air travel and pro-environmental attitudes, using a variety of constructs, and providing mixed findings. Some find no significant association (Czepkiewictz et al., 2019, 2020; Kim and Mokhtarian 2021), which is often interpreted in terms of an 'attitude-behaviour gap'. Using a previous wave of the UKHLS dataset we use in our study, Alcock et al. (2017) find no association between air travel and environmental attitudes, concern over climate change, and pro-environmental household behaviours. Other studies find contradictory and inconsistent associations between air travel and the various constructs included in the analysis (Dütschke et al. 2022; Schubert et al. 2020), with suggestive evidence that some environmental attitudes can be associated with more, rather than less air travel. Some studies, however, do find a negative association between air travel and measures of environmental concern (Bruderer Enzler 2017; Schleich et al. 2024). Several studies find significant positive associations between air travel and other (non-environmental) attitudes, such as e.g. importance of money (Alcock et al. 2017), cosmopolitan attitudes (Czepkiewicz et al. 2019, 2020a, b), tech-savviness (Kim and Mokhtarian 2021), and the enjoyment of biking (Klein and Taconet 2024).

All studies reviewed so far in this section are based on cross-sectional data, so that they identify the factors associated with air travel at a given point in time. Evidence on the factors associated with change in air travel behaviour over time is sparse. Two recent studies explored the factors associated with the intention to change air travel behaviour in relation to the COVID-19 pandemic. Javadinasr et al. (2022) investigated change in business air travel behaviour based on a two-wave panel survey (2020 and 2021). They found that higher income, highly educated and pro-environment respondents were less likely to intend to fly more after the pandemic. However, the study is focused on the impact of and recovery from COVID–19, comparing revealed behaviour in the pre-pandemic situation (wave 1) with stated preferences in the post-pandemic situation (wave 2). Also, it is focused on flights for business purposes which account for only a small share of air travel. Using a similar approach, O'Garra and Fouquet (2022) explored the willingness to reduce air travel in the post-pandemic period, finding that members of environmental organisations are more inclined towards voluntary reductions in air travel, while women and older people are less inclined. An earlier study (Davison and Ryley 2013), based on bivariate analysis of survey

data and focus groups, found that having children and entering retirement impact an individual's propensity to fly. To the best of our knowledge, no multivariate study based on longitudinal data has investigated the factors that explain actual change in air travel activity over an individual life course to date. This is what this study sets out to do, based on data for England.

Case study context

For our analysis, we use data from England spanning the period from 2012 to 2019. Due to the insular nature of the country, UK residents show a higher frequency of flights than other Western countries. Airbus (2019) reports 2.25 flights per capita in 2019 for the UK, compared to 1.35 in Germany and France, and 1.70 in the Netherlands and Italy. While domestic flights are not uncommon, especially between England and peripheral regions like Scotland and Northern Ireland, 87% of terminal passengers at UK airports travelled internationally in 2019 (DfT, 2023a). 89% of flights abroad by UK residents in 2019 were for the purpose of holidays or visiting friends and relatives (DfT 2023b).

Our study period was characterised by strong economic and population growth, and associated growth in air travel. Based on survey data, Büchs and Mattioli (2021) find a decrease in air trip rates between 2007 and 2011–2012 (in the aftermath of the global financial crisis) followed by a rebound in 2012–2017. Official figures show an increase in domestic flight travel of 11% (from 8.3 to 9.2 billion passenger kilometres) from 2012 to 2019 (DfT, 2023c), and a strong increase in the number of international trips, particularly for holiday (+41%) and visiting friends and relatives (+62%), less so for business reasons (+3%) (DfT, 2023d), while the UK population grew by 4.6% in the same period (ONS, 2024). As the number of overseas trips increased, the mode share of air travel in this segment increased from 79% (2012) to 84% (2019) (DfT, 2023e). The vast majority of international trips of UK residents has the EU-27 as destination (71% in 2012 and 72% in 2019) (DfT, 2023d).

Data and analysis approach

Our analysis is based on information drawn mainly from Wave 4 (intended fieldwork from January 2012 to December 2013) and Wave 10 (from January 2018 to December 2019) of the UK Household Longitudinal Survey (UKHLS) (University of Essex, Institute for Social and Economic Research, 2020). UKHLS is a large nationally representative panel survey that covers a range of topics, with a core set of questions and additional rotating questionnaire modules. Note that while the intended fieldwork for each wave covers 24 months, a few interviews are followed up in the first few months of the following year. Each respondent in the panel is re-interviewed at regular intervals of approximately 12 months. This means that for most respondents, there is a six-year span between the information collected in Wave 4 and Wave 10 (e.g., 2012–2018, 2013–2019). Also note that the data is hardly affected by the COVID pandemic, as just 0.4% of respondents in our sample completed their Wave 10 interview after February 2020.

At the time of writing, a later wave of UKHLS (Wave 13) is available that includes air travel frequency information for the first time since Wave 10. While this makes it possible

to analyse changes in air travel behaviour over a more recent period, we decided against it for two reasons. First, Wave 13 is based on fieldwork conducted in 2021-22, i.e., partly during and partly after the height of the COVID-19 pandemic. As such, individual changes in travel behaviour between Wave 10 and 13 would reflect life course and period effects, but also effects related to the pandemic and related travel restrictions. Given the magnitude of the latter, it is likely that these would drown out other effects, complicating the interpretation. Our goal in this study is rather to identify life course effects and the drivers of air travel activity growth during 'normal times'. This is valuable in and of itself, and will provide a baseline against which future studies can assess the shorter- and longer-term impacts of the COVID-19 disruption. Second, questions on social networks – one of the main travel-inducing factors that we explore in our analysis – have not been included after Wave 9. For these reasons, our analysis focuses on changes in air travel behaviour between Wave 4 and 10, i.e., in a pre-COVID-19 situation, and should be interpreted as such.

Both Wave 4 and 10 include information on the number of return flights taken by the respondent "for leisure, holidays or visiting friends or family" in the 12 months prior to the interview. Flights "for work or business purposes" were explicitly excluded by the survey question. While this is an underestimation of the respondents' air travel activity, one must keep in mind that most air travel is for personal purposes. In an average pre-pandemic year just 14% of the distance flown by UK residents was for business travel (O'Garra & Fouquet, 2022, p.6). Most previous multivariate studies of air travel activity (section "Literature review") focus on flights for private purposes as well.

The dependent variable in our analysis is the difference between the number of flights the respondent took in Wave 10 and Wave 4, so that a positive value indicates an increase, a negative value a decrease, and a zero value no change between the two waves (note that we do not have any information on the number of flights the respondent took in the intervening years). To reduce the influence of outliers, we top-coded the dependent variable symmetrically at both tails of the distribution at +/-8 (corresponding to the 99th percentile of the distribution in the full sample). The resulting variable approaches a normal distribution in the weighted analysis sample (mean: +0.33; median: 0, standard deviation: 1.87; skewness: +0.47; kurtosis: 8.80), although with a high proportion of zero values (Fig. 1). As such, we estimate an ordinary least square regression model to predict change in air travel frequency between the two waves.

We include several independent variables in the regression model, grouped under six headings: (1) socio-demographic and economic situation; (2) spatial attributes of the area of residence (including accessibility to airport and rail infrastructure); (3) migration background and ethnicity; (4) spatial dispersion of the respondent's social networks; (5) car ownership; (6) environmental attitudes and behaviour. These dimensions reflect the state-of-the-art of previous research, reviewed in section "Literature review". We are unable to include predictors related to non-environmental attitudes, as these are not available in the UKHLS dataset. All spatial variables refer to Lower layer Super Output Areas (LSOAs), i.e., small, homogeneous local neighbourhood units, including typically 1,000 to 3,000 inhabitants. For a full list and detailed description of the independent variables, including data sources and data preparation, see Table 2 (Online Resource 1).

Our analysis focuses on England, as many of the spatial statistics that we include in the regression model are not available for the other constituent nations of the UK. We use the appropriate UKHLS longitudinal weighting factors to correct for differences in sample

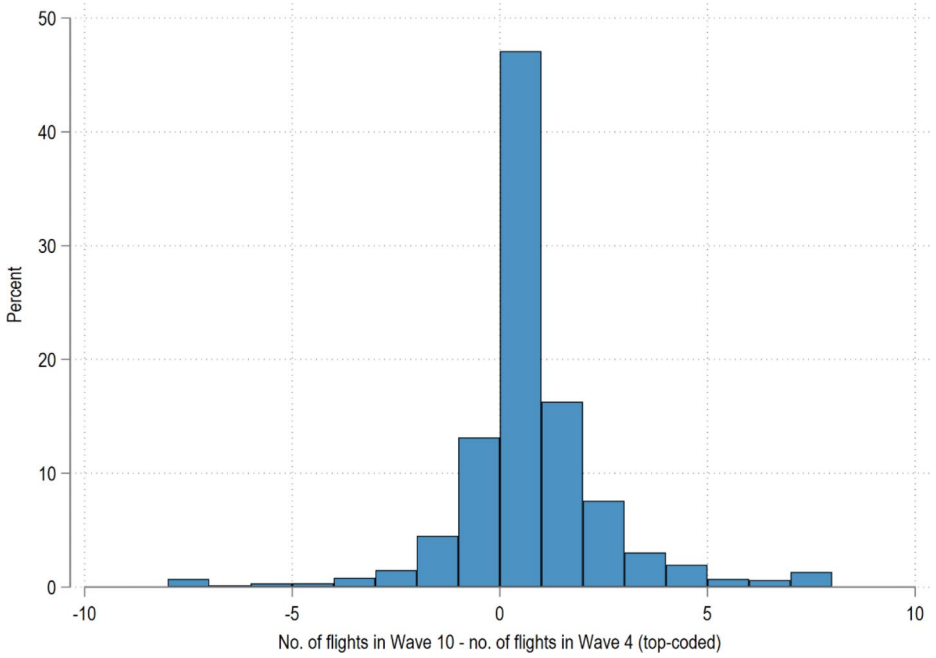

Fig. 1 Distribution of the dependent variable in the analysis sample ($n = 8793$)

selection probability, attrition between waves and other aspects of survey design (sampling clusters and strata). We further exclude from the analysis all respondents with missing values on any of the independent or dependent variables (listwise deletion). This results in an analysis sample of 8,793 individuals. By using standardised longitudinal weights, we ensure that the sample is representative of adults who lived continuously in the UK from 2011 to 2012 to 2018–2019, and at the same time avoid excessive inflation to extrapolate results to the population. For a more detailed discussion of issues related to UKHLS data collection, representativeness and weighting, see Lynn and Kaminska (2010) and Knies (2018).

For most independent variables we include information on both the situation at Wave 4 and the change occurred between Wave 4 and Wave 10. For continuous variables, we include two separate predictors (e.g., a "baseline" variable reporting income quintile in Wave 4, and a "change" variable reporting the percent change in income between the two waves). For categorical variables, we include a single "composite" predictor with categories corresponding to all (or the most relevant) transitions between states that have occurred between the two waves, including categories for respondents who reported no change. For details, see Table 2 (Online Resource 1).

Further to the independent variables listed in Table 2, we include a baseline variable for the number of flights in Wave 4 (top-coded at the 99th percentile of the distribution of this variable, i.e., 10 flights). We do this to control for 'regression to the mean', the statistical phenomenon whereby respondents with particularly low or high values in a first wave are inherently more likely to report a large change in a subsequent wave, as their values converge towards their 'true mean' (Barnett et al. 2005). In our analysis, this is likely to be magnified by the infrequent and irregular nature of air travel and by the 12-month reporting

period, resulting in larger standard deviation. Since the distribution of the number of flights in both waves is partially bounded by zero on the left side and right-skewed, we expect the regression to the mean phenomenon to manifest itself mainly in terms of respondents with a high number of flights in Wave 4 reporting a lower number of flights in Wave 10.

Further to the regression model included in this paper (Model A), we tested the sensitivity of the results to changes in three parameters: (i) excluding the baseline variable for the number of flights from the model (Model B); (ii) excluding respondents who took zero flights in both Wave 4 and Wave 10 from the sample (Model C); (iii) no top-coding of the number of flights (for both dependent variable and baseline variable) (Model D). Comparing models with and without a baseline number of flights predictor is informative about which observed effects are due to the 'regression to the mean' phenomenon, and which are robust to it. Also, many respondents in the analysis sample did not fly in either wave (3220, 37.6% of the weighted analysis sample). This group likely includes a substantial share of respondents who never fly, and these tend to be structurally different from others in many respects (Graham and Metz 2017; Kim and Mokhtarian 2021). The fact that this group accounts for a large share of respondents with zero value on the dependent variable (79.6% of them) might skew the analysis, which is why we exclude them in one of the alternative models (resulting in a smaller sample, $n=5573$). We interpret effects that are observed in Model A, but not in Model C as reflecting mainly structural differences between respondents who fly (even occasionally) and those who never fly, rather than as drivers of changes in air travel frequency between waves.

We obtain broadly consistent results across models, indicating that the analysis is robust. We comment in section "Results" on how specific results vary across models and provide interpretation for these discrepancies. We tested Model A for multicollinearity, obtaining variance inflation factors lower than 10.

Results

Descriptive analysis

We start by presenting descriptive findings about changes in air travel frequency between Wave 4 and Wave 10. The Sankey diagram in Fig. 2 shows transitions between values of the number of flights (categorised), depicted as flows. Three main findings can be highlighted. First, as already noted, about half of the respondents did not take any flight for private purposes in the 12 months prior to the interview (55.1% in Wave 4 and 49.7% in Wave 10), and a large share (37.6%) did not report any flight in either wave. Second, overall flight frequency increased between the two waves, with e.g., a larger share of respondents reporting at least four flights or more in Wave 10 (11.2%) compared to Wave 4 (6.2%). This dovetails with Fig. 1, showing that the change in the number of flights is skewed towards positive values. It is also consistent with the growth in air travel activity over the study period (see section "Case study context"). Third, there is substantial movement from one category to another between the two waves, notably between adjacent categories. Overall, 32.6% of respondents increased the number of flights, 20.2% decreased it, while 47.2% reported the same number in both waves.

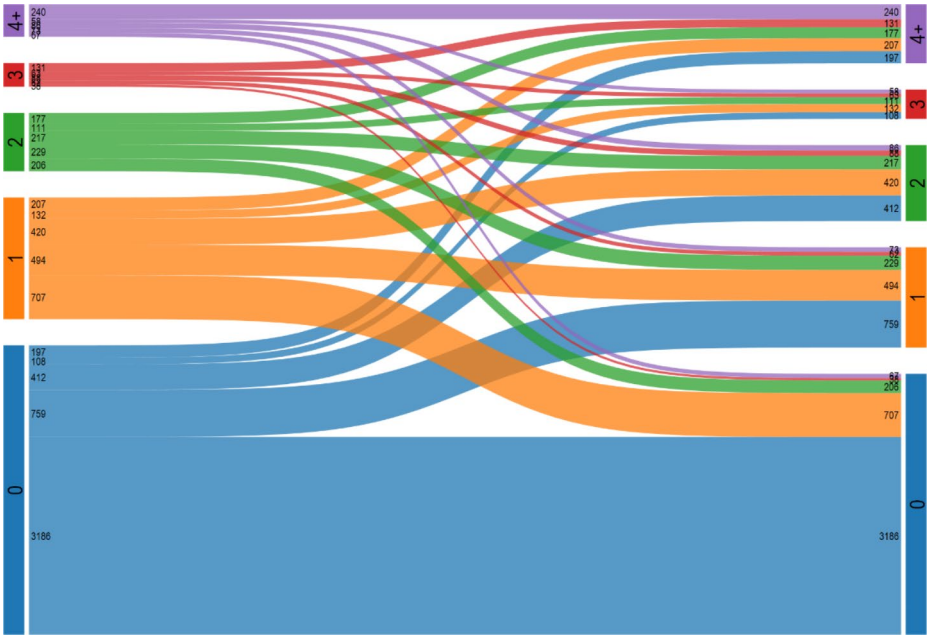

Fig. 2 Transitions in the number of flights (categorised) between 2012/13 (left) and and 2018/19 (right)*.
* note: the Sankey diagram shows weighted absolute values (unweighted $n = 8793$)

We conducted a bivariate analysis of the association between the predictors and the dependent variable (Table 3, Online Resource 2). An important finding is that nearly all groups increased the mean number of flights between the two waves, with the exceptions being factors associated with old age. This again demonstrates the existence of a strong period effect whereby levels of air travel activity increased virtually across the board between the two waves. We provide further comment on the results of the bivariate analysis below, where appropriate, to contextualise the results of the regression analysis.

Regression analysis

Table 1 shows the results of the main OLS model (Model A) and the number of model specifications in which a coefficient was significant (in the rightmost column). Table 4 (Online Resource 3) presents the detailed results for the three alternative specifications of the model (Models B to D), along with Model A to enable comparison. In the remainder of this section, we refer primarily to the results reported in Model A, while referring to the alternative models where appropriate.

The regression coefficient associated with the baseline number of flights in Wave 4 is statistically significant and negative ('regression to the mean').

Sociodemographic and economic situation

Higher income is associated with an increase in the number of flights in Model A. Thus, the higher the income the higher the increase in the number of flights between waves. The

Table 1 Regression model of change in the frequency of flights for personal reasons between 2012/13 and 2018/19*

Predictor category	Predictor	Raw coefficients	Standardized coefficient (Beta)	No. of significant effects
	No. of flights in Wave 4 (baseline)	-0.53***	-0.45	3/3
1 – Socio-demographic and economic situation	**Household income in Wave 4 (ref. cat.: 1st income quintile / bottom)**			
	2nd	0.14*	0.03	2/4
	3rd	0.30***	0.06	3/4
	4th	0.34***	0.07	3/4
	5th – top	0.60***	0.13	3/4
	Sex at Wave 4 (ref.cat.: Male)			
	Female	0.12*	0.03	2/4
	Age at Wave 4 (ref.cat. 75+years old)			
	16–24 years old	0.61***	0.10	4/4
	25–34 years old	0.30*	0.06	2/4
	35–44 years old	0.34**	0.07	4/4
	45–54 years old	0.39**	0.08	4/4
	55–64 years old	0.18	0.04	1/4
	65–74 years old	0.09	0.02	0/4
	Employment status at Wave 4 and 10 (ref. cat.: In paid employment → In paid employment)			
	Other → Other	-0.27***	-0.04	3/4
	In paid employment → Retired	-0.16	-0.02	1/4
	In paid employment → Other	0.09	0.01	0/4
	Other → In paid employment	0.02	0.003	0/4
	Other → Retired	0.004	0.0004	0/4
	Retired in Wave 4	-0.24*	-0.05	4/4
	Tertiary education qualification in Wave 4 and 10 (ref. cat.: No → No)			
	No → Yes	0.35*	0.04	1/4
	Yes → Yes	0.06	0.01	0/4
	In a cohabiting relationship in Wave 4 and 10 (ref.cat.: Yes → Yes)			
	No → Yes	0.06	0.01	0/4
	Yes → No	0.06	0.01	0/4
	No → No	-0.11	-0.03	0/4
	Responsibility for children in Wave 4 and 10 (ref. cat.: No → No)			
	No → Yes	-0.78***	-0.08	4/4
	Yes → No	-0.11	-0.01	0/4
	Yes → Yes	-0.37***	-0.07	4/4
	Long-standing illness or disability in Wave 4 and 10 (ref. cat.: No → No)			
	No → Yes	-0.24***	-0.05	4/4

Table 1 (continued)

Predictor category	Predictor	Raw coefficients	Standardized coefficient (Beta)	No. of significant effects
	Yes → No	-0.10	-0.02	0/4
	Yes → Yes	-0.28***	-0.06	4/4
	Percent change in total household net income between Wave 4 and 10	0.001***	0.06	4/4
2 – Spatial attributes of the area of residence	**Population density in LSOA at Wave 4 (1000s persons per hectare)**	0.01	0.01	0/4
	Travel time to nearest rail station at Wave 4 (mins)	-0.02	-0.01	0/4
	Travel time to nearest large airport at Wave 4 (mins)	-0.03	-0.01	0/4
	Number of airports within 60 min travel time at Wave 4	0.15**	0.06	4/4
	Annual passengers at nearest large airport at Wave 4 (millions)	0.0001	0.001	0/4
	Area of residence in Wave 4 and 10 (ref. cat.: Rest of England → Rest of England)			
	Rest of England → Greater London	0.40	0.02	0/4
	Greater London → Rest of England	0.33	0.02	0/4
	Greater London → Greater London	0.19	0.04	1/4
	Change in population density in LSOA between Wave 4 and 10 (1000s persons per hectare)	0.0004	0.0006	0/4
	Change in travel time to nearest rail station between Wave 4 and 10 (mins)	-0.07	-0.01	0/4
	Change in travel time to nearest large airport between Wave 4 and 10 (mins)	-0.05	-0.01	0/4
	Change in number of airports within 60 min travel time between Wave 4 and 10	0.12	0.02	0/4
	Change in annual passengers at nearest large airport between Wave 4 and 10 (millions)	0.01	0.03	0/4
3 – Migration background and ethnicity	**Migration generation status at Wave 4 (ref. cat.: 4th +)**			
	2nd or 3rd	-0.07	-0.01	0/4
	1st (5 + years)	0.001	0.00	0/4
	1st (less than 5 years)	-0.60*	-0.03	3/4
	Ethnic group (ref. cat.: White British)			
	Other White	0.34	0.03	0/4
	Asian or Asian British	-0.21	-0.02	1/4
	Black or Black British	-0.47**	-0.03	3/4
	Other + Mixed	-0.37*	-0.03	3/4
4 – Spatial dispersion of the respondent's social networks	**Close family abroad in Wave 3 and 9 (ref. cat.: No → No)**			
	No → Yes	0.38*	0.03	3/4
	Yes → No	0.26	0.02	0/4

Table 1 (continued)

Predictor category	Predictor	Raw coefficients	Standardized coefficient (Beta)	No. of significant effects
	Yes → Yes	0.47**	0.05	3/4
	Friends outside of local area in Wave 3 and 9 (ref.cat.: No → No)			
	No → Yes	0.04	0.01	0/4
	Yes → No	0.002	0.0004	0/4
	Yes → Yes	0.16*	0.04	2/4
5 – Car ownership	**Household cars in Wave 4 and 10 (ref.cat.: Yes → Yes)**			
	No → No	-0.02	-0.01	0/4
	No → Yes	-0.11	-0.01	0/4
	Yes → No	-0.08	0.007	0/4
6 – Environmental attitudes and behaviour	**Green self-image at Wave 4 (scale, z-score)**	0.03	0.004	0/4
	Climate change concern at Wave 4 (scale, score)	0.04	0.01	0/4
	Climate engagement at Wave 4 (scale, z-score)	-0.002	-0.001	0/4
	Climate detachment at Wave 4 (scale, z-score)	-0.03	-0.02	0/4
	Pro-environmental behaviour at Wave 4 (z-score)	-0.11***	-0.06	3/4
	Change in 'green self-image' between Wave 4 and 10 (difference in raw scores)	0.05	0.02	1/4
	Change in 'climate change concern' between Wave 4 and 10 (difference in raw scores)	0.09*	0.03	3/4
	Change in 'climate engagement' between Wave 4 and 10 (difference in raw scores)	0.01	0.02	0/4
	Change in 'climate detachment' between Wave 4 and 10 (difference in raw scores)	-0.003	-0.01	0/4
	Change in 'pro-environmental behaviour' between Wave 4 and 10 (difference in raw scores)	-0.11*	-0.04	4/4
	Constant	0.04		
	R^2	0.21		
	N	8793		

* Notes: (i) parameter estimates are raw coefficients and standardized (beta) coefficients for the ordinary least squares regression of the difference between the number of flights in Wave 10 and Wave 4 (n=8,793); (ii) significance levels: * $p<0.05$; ** $p<0.01$; *** $p<0.001$; (iii) the rightmost column reports in how many out of the four models A-D the effect was significant ($p<0.05$) – see Table 4 (Online Resource 3) for the full results

bivariate analysis (Table 3, Online Resource 2) shows that the number of flights increased by a similar amount in all income quintiles, despite the very different starting points. Note that the positive effect of higher income is absent in Model B which does not include the baseline variable. As expected, an increase in household income between the two waves is associated with an increase in the number of flights.

Women tend to increase their number of flights between the two waves more than men in the main regression model. However, this effect does not reach significance in some of the alternative models, which reduces our confidence in this finding.

Age has a clear effect, with younger adults who were in their teens or early twenties in Wave 4 showing the largest increase in the number of flights six years later, both in the multivariate and bivariate analysis. Conversely, respondents older than 65 years at Wave 4 are among the few groups to report a decline in the mean number of flights between the two waves in the bivariate analysis.

With regard to employment status, the regression coefficient for respondents who were neither employed nor retired in both waves is negative, which might be due to longer term effects of living with limited economic resources for those who are unemployed. This effect loses statistical significance when respondents who did not fly in either wave are excluded from the analysis (Model C), which suggests that this group is more likely not to fly in either wave (or at all). Respondents who entered employment between waves show one of the largest increases in the number of flights in the bivariate analysis (+0.73), but no significant coefficient in the multivariate analysis. The transition from employment into retirement is associated with fewer flights, but this is only statistically significant when the baseline variable is not included in the regression model. People who retired before Wave 4 have the strongest negative regression coefficient.

Gaining tertiary education qualification is associated with the largest increase in the number of flights in the bivariate analysis (+1.07) and with a positive coefficient in the main regression model. However, this effect does not reach significance in some of the alternative models, which reduces our confidence in this finding.

We find no significant effect of changes in the respondents' relationship situation, although people who started a cohabiting relationship between the two waves had one of the largest increases in the number of flights in the bivariate analysis (+0.61).

Becoming responsible for children between the two waves is associated with a large negative coefficient in the regression analysis. Respondents who were responsible for children in both waves also tended to reduce the number of flights, once other factors are controlled for.

The net effect of developing a serious illness or disability between the two waves is to reduce the number of flights in Wave 10, which makes intuitive sense. The same goes for respondents who were ill or disabled in both waves.

Spatial attributes of the area of residence

Most baseline predictors are not statistically significant, except for respondents with good accessibility to several airports, who increased their number of flights more than others. These respondents also show a large absolute increase in the bivariate analysis (+0.53). We also find no significant association between changes in the attributes of the residential area (due to relocation or other reasons) and changes in air travel frequency. Only in alternative Model D, where the reported number of flights was not top-coded, we observe a significant increase in the number of flights among respondents who lived in Greater London in both waves. This might indicate that the number of very frequent flyers in Greater London increased between 2012 and 2019.

Migration background and ethnicity

We find a negative regression coefficient for recent migrants to the UK, who had been in the country for less than five years in Wave 4, but no effect for migrants who in Wave 4 had been in the UK for longer than five years. There is also a negative net association between some ethnic identifications (Black and 'Other / Mixed') and change in the number of flights in most variants of the regression model. This effect disappears in Model B, where the baseline number of flights is not controlled for.

Spatial network dispersion

Respondents with close family members abroad in both waves, as well as those who 'acquired' them in the intervening six years (e.g., because the relatives moved abroad), reported some of the largest increases in the number of flights between the two waves in the bivariate analysis (ca. +0.50). This is confirmed in most regression models and applies to respondents who had friends outside of the local area in both waves as well. The coefficients do not reach significance when the baseline number of flights is not controlled for (Model B).

Car ownership

We find no net association between (changes in) household car ownership and changes in air travel frequency.

Environmental attitudes and behaviour

Most baseline variables show no significant effect in the regression model, meaning for example that those reporting greater climate concern in Wave 4 did not increase their number of flights less than others. However, those who engaged more in pro-environmental behavior within the home and when purchasing in Wave 4 increased their flying less than others (as evidenced in a negative coefficient – although it loses statistical significance when the baseline number of flights is not included). Most variables assessing change in environmental attitudes between the two waves do not have a statistically significant effect on change in air travel frequency, neither in the bivariate nor the multivariate analysis. A counterintuitive finding, however, is that an increase in climate change concern between the two waves is associated with an increase in the number of flights in most regression models. Note however that the coefficients become non-significant when respondents who did not fly in either wave are excluded from the analysis (Model C). We also find that an increase in pro-environmental behaviour within the home or when purchasing between the two waves is associated with a decrease in the number of flights in all regression models.

Discussion

Our study presents an array of findings that contribute to the literature, especially to research focused on travel behaviour from a life course perspective ('mobility biographies') and on the determinants of air travel. We discuss the most important findings here.

We find that the number of flights over time increased by a similar amount in all income quintiles. This is consistent with evidence that the level of inequality in air travel between income groups is large and persisting (Büchs and Mattioli 2021), and that affluent social groups develop new and more air-travel intensive social practices over time (Cass 2022).

The findings for gender are consistent with cross-sectional evidence suggesting that women fly more for personal reasons than men, notably when the presence of children is controlled for (section "Literature review"), and suggests that this effect may be becoming stronger over the respondents' life courses.

Younger adults show the largest increase in the number of flights, probably reflecting a life course effect, whereby young adults acquire more independence in terms of income and travel in their twenties, while not yet having many family- or work-related responsibilities. Our finding is also consistent with evidence that new cohorts tend to travel more internationally, i.e., a cohort effect which is due to earlier and more intensive socialisation as children into international travel (Mattioli et al. 2022). Conversely, respondents being older than 65 years or in retirement at Wave 4 report a decline in flights, which is likely explained by life course and ageing effects.

Several life course events (entering employment, gaining tertiary education, starting a cohabiting relationship) are clearly associated with increased flying in the bivariate analysis but show less or no significance in the multivariate analysis. The reason may be that the increases are due to other life course transitions that tend to coincide. Future research should trace the effects of interactions between life course transitions on travel. We find no significant effect for entering retirement in the most models. Previous qualitative research (Davison and Ryley 2013) suggests that while some people increase air travel after retirement due to greater time availability, other reduce it due to health problems, which might explain this.

Being responsible for children (or becoming so between the waves) tends to reduce the number of flights. This is consistent with previous cross-sectional evidence (section "Literature review"), as well as with qualitative studies (Davison & Ryley, 2023) highlighting the greater difficulty and cost of flying with children, and particularly infants. The observation that the reduction in flights also refers to respondents who already had children in Wave 4 may reflect that this group is likely to include respondents with more than one child and those who already had children further increased their number between waves.

The negative regression coefficient for recent migrants to the UK we found is consistent with cross-sectional evidence (section "Literature review"). Research on daily travel and car use has found evidence for a 'transport assimilation' effect, whereby migrants initially diverge from the average travel behaviour of host country residents but then converge towards it over time (Delbosc & Rhafi, 2023). Our findings suggest that something similar happens for air travel, with newly arrived migrants flying a lot more than average in the first few years, but then reducing flight frequency over the first 5–10 years after arrival, stabilising at values around the population average. It is possible that the effect is even more pronounced in the first three years after arrival, as all respondents classified as recent migrants

in our sample had lived in the UK since at least Wave 1 (2009–2010). As such, our analysis captures the 'transport assimilation' effect after the third year of residence in the country.

We find little evidence for effects of the spatial environment at the residential area, except that good accessibility to several airports is associated with an increased number of flights. This could be interpreted as evidence of an 'induced demand' effect of good airport accessibility (Mattioli et al. 2021) unfolding over time, i.e., that people tend to increasingly take advantage of access to airports over time (Cass 2022). However, the lack of association between changes in the residential area and changes in air travel frequency contrasts with existing cross-sectional evidence on the positive association between air travel and both urbanity and airport accessibility (section "Literature review"). For example, while previous studies show that living in Greater London is associated with greater flight frequency (Mattioli et al. 2021), in our analysis neither moving to or away from London is significantly associated with a change in flight frequency. Overall, this suggests that the cross-sectional association between spatial factors and air travel found in previous studies is due to unobserved confounding factors, possibly reflecting residential self-selection of some sorts. An alternative explanation is that there is a lag in the impact of residential relocation on air travel behaviour, which goes beyond the 6-year period between waves in our analysis. It is also possible that the number of respondents in our sample who relocated between waves is too small to produce statistically significant results (e.g., just ca. 100 respondents relocated to and from Greater London).

Dispersion of personal social networks, whether family or friends, is associated with an increase in flight frequency over time, confirming that this is an important (albeit overlooked) determinant of air travel (section "Literature review"). This result is however at odds with the expectation that air travel for visiting friends and family tends to reduce over time, as relationships wither because of distance. It may be that people who have dispersed social networks are also more likely to develop new long-distance relationships and to expand their activity spaces over the life course, in ways that require more and more air travel.

The lack of association between (changes in) household car ownership and air travel frequency is in contrast with previous cross-sectional studies (section "Literature review"), including previous analysis of UKHLS Wave 4 data (Mattioli et al. 2021), which found a positive net association between car ownership and air travel. Our findings suggest that there is no causal relationship between the two, and that the cross-sectional association is likely due to uncontrolled factors, such as an underlying 'mobile lifestyle' that is conducive to both.

With regard to environmental attitudes and behaviour, we mostly find a lack of association with air travel, which provides further longitudinal evidence that there is pronounced 'attitude behaviour gap' for air travel (Alcock et al. 2017). However, we find negative effects for those who engaged more in pro-environmental behavior within the home and when purchasing in Wave 4, as well as for those who increased their pro-environmental behaviour between the two waves. This could be interpreted in terms of a positive 'spillover effect' (Maki et al. 2019) whereby pro-environmental behaviour in one area of life tends to result in more pro-environmental behaviour in other areas over time. Conversely, it is inconsistent with the 'moral licensing' hypotheses, whereby people would try to 'morally offset' higher emissions from flying with greater engagement in lower-cost pro-environmental behaviours such as recycling (Gholamzadehmir et al. 2019).

A counterintuitive finding is that an increase in climate change concern between the two waves is associated with an increase in the number of flights. This dovetails with the findings of some previous cross-sectional research (Dütchke et al., 2022; Schubert et al. 2020), and could be interpreted as evidence of reverse causality, whereby greater participation in air travel tends to increase climate change concern (through e.g., the experience of climate impacts in far-off places, increased cosmopolitanism, or increased concern for the respondent's own climate impact), rather than the other way around. It could also be interpreted as evidence of spurious correlation with some of the same factors (e.g., an increase in cosmopolitanism resulting in both more climate concern and more air travel). Whatever the underlying mechanisms, our findings help elucidate why air travel activity increased in England during a period (2012–2019) when climate change risk perception and the public salience of environmental issues heightened as well (Kirby 2023; Liu et al. 2022).

More broadly, the lacking or counterintuitive associations with environmental attitudes might result from the fact that most people tend to underestimate the climate impact of air travel relative to other behaviours (Schleich et al. 2024; Wynes and Nicholas 2017).

Conclusion

Our study demonstrates that it is possible to investigate change in air travel behaviour over time based on panel survey data, in a manner akin to 'mobility biographies' studies on daily travel behaviour. As discussed in the introduction, the evidence produced can inform three debates: i) on the impact of life-course events on travel behaviour; ii) on what factors are causally related to air travel; iii) on the drivers of air travel growth, and related implications in terms of inequality and 'institutionalisation' of air travel. We discuss these points below, drawing consequences for research and policy, respectively.

Debate I: impact of life-course events

Our study shows that, much like car travel, air travel behaviour is affected by key events in a person's biography. Interestingly, it seems that the same event can affect the use of the two main CO_2-emitting travel modes in different directions, with e.g., childbirth typically increasing car use (de Haas et al. 2018; Prillwitz et al. 2006; Scheiner and Holz-Rau 2013) but decreasing air travel frequency (as shown in our analysis). An interesting direction for future research would thus be to explore how the overall amount and composition of transport CO_2 emissions change over the life course, and what factors drive these changes. Most mobility biographies research to date has focused on outcomes such as frequency of travel mode use or mode choice rather than on the resulting emissions – but the latter are often the outcome of interest from a policy perspective.

Debate II: causality issues

While panel analysis is not strictly sufficient to provide evidence for causal relationships, our findings strengthen previous cross-sectional evidence on which factors induce air travel activity. They provide, for example, more robust evidence that social network dispersion tends to result in more air travel. This factor urgently deserves more attention from transport

and climate research, as it can contribute to the lock-in and institutionalisation of ever-increasing levels of air travel. The findings also support the existence of a 'transport assimilation' effect for migrants, whereby they tend to fly more in the first few years after arrival, but then gradually less, confirming previous cross-sectional research (Mattioli and Scheiner 2022). This parallels the assimilation effect observed for car use (Delbosc & Rhafi, 2023), except in the opposite direction, i.e., from more to less CO_2 emissions. Future studies might explore how the total transport-related CO_2 emissions of migrants change as they move to and assimilate into the host country.

On the other hand, our findings lead us to question some causal associations posited in the literature, such as the hypothesis of a direct relationship between urbanity and air travel, as people 'compensate' for deficiencies in urban environments with more long-distance travel (Czepkiewicz et al. 2018). It may be that cross-sectional associations between urbanity and air travel frequency are due to intervening, unobserved factors such as attitudes, lifestyles, and social norms. From a policy perspective, this would imply that climate policies aiming at urban densification and car ownership reduction do not run the risk of inadvertently 'backfiring' by inducing more air travel.

With respect to a possible 'induced demand' effect of airport accessibility (Bruderer Enzler 2017; Kim and Mokhtarian, 2021; Mattioli et al. 2021), our findings are not clear-cut: respondents who relocated to areas with better accessibility to airports between the two waves did not increase their number of flights more than others, but respondents who already lived in areas well-served by several airports did. This discrepancy might indicate that the induced demand effect takes a few years to unfold but persists over time. If the induced demand hypothesis were confirmed, it would support climate policy arguments for a moratorium on airport expansion (Climate Change Committee 2023; Element and Energy 2022; Gössling and Lyle 2021; Greenpeace 2023; Kuhnhenn et al. 2023; Stay and Grounded 2019; Transport & Environment, 2023).

With regard to environmental attitudes, our findings are broadly consistent with the notion of a large 'attitude-behaviour gap' for air travel. This challenges the idea that growing levels of climate awareness will lead people to reduce air travel activity, and Gössling et al.'s (2020) hypothesis that the attitude behaviour gap is closing because of the 'flight shame' movement since 2018 and the associated shift in social norms. However, 2018–2019 data used in our analysis may underestimate the longer-term impacts of those debates, as well as of COVID-19 – something which could be explored using subsequent survey waves. Our findings are also inconsistent with recent longitudinal studies finding greater intention or willingness to reduce air travel post-COVID among environmentally oriented people (Javadinasr et al. 2022; O'Garra and Fouquet 2022). This might be explained by a gap between stated intentions and actual behaviour or by the fact that our data refers to the pre-pandemic situation. Interestingly, however, we also find suggestive evidence of a causal relationship between engaging in pro-environmental domestic and purchasing behaviour and reduced air travel frequency. Further research is needed to ascertain whether this can be interpreted in terms of a 'positive spillover effect' (Maki et al. 2019).

Debate III: drivers of air travel growth

Our study shows that average levels of air travel activity have increased among virtually all social groups in England between 2012 and 2019, including for those who have experienced

life transitions that tend to decrease flight frequency (e.g., childbirth). This demonstrates the existence of a strong period effect, reflecting both longer-term growth and a shorter-term 'rebound' of air travel activity after the economic crisis of 2007–2012. We also find that higher-income households were as, or more likely as others to increase their (already higher) number of flights between 2012 and 2019. This suggests that, up to COVID-19, the most affluent sectors of the population were rapidly changing their lifestyles to integrate ever-increasing levels of air travel, and that currently high levels of inequality in air travel participation are likely to persist over time. This supports the argument that climate policy measures such as flight taxes and 'frequent flyer levies' would be equitable from a distributional perspective (Büchs and Mattioli 2024).

One of the clearest findings in our analysis is that younger adults increased air travel frequency the most between 2012 and 2019. While this partly reflects a life course effect, it is possible that earlier and more extensive socialization to air travel during childhood will lead new cohorts to fly more frequently than previous cohorts over their entire life course (Mattioli et al. 2022), reflecting the progressive institutionalization of air travel in our societies, while also contributing to it.

Limitations

There are two limitations to our analysis that must be kept in mind. First, our data refers to the pre-COVID-19 situation. This allows us to investigate the drivers of change in air travel frequency over a period of growth, which is informative as we are interested in the drivers of growth, and the long-term trend is upwards (Gössling et al. 2021; EASA 2023; IATA, 2024). Our study is the first multivariate longitudinal study of air travel in a life course framework. As such it provides a baseline for future research, and this baseline should not be biased by a huge disruption that may have affected people's life courses in very different ways. That said, it is possible that the COVID-19 disruption has changed the determinants of air travel behaviour in some long-lasting ways. Research to date has shown that, in the short-term, COVID-19 reduced willingness to fly (particularly among older people), made air travel more expensive, impacted international travel more than domestic travel, and made people gain experience in domestic and surface-based travel (Li and Wang 2024; Manca et al. 2023; Skarp and Hoolohan 2024). There are also studies suggesting that the willingness to voluntarily reduce air travel for environmental reasons has increased among certain groups (O'Garra & Fouquet 2022). There is however still very little empirical evidence on the long-term consequences of the COVID-19 disruption on air travel behaviour (Li and Wang 2024). Post-COVID waves of UKHLS including questions on air travel (not currently available to researchers) should make it possible to explore these questions. Our study provides an essential baseline against which to compare their results.

Second, our analysis refers to personal air travel only, i.e., it does not include business travel. Some of the trends and associations found here (e.g., between female sex, younger age and increasing air travel) might be different had all travel purposes been considered, although the two segments have different drivers so there is value in analysing them separately. More research is needed on the drivers of business air travel, both from a cross-sectional and longitudinal perspective.

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Declarations

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