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In pursuit of progressive and effective climate policies: Comparing an air travel carbon tax and a frequent flyer levy☆

Roger Fouquet [a, b, *], Tanya O'Garra [c, d]

[a] Energy Studies Institute, National University of Singapore, Singapore
[b] Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science (LSE), UK
[c] Department of Economics, Middlesex University, UK
[d] Department of Geography and the Environment, London School of Economics and Political Science (LSE), UK

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ABSTRACT

This paper investigates the trade-offs between progressivity and effectiveness for a carbon tax versus an 'excessive consumption' levy. To do this, we compare the distribution of consumer welfare impacts and environmental effectiveness of an air travel carbon tax and a frequent flyer levy. Results show that both policies have the potential to achieve substantial carbon mitigation with minimal impacts on consumer welfare. Nevertheless, compared with a carbon tax, a frequent flyer levy is more progressive and effective at reducing emissions – thus, there is no trade-off between progressivity and effectiveness by using an excessive consumption levy to mitigate air travel emissions. Furthermore, considering the pronounced growth in demand projected for air travel over the next 30 years, results show the frequent flyer levy will remain more progressive and effective over time. Although further research is needed to assess the trade-offs on the supply-side (e.g., protection of regular customers, dynamic efficiency) and related to implementation (e.g., data privacy, the role for revenue recycling), such an excessive consumption levy has the potential to be an equitable, effective and politically acceptable environmental policy for curbing carbon dioxide emissions. This is relevant not only for air travel but for other forms of consumption in which the affluent are responsible for a large share of demand and associated carbon emissions.

1. Introduction

As societies shift towards low-carbon energy systems, it is essential that policies supporting these transitions are designed to minimise unfair burdens on the poor. Although carbon taxation is usually considered the most economically efficient approach to reducing emissions (Goulder et al., 2019; Akerlof et al., 2019) and a key approach to shifting consumer behaviour towards green options, it is also often found that carbon taxes are regressive due to the relatively larger tax burden borne by low-income groups. Indeed, the distributional impact is a key factor influencing public acceptability, and the political viability of carbon pricing policies (Carattini et al., 2019). While revenue recycling can reduce the regressivity of carbon taxes (e.g., Goulder et al., 2019; West and Williams, 2004; Metcalf, 1999; Poterba, 1991), there remains substantial political and public opposition to carbon taxes on fuels worldwide (Carattini et al., 2019).

One alternative to a flat-rate carbon tax involves targeting excessive consumption (Benoit, 2020). This is a particularly attractive option for goods and services which are difficult to decarbonise, and for which consumption levels and carbon emissions are inextricably linked. Excessive consumption policies may simultaneously reduce carbon emissions while addressing inequalities of consumption (Cass et al., 2022). Given that consumption levels tend to increase with income[1] (Chancel, 2021; Wiedmann et al., 2020; Oswald et al., 2020; O'Garra and Fouquet, 2022), such policies have a greater likelihood of being progressive – and hence, acceptable to the general public.

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* Corresponding author. Energy Studies Institute, National University of Singapore, Singapore.
E-mail address: fouquet@nus.edu.sg (R. Fouquet).

[1] Closely related, there is also evidence that emissions rise with income (Levinson and O'Brien, 2019).

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At the same time, it is vital to assess the effectiveness of more progressive policies at delivering emissions reductions. While carbon taxes are consistently found to be cost-effective at reducing emissions (Green, 2021; Metcalf, 2019; Goulder and Parry, 2008), to our knowledge, the effectiveness of excessive consumption levies has not been assessed. Given that the primary objective of these policies is to reduce emissions, the environmental impacts should be considered in parallel to the distributional impacts to identify trade-offs between the two.

With this in mind, this paper seeks to shed light on the trade-offs between progressivity and cost-effectiveness associated with an excessive consumption levy compared to a carbon tax. To do this, we compare a carbon tax applied to air travel, and a frequent flyer levy. While carbon taxes have received considerable academic attention, albeit mostly in the context of gasoline and road transport (Goulder et al., 2019; Akerlof et al., 2019; Baranzini et al., 2015),[2,3], the frequent flyer levy (FFL), which imposes an increasing levy with the number of flights each traveller takes, has not been analysed in detail. Nevertheless, it is increasingly seen as a viable alternative tool to mitigate emissions from air travel due to aviation kerosene combustion (Devlin and Bernick, 2015; Murray, 2015; Carmichael, 2019; Chapman et al., 2021).[4]

Given the link between income and air travel - with recent studies finding that high-income travellers fly disproportionately more than lower-income travellers (O'Garra and Fouquet, 2022; Cass et al., 2022; Gössling and Humpe, 2020; Banister, 2019; Otto et al., 2019) - a FFL is likely to be more progressive than a carbon tax. A first aim of the paper is to confirm this expectation.

The second (and main) aim of this paper is to compare the distributional impact and effectiveness trade-offs of the two policies. Here, the total emissions reductions differ for each policy – policies with higher welfare costs may have higher emissions reductions, making a direct comparison meaningless. To ensure comparability, effectiveness is measured as the total emissions reduced divided by the total welfare costs of abatement to the consumer. Thus, the 'effectiveness' measure in this paper indicates the kg of emissions reduced per £ of consumer welfare lost.

To compare the distributional impact of these two pricing policies, we estimate the consumer welfare loss at different income quintiles in the UK. Our approach produces estimates that account for both changes in expenditure as well as consumption adjustments in response to policy-induced price changes. Although more complex to estimate than the budget share,[5] which is the metric used in many carbon policy incidence studies (e.g., Andersson and Atkinson, 2020; Grainger and Kolstad, 2010; Metcalf, 1999; Poterba, 1991), it is important to include demand responses for policies that might potentially lead to large price changes. Many environmental policies imply such large price (and consumption) changes; for example, UK ministers were considering a carbon tax on air passenger travel that could increase the cost of travel by a substantial 6% (Paton, 2019). Thus, to estimate consumer welfare losses from large carbon taxes, it is necessary to identify the shape of the demand curve in order to understand how consumer responses (i.e., price elasticities) change as consumption is reduced.

Full demand curves are constructed by combining current price elasticity estimates with estimates produced from a temporal benefit transfer approach applied to long run data - a method developed in Fouquet (2018) to estimate the benefits of energy service consumption. Using this method, we estimate the incidence associated with carbon taxes and the FFL for different income groups (quintiles). For comparative purposes, we also calculate incidence in terms of the budget share, which - as noted - does not account for demand responsiveness to price changes.

Results show that both policies can achieve reductions in emissions at low costs. However, the FFL is substantially more progressive than the carbon tax, irrespective of the metric used to measure consumer welfare impacts. The analysis indicates that, as demand grows over time, the FFL remains a more progressive policy. Crucially, it is consistently more effective at reducing emissions[6] relative to welfare losses. Thus, the introduction of a frequent flyer levy rather than a carbon tax for air travel does not force policy-makers to make a difficult trade-off between policy progressivity and effectiveness[7] - although other trade-offs may exist, and will be discussed.

This paper makes several important contributions. Firstly, while the distributional impacts of energy taxation policies have been extensively studied with regards to road transport (e.g., Sterner, 2012; Rausch et al., 2011; Bento et al., 2009; West and Williams, 2004; Chernick and Reschovsky, 1997; Poterba, 1991), to our knowledge, this is the first in-depth analysis of the incidence of environmental policies on air travel. Although passenger air travel currently only accounts for about 2–3% of global carbon emissions (Graver et al., 2019), this is largely generated by the fraction of the world population that flies regularly (Gössling and Humpe, 2020). However, demand has been rising by about 5.9% globally a year since 2010 (ICAO, 2019) with studies estimating that by 2050 aviation will account for about one quarter of all global carbon emissions (Pidcock and Yeo, 2016). Technological improvements and alternative fuels, such as biofuel, have some potential, yet studies show that these improvements will not be enough to reduce emissions in the context of such pronounced growth in demand (Prussi et al., 2019; Pavlenko, 2018; Graver et al., 2019; Kousoulidou and Lonza, 2016).

In the UK, where this study is based, passenger traffic is estimated to nearly double by 2050 (DfT 2018), which implies annual increases of about 38 mtCO$_2$e emissions with current technologies (see estimates in Section 4.3). Some of this increase may well occur as a result of rising incomes; for these consumers, the benefits from air travel are likely to be significant. However, the low costs of air travel also promote travel that delivers minimal marginal benefits – weekend getaways, short-haul flights, and business meetings that could be conducted online. Thus, identifying policies that can reduce low-value air travel among frequent flyers, yet allow for modest growth in high-valued air travel demand will be of great importance as this hard-to-decarbonise industry expands.

Also, this is the first study to explicitly consider the incidence of a

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[2] For a richer discussion of the introduction of a carbon taxation, its incidence and its revenue, see Goulder (1995), Parry et al. (1999), Hassett et al. (2009), Rausch et al. (2011).

[3] The regressivity of carbon taxes is moderated and even reversed in some cases for road transport sector taxation policies (see Ohlendorf et al., 2021). To date, no studies have evaluated welfare impacts of carbon pricing policies for air travel.

[4] In 2019, the Committee on Climate Change (CCC, 2019) urged the UK government to introduce such a policy measure. While the proposal did not provide details on features of the FFL, the basic idea is that the levy would target individual consumption of air travel and would increase with each additional flight taken.

[5] This refers to the proportion of a person or household's budget that would be spent on the carbon tax or FFL assuming that demand is not responsive to price changes (equivalent to assuming a price elasticity of zero).

[6] We acknowledge that aviation is responsible for other pollutants, such as nitrogen oxides (NO$_x$) aerosols, particle emissions and water vapour in the form of contrails. Research suggests that these other non-CO$_2$ emissions may increase the impact of aviation on the climate by a factor of 2–5 (IPCC 1999) via a process known as 'radiative forcing' (Lee et al., 2009). The sensitivity analysis in Appendix D presents a range of values according to varying carbon tax and FFL prices, which reflect variations in 'radiative forcing'.

[7] There is a literature comparing progressivity and economic efficiency. The evidence related to environmental and carbon taxes (Bento et al., 2009; Goulder et al., 2019) and to increasing block-pricing, which are similar to 'excessive consumption' levies (Borenstein, 2012; Borenstein and Davis, 2012), finds a trade-off between progressivity and efficiency. While this literature implicitly relates to environmental impact, here, the focus is on investigating whether more progressive policies impose greater welfare costs relative to the emissions reduced explicitly.

carbon pricing policy targeting excessive consumption.[8] Most studies seeking how to offset the regressive impact of carbon policies focus on ex-post measures, which include revenue recycling, such as lump-sum transfers (e.g., Goulder et al., 2019; Rausch et al., 2011; West and Williams, 2004). Although lump-sum transfers have been implemented successfully in some contexts (PBO, 2019; Carattini et al., 2017), their use is still very rare; furthermore, studies suggest that public acceptability of different revenue recycling mechanisms depends on how clearly their progressive effects are communicated to the public (e.g. Klenert et al., 2018; Carattini et al., 2017). We consider that excessive consumption levies such as the FFL should not be considered substitutes, but rather complements to revenue recycling approaches. Certainly, revenue recycling can be applied equally to carbon taxes and FFL, improving the progressivity of both. Our intention is not to focus on how revenue recycling can enhance the fairness of different policies, but to examine ex ante measures.

Indeed, less research has been conducted on ex ante measures, which aim at avoiding regressive impacts through differential tax rates, exemptions and other design features (see Wang et al. (2016) for a review). To examine the potential for ex ante approaches to improve the progressivity of carbon mitigation policies, we compare a carbon tax with a frequent flyer levy and provide, to our knowledge, the first in-depth analysis of the distributional impact of excessive consumption levies, explicitly focusing on climate mitigation. Since our original analysis (Fouquet and O'Garra, 2020), Chapman et al. (2021) and Cass et al. (2022) have also assessed the impact of FFL on different income groups, however, they make strong assumptions about price elasticities and only focus on the financial expenses incurred rather than the full consumer welfare effects.

The rest of this paper is structured as follows: Section 2 describes the incidence measures used in this study in the context of previous incidence studies; Section 3 summarises the demand curve estimation process and shows the demand curve estimates; Section 4 provides estimates of incidence and carbon emission reductions from carbon taxes and frequent flyer levies; Section 5 comments on how the airline industry might react to the introduction of a frequent flyer levy and a carbon tax, and on the challenges of implementing a frequent flyer levy; Section 6 presents the conclusions, and discusses potential energy policy implications.

2. Measuring the distribution of consumer welfare impacts

Our intention in this study is to compare the distribution of consumer welfare impacts and the effectiveness of two policies designed to curb carbon emissions from air travel. A complete analysis might ideally account for all general equilibrium effects, yet this would require a great deal of information about elasticities of demand and supply (and the structures) of all the markets affected by the policies (Kotlikoff and Summers, 1987; Goulder, 1995; Rausch et al., 2011; Goulder et al., 2019). Our intention here is not to provide a general equilibrium analysis, but to compare policies.[9] Hence, as with most related studies on energy, environmental and carbon taxes (West and Williams, 2004; Grainger and Kolstad, 2010; Sterner, 2012), we assume that the supply of air travel is perfectly elastic, implying that all the additional expense of the tax or levy will be paid by the consumer rather than in part by the supplier[10]. Our analysis thus focuses exclusively on the demand-side of the air travel market. While this might not reflect the actual market structure, we assume that the two policies have the same impact on the supply-side – in Section 5, we discuss this assumption and how the supply-side impact of the two policies might differ.

To estimate the consumer welfare loss, ideally, we would measure the equivalent (or compensating) variation[11] which compensates for income effects resulting from price changes. However, the measurement of equivalent variation is challenging because it depends on knowledge of the Hicksian compensated demand curves, which are difficult to estimate (Just et al., 2004). Often, the solution is to make assumptions about the indirect utility function in order to estimate the Hicksian demand curves and the equivalent variation. Instead, as discussed below, we estimate the shape of the Marshallian demand curve empirically without making any assumptions about the indirect utility function or the shape of the demand curve; our analysis thus focuses on changes in consumer surplus (Just et al., 2004). Willig (1976) shows, that in most applications the Marshallian (uncompensated) demand curve and the associated consumer surplus approximate the Hicksian demand curve and equivalent (or compensating) variation closely. Using a 'rule-of-thumb' proposed by Willig (1976 p.596) to estimate the error from using consumer surplus versus equivalent variation,[12] we calculate that if the changes in consumer surplus in this study are greater than about 2% of income, then the consumer surplus will noticeably under-estimate the equivalent variation. In the only identified study to compare incidence measures using equivalent variation and consumer surplus (applied to gasoline taxes in the U.S.), West and Williams (2004) find negligible differences between these measures, even with large changes in prices.

The first step in the process will be to estimate price elasticities for different income quintiles. In general, due to larger income effects amongst the poor, we expect that lower income quintiles will be more price responsive. This is confirmed by West (2004), West and Williams (2004), Santos and Catchesides (2005) and Tilov and Weber (2020) who uncover larger gasoline price elasticities for low-income households. For air travel, which is considered a luxury good (Gallet and Doucouliagos, 2014; Peng et al., 2013), lower income households may not have formed travel habits that depend on air travel, and be willing to substitute away if prices rise. Greater substitution effects would also imply higher price elasticities amongst lower income quintiles. In their study, Chapman et al. (2021) assume that poorer air travellers are more price-sensitive than affluent flyers.

In almost all demand studies, however, price elasticity estimates are based on behaviour at the margin (i.e., the equilibrium of demand and supply). As the price increases due to a tax or a levy, and consumption falls, the analysis moves away from the margin and up the demand curve. A major limitation of studies of consumer responses is that, in most cases, the shape of the demand curve is not known (as noted in

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[8] There have been a number of studies examining the incidence of non-linear pricing policies applied to electricity consumption (e.g., Borenstein, 2012; Borenstein and Davis, 2012), household water use (e.g., Nauges and Whittington, 2017; Ruijs et al., 2008), and irrigation for agriculture (e.g. Bar-Shira et al., 2006), but none specifically address non-linear carbon pricing mechanisms.

[9] In a meta-analysis of the distributional impacts of carbon pricing policies, Ohlendorf et al. (2021) find no difference between estimates from studies considering general equilibrium effects and those using partial equilibrium analyses.

[10] We expect that air travel among higher income groups is less responsive to price changes, while air travel among lower income groups is more price elastic. Hence, our overall estimates may overestimate regressivity, as low-cost airlines may be less able to pass on additional costs from a carbon tax compared to higher-end airlines – thus reducing the impact on lower-income air travellers.

[11] The equivalent variation provides a welfare estimate of the monetary transfer that would have the same effect on a consumer's utility as the price and income changes due to the tax or levy.

[12] According to this rule-of-thumb, as long as the product of the consumer surplus as a share of income with the income elasticity of demand is less than 5%, the error from using the consumer surplus rather than equivalent variation will be less than 0.5% (Willig, 1976 p.596). Given that air travel is a luxury good, often with elasticities in the range of 1.5–3 (Gallet and Doucouliagos, 2014; Peng et al., 2013), then as noted in the main text, consumer surplus changes in this study would have to be greater than about 2% of income to lead to noticeable differences between estimates.

Cohen et al., 2016). To generate estimates of consumer responsiveness to price changes, assumptions are usually made about the functional form of the demand curve – for instance, West (2004) assumes a linear demand curve, whereas West and Williams (2004) assume a constant price elasticity along the demand curve. However, as the authors acknowledge, these assumptions will introduce error for a large price change if the elasticity changes along the demand curve. As an interesting variation on this approach, Chapman et al. (2021 p.30) assume that for each additional flight taken the price elasticity increases by 0.01. This is a way to incorporate changes in price elasticities along the demand curve; however, it is not based on any empirical evidence about how price elasticities change along the demand curve. Since we are interested in assessing the impact of potentially large price increases, any simplifying assumptions about the price elasticities may introduce substantial error into our estimates of consumer surplus loss. Indeed, we show in Appendix B3 that the assumption of constant price elasticity generates unrealistic demand curves.

To address this problem, we use a method developed in Fouquet (2018), in which empirical evidence about willingness-to-pay values and income elasticities of demand is used to construct full demand curves (described in Section 3). This approach allows us to implicitly generate estimates of consumer responses and welfare losses away from the margin that do not depend on ex ante assumptions about price elasticities. These demand curves are then combined with conventional price elasticities at the margin to create full demand curves and estimate consumer surplus losses from the carbon tax and frequent flyer levy.

Using these consumer surplus measures, we face the question of how to measure incidence. The common approach is to calculate estimated welfare loss as a proportion of income – using either current (annual) income, or lifetime income which is often proxied by current expenditure (Attanasio and Pistaferri, 2016; Poterba, 1989). As our study does not use expenditure data, we report incidence using annual income. Based on findings in previous studies that compare incidence using annual versus lifetime income (e.g., Andersson and Atkinson, 2020; Sterner 2012; Grainger and Kolstad, 2010; Hassett et al., 2009) we expect that our findings may overestimate regressivity.[13] As an additional and novel measure, we also estimate incidence as the ratio of consumer surplus losses from carbon pricing policies against total consumer surplus from air travel. Total consumer welfare is rarely measured because of the challenge of constructing full demand curves – see Hausman (1999), Cohen et al. (2016), Brynjolfsson et al. (2019) for a few exceptions. Since we produce full demand curves for each income quintile, we are able to estimate the total consumer surplus from air travel for each quintile. This allows us to assess the relative loss in consumer surplus of both policies and compare these results with the more conventional measure of losses relative to annual income. Thus, we provide the first analysis of incidence of an environmental pricing policy in terms of the proportional loss in consumer welfare.

Finally, following Sterner (2012), we also use the Suits (1977) index to assess the overall degree of progressivity of the tax and levy. This index is similar to the Gini coefficient by offering a simple geometric summation across the whole income distribution. Thus, this index offers a formal comparison of the tax incidence of the air travel carbon tax and the FFL.

As a comparison, Chapman et al. (2021) (i) make more assumptions about the price elasticities of demand (both across income quintiles and along the demand curve), (ii) only estimate the additional expenses incurred, rather than any direct consumer welfare losses from changes in travel behaviour, and (iii) do not use a formal metric for assessing the progressivity of the policy. Meanwhile, Cass et al. (2022) do not provide any information about their price elasticity assumptions, and only assesses the financial burden of a FFL.

3. The demand for air travel by income quintile

This section summarises the analysis undertaken to, first, estimate price elasticities of demand in order to indicate behavioural responses to policies (at the margin) and, second, construct full demand curves for air travel in order both to reveal additional price elasticities (away from the margin) and estimate the losses in consumer surplus from policies. This analysis also generates the total consumer surplus from air travel by income quintile, which will highlight the inequality of consumption. This approach forms the foundation for comparing relative losses associated with the introduction of a carbon pricing policy.

The demand for passenger air transport services reflects individuals' willingness to pay (WTP) for travelling from one location to another. Travel behaviour depends on a number of factors, which can be split into geographical-economic factors (e.g., income, exchange rates, trade and tourism) and service-related factors - e.g., prices, route availability and frequency and access to airports (Jorge-Calderón, 1997; Button and Taylor, 2000). At its most simple, air travel behaviour responds to changes in income and real prices, which constrains individuals' WTP and consumption (Brons et al., 2002; Peng et al., 2013). Fig. 1 shows how UK air travel by income quintile has increased over the last hundred years.

Our first econometric model of air travel demand estimates *price elasticities* by income quintile using recent monthly data (1998M1-2019M12). Estimates are produced using crude oil prices as an instrumental variable, to avoid biased estimates due to endogeneity (caused by air travel demand influencing air travel prices). Due to space limitations, the formal model, associated data, and instrumental variable analysis are presented in Appendix A1-A2.

This model estimates price elasticities indicating how air travelers would respond to the introduction of a carbon tax or a FFL (see Table 1). In general, they indicate greater price sensitivity than older econometric studies. In meta-analyses, Brons et al. (2002) and Peng et al. (2013) conclude that price elasticities for air travel demand averaged −1.1 and −1.3 respectively – interestingly, these are very similar to the implied price elasticities we estimate away from the margin (see Fig. 2). Furthermore, Granados et al. (2012) find that price elasticities of air travel demand associated with online purchases are significantly higher than for elasticities when tickets were bought off-line. The meta-analyses (Brons et al., 2002; Peng et al., 2013) are based on older and predominantly off-line demand, whereas our results are based mostly on recent online purchases, implying the price elasticities (at the margin) in our study are expected to be higher than the averages in the meta-analyses. Finally, there is no comparative econometric evidence on the difference in air travel price elasticities across the income distribution. Nevertheless, West (2004), West and Williams (2004), Santos and

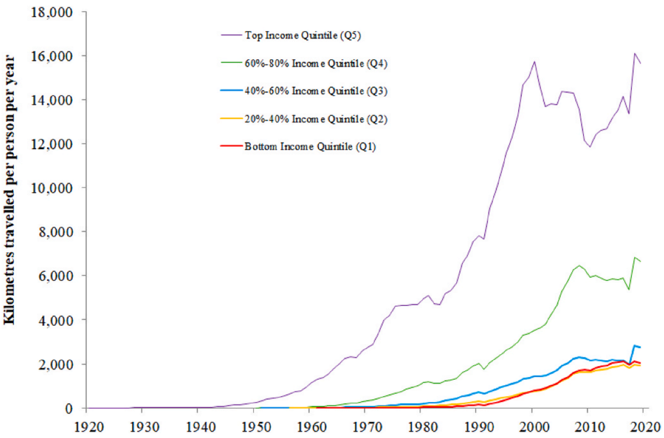

Fig. 1. Annual air transport consumption in the UK by income quintile, 1920–2019.

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[13] Rausch et al. (2011) however find no difference in the distributional impacts of carbon taxes whether measured against annual or lifetime income.

Table 1
Price elasticities of demand for air travel (at the margin).

	Q1	Q2	Q3	Q4	Q5
Price elasticities	−8.0*** (2.15)	−4.9*** (1.55)	−4.0*** (1.47)	−4.7*** (1.55)	−2.6 (1.75)

Source: see Appendix A1-A3 for the model, the data and fuller details on the estimates including the income elasticities. Notes: dummy variables for the months of June to October were included; for all dummies, except in the Q5 model, their coefficients had p-values <0.01. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Robust standard errors in parentheses.

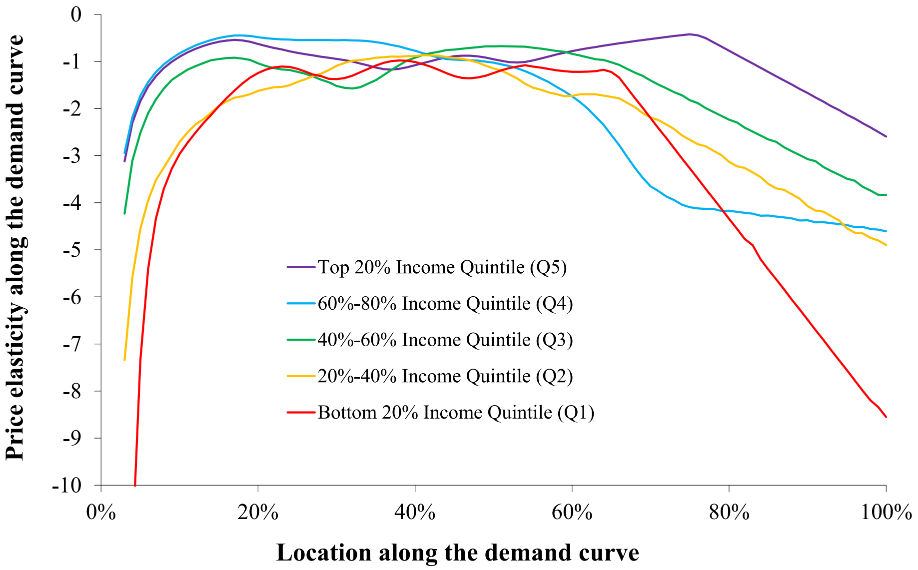

Fig. 2. Price elasticities along the 2019 demand curve for air travel in the UK by income quintile (see Fig. 3).

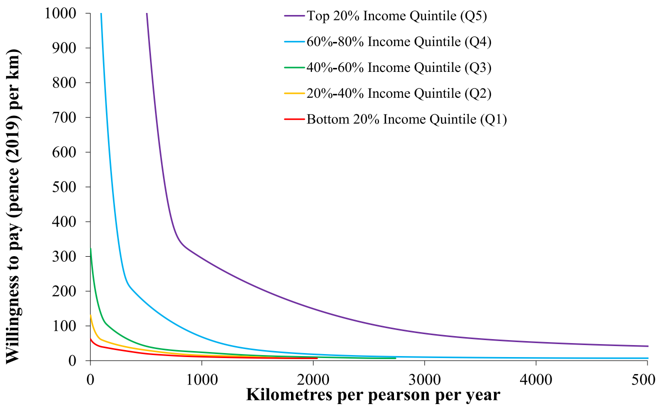

Fig. 3. Demand for air transport in the UK by income quintile in 2019.

Catchesides (2005) and Tilov and Weber (2020) find that low-income car drivers have higher price elasticities than richer drivers, and Chapman et al. (2021) assume higher price elasticities for lower income flyers – all consistent with our results.

However, as discussed in section 2, the price elasticity estimated econometrically only refers to demand at the margin. For large price increases, consumption moves away from the margin and up the demand curve. Rather than assume a constant price elasticity of demand, an additional approach is needed to estimate the price elasticities away from the margin.

This 'exo-margin' approach involves constructing full demand curves which implicitly indicate the *price elasticity* of demand along the entire demand curve. Following the method developed in Fouquet (2018), entire demand curves for each income quintile are constructed using a temporal 'benefit transfer' method. Using the equilibrium price as a measure of WTP for the marginal level of consumption, the benefits transfer approach transfers this WTP value across time.[14] Specifically, a WTP value in one year is multiplied by the change in income and the income elasticity to reveal the WTP for this level of consumption in the next and subsequent years. By observing the equilibrium prices (and, therefore, the WTP values) for different consumption levels in different years and performing benefit transfers for each available year, an entire demand curve (i.e., WTP schedule) in each year for each income quintile can be constructed.

An important assumption made is that preferences change gradually over time and are incorporated in the income elasticities. The evidence from the urban transport literature suggests that, while preferences are stable from one year to the next (Parody, 1977; Silman, 1981; McCarthy, 1982), WTP values (taking account of inflation) do rise over time (Habib et al., 2014). Although preferences are subject to change over decades, they provide significant useful information for planning and analyses (Badoe and Miller, 1995; Gunn, 2001). For air travel, certain factors are likely to influence changes in preferences over decades (e.g., airport development, advertising, social expectations about tourism, etc.). It is assumed that the influence of these factors on the relationship between per capita income and air travel preferences are incorporated in the variations in income elasticity of demand (Jorge-Calderón, 1997, Button and Taylor, 2000; Peng et al., 2013; Gallet and Doucouliagos, 2014). Thus, it is assumed that this model is broadly valid for transferring WTP values over time. For more detail about the method and the assumptions used to generate demand curves, see Appendix B1 and Appendix G.

To provide the coefficients for the benefit transfers, our second econometric model - which builds on the same theoretical foundations

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[14] Traditionally, benefit transfers are used across space, from country to another, taking account of key variables such as income – see Appendix B for more discussion (Johnston and Rosenberger, 2010; Bateman et al., 2011).

as our first model - estimates *income elasticities* using annual time series (the data and estimates are presented in detail in Appendix A1-A3). As explained above, these annual income elasticities (see Table A4 in the Appendix) are used in conjunction with the change in income (see Figure A2 in the Appendix) to determine the change in WTP over time. Thus, the income elasticities reveal how much demand curves shift over time.

Once constructed, the annual demand curves indicate the price-consumption relationships and reveal the implicit price elasticities as consumption falls. Fig. 2 presents price elasticities starting at the margin (i.e., on the right, and equal to 100% of consumption) and moving up the curve. As explained in relation to Table 1, consumers (especially poorer travellers) are very sensitive to prices at the margin. This is expected as the marginal flight may be a 'luxury' to the consumer, who will decide to buy the ticket if the price is low enough or substitute to an alternative way of travelling or holiday if the price is too high. However, for most of the demand curve, Fig. 2 shows that price elasticities are around −1. That is, the price elasticities estimated from demand curves constructed using the benefit transfer method are almost identical to the averages from meta-analyses of air travel price elasticities (Brons et al., 2002; Peng et al., 2013). These price elasticities in Fig. 2 will be used to determine the impact of the carbon tax and FFL on consumption in Section 4.

These price elasticities are also used to re-construct full demand curves to estimate full consumer welfare from air travel. These re-constructed demand curves will combine the price elasticities at the margin (using standard econometric techniques) with the empirically-estimated WTP values away from the margin. Appendix B2-B3 offers support for the validity of these demand curves (based on comparing the consumer expenditures at each point along the demand curve with actual consumer expenditures for air travel) and show that this method is more valid than alternatives such as linear demand curves or constant-elasticity demand curves, which do not pass the validity test. Thus, compared with standard approaches (see West and Williams, 2004 for a discussion), these demand curves offer an improved way to estimate welfare gains and losses.

Fig. 3 presents these demand curves for air travel for each quintile in 2019. The results confirm expectations that the demand curve is highest for the richest income quintile (Q5), descending to the poorest income quintile (Q1). Fig. 3 also shows that, as expected, estimated WTP is highest for the first few kilometres travelled.[15] However, these values vary widely according to the income quintile. For instance, at the 10th km, the WTP of the top income quintile (Q5) is 11,050 pence or £(2019) 110.50, whereas it is only 60 pence for the bottom quintile (Q1). Here, due to a lack of detailed information about prices at different income levels, the WTP for the marginal km is assumed to be the same – 6.7 pence (£2019), which is the average price in 2019. As a result, there are greater differences in the WTP from, say, the 10th km to the 100th km (or the 100th km to the 1,000th km) of the upper quintiles than for the lower quintiles. In other words, as income rises, the demand curves become more convex – and the differences in convexity have crucial implications for the welfare impacts of behavioural changes and carbon taxes or frequent flyer levies, for instance, across the income distribution, as discussed below.

The area below each demand curve and above the price line indicates the consumer surplus in each income quintile for each year. As for 2019, we produce demand curves and calculate the full air transport consumer surplus for each year for each income quintile. As a point of interest, we estimate how the consumer surpluses for air travel have changed over time and across quintiles (see Figure B3 in the Appendix). It took fifty years before the Wright Brothers' 1903 invention started to produce noticeable net benefits to consumers. Prior to the 1970s, only the top income quintile generated substantial consumer surplus from air travel. Then, the second-top income quintile began to reap benefits. Only from the 1990s have other segments of the population gained – almost one century after the Wright Brothers' invention. Looking over more than one century of aviation, while the bottom income quintile gained a summed consumer surplus equal to 51% of its contemporary income, the top income quintile reaped a summed consumer surplus equal to 513% of its contemporary income – thus, the affluent (Q5) have benefitted relatively ten times more from aviation than the poor (Q1). Over the same period, the wealthy (Q5) caused eighteen times more air travel-related climate damage than the bottom income quintile (see Appendix C).

4. Consumer welfare impacts of carbon policies

In this section, we use the price elasticities in Fig. 2 and demand curves in Fig. 3 to explore the impacts of carbon taxes and the frequent flyer levy on consumer welfare by income quintile. Due to the disruptive nature of Covid-19, it is difficult to produce an analysis of the impacts of air travel policies at present. Hence the analysis will use the year 2019 (pre-Covid-19) as indicative of the present period and, then (in sub-section 4.2), look forward to the period between 2030 and 2050. It is expected that the aviation industry will have fully recovered to its long run trajectory by 2030 (Pearce, 2020) with no long-term impacts on preferences or demand for air travel, so this long run perspective offers an understanding of how growing demand affects incidence. Finally, we complete this section with an analysis of the environmental effectiveness of the two main policies examined over time. This helps provide a complete picture on the impacts of carbon pricing policies on air travel-related welfare and emissions over time.

4.1. *The incidence of a carbon tax and a frequent flyer levy*

The central aim of this sub-section *is to assess the distribution of welfare impacts (i.e., incidence) of carbon taxes and FFL,* with the goal of identifying which policy will have the greatest potential to reduce carbon dioxide emissions with minimal impacts on welfare. Focusing first on a carbon tax,[16] there are many possible values suggested in the literature for an aviation carbon tax. Based on recommendations by Burke et al. (2019), which provides a review of the literature on the social costs of carbon and possible carbon taxes for the airline industry, the carbon tax considered in this paper is imposed directly on the consumers and is set at £50 per tonne of carbon dioxide. On current technology, this is equivalent to a rise of 0.3 pence (4.4%) per passenger-km travelled.

With regards to the FFL, a challenge is in selecting a specific levy comparable to the carbon tax – and as Ito (2014) shows there is an infinite number of potential pricing schedules. To offer comparability, the carbon tax needs be used as the reference, but the tax is 'pivoted' to reflect a rising levy with each extra flight to address 'excessive travel'. To be specific, the selection criterion is to set the FFL equivalent to the carbon tax at the median number of flights. Only 51% of the population fly in any year and 59% of air travellers take less than three flights per year in the UK (CAA, 2019). With this in mind, the levy is set equivalent

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[15] It is important to stress this is an average of millions of consumers. In reality, individual consumers value travel to a certain destination and, therefore, would place equal waiting on each kilometre associated with a first flight equally, and then presumably place equal waiting on each kilometre associated with the second flight equally, and so on. For instance, 2,300 km is equivalent to a return flight from London Gatwick Airport to Alicante in Spain. Thus, this analysis is based on the average consumer for each income quintile.

[16] While demand-reducing measures, such as a carbon tax, could be implemented in conjunction with offsetting policies such as CORSIA (Scheelhaase et al., 2018; Graver et al. 2019), we consider alternative measures in isolation in order to avoid the uncertainty and complexity of analysing two overlapping and interacting systems, and disaggregation of the respective impacts of each policy measure.

to the carbon tax for the second flight. In other words, it is assumed that the first flight would be exempt from the levy, the second flight would be at the rate of the proposed carbon tax[17] (i.e., £50 per tonne of carbon, which is currently equivalent to 0.3 pence per km), the third flight would be double the proposed carbon tax, the fourth flight triple the carbon tax and so on, with linear increments in cost with each additional flight[18] – Cass et al. (2022) adopt our FFL schedule as presented in Fouquet and O'Garra (2020). Chapman et al. (2021) propose that the first leisure flight is charged £0, the second flight £25, and the increment increase rises by £10 thereafter (£35, £45, £55) for each additional flight; for business travel, there is no 'free ride' and the levy schedule shifts forward one flight (£25 on the first flight). In Appendix D, a sensitivity analysis modifies the level of the tax and levy, and modifies the 'sliding fee schedule' for flights. Although the two policies are not directly comparable in terms of average price burdens or emissions reductions,[19] their ratios of emission-reduction-to-consumer-welfare-loss can be directly compared in section 4.3 to assess their effectiveness.

Fig. 4 compares the incidence of a carbon tax and a FFL. Results in panel A of Fig. 4 show that the carbon tax has a degree of progressivity, since consumer surplus losses relative to income are greater for the affluent (Q4 and Q5) than for quintiles Q2 and Q3, whilst the relative loss is greatest for the bottom quintile (Q1). Progressivity is generally expected in cases when the good or service is consumed predominantly by the richer quintiles (West and Williams, 2004; Grainger and Kolstad, 2010; Sterner, 2012) – such as air travel. However, the use of total air travel consumer surplus as the denominator suggests that the poor will suffer relatively more from a carbon tax – the bottom quintile (Q1) would lose 3.7% of their air travel consumer surplus, compared to losses of only 0.3% for the top quintile (Q5) (Panel B of Fig. 4). The Suits (1977) 'Progressivity' Index (reported in the right-most column of Table 2) confirms these results: the value for the carbon tax is −0.26 (negative values indicate regressivity) using consumer surplus as the denominator, while the index has a value of 0.05 (indicating progressivity) using annual income as the denominator. As seen in Fig. 4, the progressivity of the carbon tax depends on the denominator used. This suggests that studies using annual income as the denominator could be skewing results towards progressivity[20].

The FFL on the other hand appears progressive independent of denominator used, as affluent quintiles are discouraged from flying excessive distances while paying proportionally more for the additional flights. The poorer quintiles' do not suffer from the levy because their average travel is below the 2,500 km limit (see Section 4.3 for analysis of future scenarios in which they do travel more than this amount). The burden on the second highest quintile (Q4) is halved, while the loss for the most affluent quintile (Q5) is doubled compared with the carbon tax (see the second panel of Table 2). This suggests that the FFL is more progressive than the carbon tax. The Suits (1977) Index indicates a value of 0.43 (i.e., very progressive) for a FFL using annual income and 0.12 (i.e., progressive) using total consumer surplus as the denominator.[21] *Thus, all the evidence indicates that the FFL is more progressive than the carbon tax.*[22]

As a comparison, Table 2 (bottom two panels) also presents the breakdown of consumer welfare impacts without a demand response. Results indicate that all consumer welfare losses are higher when behavioural responses are not accounted for. This reflects the fact that the behavioural response acts as a way of optimising consumer behaviour as prices change (i.e., consumers reduce consumption if the WTP values are lower than the new price). The over-estimate of the consumer welfare loss from ignoring the demand response (i.e., assuming a price elasticity of zero) is on average 7.6% (i.e., the difference between the financial loss (£) of the first and third panel in Table 2). However, it is 5.2% for the top income quintile Q5 and 15.5% for Q1, because poorer travellers have a larger price elasticity (i.e., a greater demand response). For the FFL, the average over-estimate is 43.7%, since consumers undertake large reductions (see Section 4.3) – as FFL only affects Q4 and Q5, there is no clear distributional impact. In sum, failure to include a demand response can greatly over-estimate the welfare losses and disproportionately over-estimate the poor's losses.

4.2. *Consumer welfare impacts over time*

In this section, we investigate the impacts of carbon taxes and frequent flyer levies as demand increases over time. To do this, demand curves need to be constructed for each year of interest and each quintile. This uses the same approach as laid out in Section 3 and applied above for the year 2019. The main differences are (i) a BAU scenario of air travel for each quintile is produced; which is based on (ii) modestly lower income and price elasticities than in 2019, as they are adjusted to account for long-run trends in these parameters, as reflected in Table A4 in the Appendix (see also Appendix E for details); and on (iii) the growth in per capita income over time. This BAU scenario uses OECD's (2019) long run projection of UK GDP up to 2060 and ONS's (2019) projection of UK population to 2100 to estimate per capita GDP growth (discussed in more detail in Appendix E). By assuming no changes to the income inequality between 2018 and 2050, estimates of average income by quintile are produced.

Despite many uncertainties about the future of the air travel industry, Pearce (2020), as chief economist for IATA, suggests that air travel will take two to three years for demand to return to 'normality'. His forecasts create the link between the recovery of air travel with the long run trend in air travel presented (shown in Figure E2 in the Appendix), and which assumes air travel returns to the long run trend by 2030. By combining them with income elasticities of demand for air travel, and constant real prices, the BAU scenario anticipates an average rise in passenger-kms travelled of 46% by 2030, and 114% by 2050, compared with 2019. With real air travel prices assumed to remain

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[17] As with the carbon tax, the assumption is that the levy is imposed on the consumer.

[18] Here, because the demand curves are constructed based on the kilometres travelled by the average consumer, it is assumed that each (return) flight is equivalent to 2,500 km to a return flight (e.g., roughly London to Alicante in Spain, and back) – in fact, since emissions are related to distance travelled, a levy might be best placed on kms travelled rather than flights. Thus, the frequent flyer levy becomes increasingly expensive with each individual's additional flight (or, here, distance travelled) and, therefore, discourages excessive and 'unnecessary' travel, where 'unnecessary' travel is personal and refers to travel which generates relatively little welfare to the individual - each person faced with a rising cost of an extra flight can assess which flights are unnecessary. As with the carbon tax, the assumption is that the levy is imposed on the consumer.

[19] Although beyond the scope of this first economic analysis of FFL, future research could seek to identify the optimal carbon tax and FFL, and then compare the two.

[20] As explained in section 2, consumer expenditure is often used as the denominator. Given that consumer expenditure tends to be higher (lower) for the bottom (top) quintile than annual income, an estimate of progressivity using the consumer expenditure would indicate greater progressivity than using the annual income as the denominator.

[21] Given the discussion at the end of section 3 on the sum of total consumer surplus values over time, one could explore using this sum as the denominator to offer an indication of the historical regressivity of a policy.

[22] To test the stability of this result, Appendix D provides detailed sensitivity analyses, altering the price and the price elasticities. The first sensitivity analysis estimates the impact of raising the social cost of carbon dioxide between £20 and £200 per tonne. The second analysis examines the impact of assuming unit and constant price elasticity along the demand curve. The evidence from all tests shows that changing price and price elasticity assumptions do not alter the main results (i.e., the comparison across the income distribution or between the two policies).

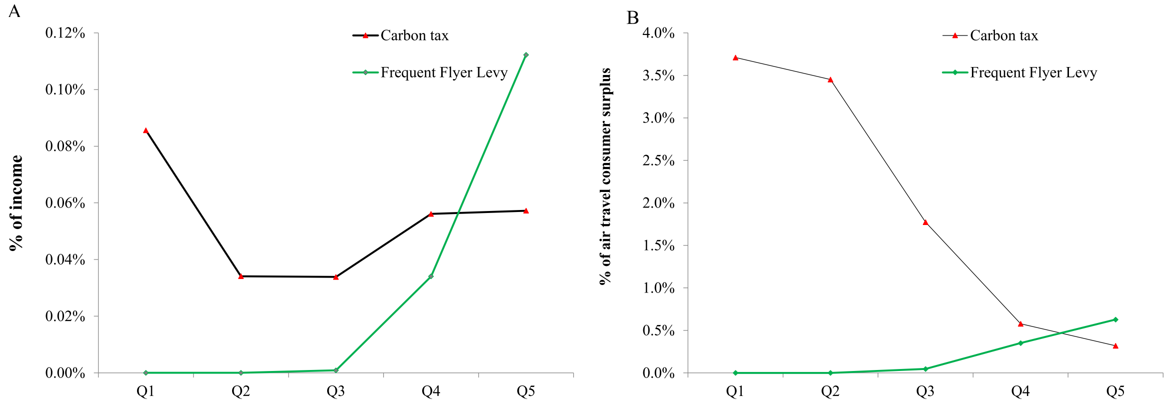

Fig. 4. The Distributional Impact of a Carbon tax and Frequent Flyer Levy on Consumer Welfare Losses relative to (A) Annual Income and (B) Total Air Travel Consumer Welfare.

Table 2

Consumer welfare impacts, Effectiveness and Progressivity of a Carbon Tax and a Frequent Flyer Levy, Pre-Covid-19 (with the Price of Carbon of £50 per tonne).

	Q1	Q2	Q3	Q4	Q5	Average	Progressivity Index
Carbon tax (ΔP_{ATt} = 4.4%) with Demand Response							
CS Loss (£)	5.32	5.26	7.66	18.23	44.87	**16.27**	
% CS Loss rel. CS Air Travel	3.7%	3.5%	1.8%	0.6%	0.3%	**0.5%**	**−0.26**
% CS Loss rel. Income	0.09%	0.03%	0.03%	0.06%	0.06%	**0.05%**	**0.05**
Frequent Flyer Levy (ΔP_{ATt} = 4.4%) with Demand Response							
CS Loss (£)	0.00	0.00	0.20	11.06	88.03	**19.86**	
% CS Loss rel. CS Air Travel	0.0%	0.0%	0.0%	0.4%	0.6%	**0.6%**	**0.12**
% CS Loss rel. Income	0.00%	0.00%	0.00%	0.03%	0.11%	**0.06%**	**0.43**
Carbon Tax (ΔP_{ATt} = 4.4%) without Demand Response							
CS Loss (£)	6.14	5.79	8.27	20.09	47.21	**17.50**	
% CS Loss rel. Income	0.10%	0.04%	0.04%	0.06%	0.06%	**0.06%**	**0.04**
Frequent Flyer Levy (ΔP_{ATt} = 4.4%) without Demand Response							
CS Loss (£)	0	0	0.72	17.54	124.84	**12.37**	
% CS Loss rel. Income	0.00%	0.00%	0.00%	0.05%	0.16%	**0.04%**	**0.40**

Sources: authors' own calculations - see text. As a reminder: (i) the Carbon Tax (column 1) is set at £50 per tonne of carbon dioxide; (ii) the Frequent Flyer Levy is £0 for the first flight (i.e., 2,500 km); £50 per tonne for the second flight (2,501km-5,000 km), £100 for the third flight (5,001km-7,500 km), etc.. in any year; (*) The increase of 4.4% on the frequent flyer levy reflects the increase in air travel for the second 'flight' (i.e., 2,501km-5,000 km); the third flight implies an increase of 8.8%, etc …; (iii) to ensure a comparable analysis, both taxes and levies are imposed directly on the consumer; (iv) as discussed in Appendix B5, the consumer welfare values risk being mis-estimated by less 0.1% - based on Willig's (1976) table of the deviation of consumer surplus from compensating and equivalent variation.

constant, BAU consumer surplus values can be calculated (see Appendix B and G)). The BAU values are compared with the consumer surplus values after the introduction of the carbon tax or levy as presented in Section 4.1. The difference between the two welfare gains indicates the losses from introducing the policy.

Results are shown in Table 3. They indicate that, as demand increases over time, the FFL remains a more progressive policy – as shown by the Suits (1977) Index values. Again, the degree of progressivity of both the tax and the levy depends on the denominator used. For most quintiles the values are similar between 2019 (see Table 3), 2030 and 2050. The main difference is that, especially in 2050, the lower quintiles (Q1-Q2) are affected by the FFL, because their demands grow in the BAU scenario to the degree that consumption is above 2,500 km. Both policies become less progressive over time, reflecting the growing demand for air travel amongst the lower income quintiles. Thus, it is important to be aware of the erosion in progressivity – as discussed in Andersson and Atkinson (2020).

4.3. *Emissions and policy effectiveness*

In addition to examining the distributional impact of the two policies, it is important to also assess the emissions reductions associated with the two policies. While there is uncertainty about substitution behaviour, O'Garra and Fouquet (2022) provide evidence on the scale of substitution when air travel is reduced, finding that emissions reductions are likely to be 50%–79% of the maximum potential reduction (i.e., the emissions reduction if all travel reductions resulted in elimination of travel altogether, and no substitutes used). However, they do not find any significant variation across income quintiles in the substitution behaviour away from air travel, and so we do not anticipate that this would alter the comparisons across income levels or between policies. Using the midpoint estimate as reported in O'Garra and Fouquet (2022), we assume that air travel reductions from the carbon tax and FFL lead to 64.5% of total possible emissions reductions.

To calculate emissions reductions, we first make assumptions about emissions under business-as-usual (BAU) scenarios. To do this, we use the BAU scenario outlined above and assume a constant emissions-to-passenger-km coefficient at the 2019 level. We estimate hence that emissions from passenger air travel in the UK would be around 55 million tonnes of carbon dioxide by 2030 and 88 million tonnes by 2050 (see Appendix E for further details on the process). As way of comparison, these would be equivalent to respectively 15% and 25% of total emissions for the UK in 2019 (BEIS, 2020). Thus, given the anticipated shrinkage of emissions from the power sector (Tsao et al., 2018), and possibly car travel with a shift to electric vehicles over the next thirty years (Morgan, 2020), air travel unchecked could become the single most important source of carbon dioxide emissions in the UK by 2050.

On average, we estimate that emissions in 2019 would have declined

Table 3
Incidence of a carbon tax and a frequent flyer Levy, 2030 and 2050.

	Q1	Q2	Q3	Q4	Q5	Average	Progressivity Index
Carbon tax ($\Delta P_{ATt} = 4.4\%$) 2030							
% CS Loss rel. CS Air Travel	5.19%	3.37%	1.88%	0.90%	0.39%	**0.59%**	**−0.29**
% CS Loss rel. Income	0.12%	0.06%	0.06%	0.08%	0.08%	**0.08%**	**0.03**
Frequent Flyer Levy ($\Delta P_{ATt} = 4.4\%$) 2030							
% CS Loss rel. CS Air Travel	0.11%	0.39%	0.77%	1.39%	1.05%	**1.08%**	**0.05**
% CS Loss rel. Income	0.00%	0.01%	0.02%	0.13%	0.22%	**0.14%**	**0.36**
Carbon tax ($\Delta P_{ATt} = 4.4\%$) 2050							
% CS Loss rel. CS Air Travel	5.14%	3.04%	1.80%	0.66%	0.32%	**0.50%**	**−0.33**
% CS Loss rel. Income	0.20%	0.10%	0.09%	0.13%	0.11%	**0.11%**	**−0.02**
Frequent Flyer Levy ($\Delta P_{ATt} = 4.4\%$) 2050							
% CS Loss rel. CS Air Travel	2.07%	1.52%	1.48%	1.06%	1.27%	**1.25%**	**−0.01**
% CS Loss rel. Income	0.08%	0.05%	0.08%	0.20%	0.44%	**0.28%**	**0.31**

Sources: authors' own calculations - see text. As a reminder: (i) the Carbon Tax (column 1) is set at £50 per tonne of carbon dioxide; (ii) the Frequent Flyer Levy is £0 for the first flight (i.e., 2,500 km); £50 per tonne for the second flight (2,501km-5,000 km), £100 for the third flight (5,001km-7,500 km), etc.. in any year; (*) The increase in the price due to the frequent flyer levy reflects the increase in air travel prices for the second 'flight' (i.e., 2,501km-5,000 km); the third flight doubles the price increase, while the fourth one triples the price increase, etc …; (iii) to ensure a comparable analysis, both taxes and levies are imposed directly on the consumer.

by 8.5% in response to the carbon tax, while those resulting from the FFL would have fallen by an average 11.6% (see the first panel of Table 4).

Table 4
Emissions reductions, effectiveness and progressivity of a carbon tax and a frequent flyer levy (2019–2050).

	Q1	Q2	Q3	Q4	Q5	Average
Carbon tax ($\Delta P_{ATt} = 4.4\%$) 2019						
% CO2 Emissions Reduction	14.9%	11.0%	9.0%	11.6%	6.0%	**8.5%**
Effectiveness	4.7	3.3	2.7	3.5	1.7	**2.5**
Progressivity*						**−0.26**
Frequent Flyer Levy ($\Delta P_{ATt} = 4.4\%$) 2019						
% CO2 Emissions Reduction	0.0%	0.0%	5.7%	16.1%	13.7%	**11.6%**
Effectiveness			64.3	8.0	2.0	**2.8**
Progressivity*						**0.12**
Carbon tax ($\Delta P_{ATt} = 4.4\%$) 2030						
% CO2 Emissions Reduction	16.2%	9.8%	8.4%	9.4%	4.7%	**7.4%**
Effectiveness	3.8	1.8	1.5	1.9	1.0	**1.5**
Progressivity*						**−0.29**
Frequent Flyer Levy ($\Delta P_{ATt} = 4.4\%$) 2030						
% CO2 Emissions Reduction	6.9%	11.7%	8.2%	31.9%	19.2%	**19.6%**
Effectiveness	76.2	18.9	3.5	4.1	1.5	**2.1**
Progressivity*						**0.05**
Carbon tax ($\Delta P_{ATt} = 4.4\%$) 2050						
% CO2 Emissions Reduction	15.4%	9.2%	8.6%	8.3%	2.5%	**6.2%**
Effectiveness	2.1	1.0	0.9	1.1	0.4	**0.8**
Progressivity*						**−0.33**
Frequent Flyer Levy ($\Delta P_{ATt} = 4.4\%$) 2050						
% CO2 Emissions Reduction	15.1%	9.0%	14.6%	20.8%	15.7%	**16.1%**
Effectiveness	5.0	1.9	1.9	1.7	0.6	**0.9**
Progressivity*						**−0.01**

Sources: authors' own calculations - see text. The reductions in emissions (kg) and welfare (£) in any particular year (e.g., 2030) are compared with a BAU scenario in the particular year (i.e., 2030) – see text and Appendix E-F for details. (*) Here, the progressivity index presented here is based on the % consumer surplus from introducing the policy relative to the total consumer surplus for air travel presented in Tables 2 and 3

An important difference between the two policies is in how those reductions are distributed across the income quintiles. In the case of the carbon tax, we estimate that the lowest quintile (Q1) reduces emissions by 14.9% (equivalent to 25.1kgCO$_2$e) in response to the 4.4% increase in air travel prices, because of the high price elasticity at the margin (see Fig. 2 in Section 3). The top quintile (Q5) however reduces emissions by 6.0% (equivalent to 78.2kgCO$_2$e). In comparison, a FFL leaves emissions unchanged for the bottom quintile, while the top quintile reduces emissions by 13.7% (equivalent to 177.3kgCO$_2$e). Hence, the FFL reduces emissions of the major emitters, rather than those of the most responsive emitters.

As a comparison, Chapman et al. (2021) estimates that, by 2050, a FFL would leave the lowest income quintile air travel practically unchanged (compared with the current policy) and reduces the top income quintile air travel by almost 30%. It finds that the lowest income quintiles' expenses would increase by just under £6 per flight and the top income quintile's expenses would rise by £44 per flight. Thus, although it does not assess the effectiveness of the policy or use a formal metric for determining the distributional impacts (see Section 2), its results confirm our findings that the FFL is a progressive policy and that it would reduce inequality of consumption and pollution responsibility. Cass et al. (2022) do not report the impact on distance.

5. Supply-side and policy considerations

This section briefly comments on important issues related to the impact of a frequent flyer levy on the airline industry and on its implementation as a policy, which may offer additional interpretation of the results. In Section 2, simplifying assumptions were made about the supply-side of the market to ensure the analysis was tractable. These included assuming that the supply of air travel is perfectly elastic and that a carbon tax and a FFL would impact the supply-side in the same way. We will now comment on how the supply-side impacts may differ according to the policy.

The evidence presented in Section 4.3 indicates that a FFL would reduce average distance travelled per passenger compared with a carbon tax. Whether these reductions are associated with changes in passenger load per plane, flight frequency, or the termination of certain routes, is not considered in this study. However, if the greater travel reductions associated with the FFL were to occur as a result of reduced frequency and routes,[23] then there would be welfare impacts due to the loss of

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[23] As a comparison, Frontier Economics (2019) argue that the impact of the Air Passenger Duty (APD) in the UK, which is a flat fee differentiated by distance bands and by economy and non-economy tickets, was to reduce the frequency of certain flights and possibly to halt certain marginal routes.

choice. On the other hand, airlines, passengers and the environment may benefit from the reduced congestion that would result from such changes; prior to Covid-19, airport congestion had been a major problem, with delays generating increased emissions whilst incurring substantial financial costs for airlines (Dixit et al., 2021). A FFL might even help avoid (controversial) infrastructural investments, such as new runways and terminal expansions, designed to deal with this congestion.

A FFL is also likely to impact more affluent, non-economy travellers proportionally more than a carbon tax. As a consequence, a FFL is likely to reduce airline total profits (see Appendix H for details). The first supply-side reaction might involve airlines pressuring government to avoid a FFL.[24] A second industry reaction might be to protect loyal business class and premium customers with enhanced frequent flyer programmes. In response, government should carefully assess the incentives these programmes create and determine whether introducing restrictions on air mile loyalty schemes would moderate excessive flying behaviour (Carmichael, 2019).

Thinking about the longer-term impacts, a basic FFL (i.e., a levy not linked to emissions) does not provide incentives for dynamic improvements in fuel efficiency or reductions in the carbon content of flights compared with a carbon tax. Although a (distance-related) FFL would create an incentive for airlines to take the shortest route, the shortest route may not necessarily be the one that minimizes fuel – due to wind speeds and directions (Baumeister et al., 2017). One option might be for the FFL to be designed so as to combine the number of flights taken, or kilometres flown, with the passenger carbon emissions per flight or distance flown (i.e., reflecting the flight's fuel efficiency and carbon emissions, and the passenger's class or surface area used). This could be especially effective because air travellers – particularly frequent flyers – would likely put pressure on airlines to be more efficient and find low carbon solutions (see Appendix H for more details).

Turning to broader policy issues, the present study has not yet commented on the implementation requirements of a FFL, which may be more burdensome than those associated with a carbon tax and would require consideration of technical feasibility and legal constraints, as noted in Devlin and Bernick (2015), Murray (2015), Carmichael (2019) and Chapman et al. (2021). For example, a key requirement for FFL administration would be a central database storing data on flights taken and number of kilometres flown per year (or other accounting period) associated with individuals' passport numbers. This could be linked up to airline purchasing websites; passengers would need to submit their passport numbers to airline companies before making a ticket purchase, so that this information could be used to identify the specific tax that the passenger would pay (Murray, 2015).[25] Despite concerns about privacy, costs and the technical feasibility of setting up and maintaining such a database, these are considered surmountable[26] (Carmichael, 2019), especially if the system is modelled closely on the existing Air Passenger Duty (APD) system in the UK, as suggested by Murray (2015). For instance, APD exemptions (e.g., associated with age) already require information to be input prior to buying the ticket. As with the APD, the HMRC could be tasked with managing the database and administering the FFL. This would take advantage of the current infrastructure for collecting tax revenues and would require relatively limited administrational and organisational changes (Murray, 2015).

While there is great uncertainty about the scale of these administrative costs, it is possible to assess how large they would need to be before the costs of a FFL outweigh the benefits. From a budgetary perspective, government would receive £1.58 billion in revenue from a carbon tax at £50 per tonne and £1.89 billion in revenue from the FFL outlined in section 4.1, which also centres on £50 per tonne of carbon – for the traveller's second flight (see Table 2). Hence, the revenue gains to the government from this specific FFL compared with the carbon tax would be equivalent to £0.31 billion. From a consumer welfare perspective, the (distributionally-adjusted) welfare gains of the FFL relative to a carbon tax would be equivalent to £0.71 billion (see Appendix H for details). To put this in context, the administrative costs for all transport related activities of the UK government in 2015–6 were £0.27 billion (Institute of Government, 2022). Thus, these budgetary and welfare gains of the FFL relative to the carbon tax are almost certainly greater than the administrative costs of implementation. Future research examining the barriers and opportunities associated with implementation are warranted, with estimates of costs associated with different options.

Another issue to consider relates to the harmonisation of FFLs domestically and regionally. This will be necessary to create a common ground for airlines operating within and between different countries. However, the need for harmonisation pertains equally to carbon pricing and taxation systems, and has been debated for decades (e.g., Poterba, 1991; Hoel, 1993; Metcalf and Weisbach, 2009). Indeed, the introduction of harmonised carbon prices across jurisdictions in the UK remains a work in progress (Serin and Burke, 2019; Burke et al., 2019). Certainly, carbon pricing has the advantage over a FFL as it could facilitate international negotiations by setting a single focal point, rather than a multitude of (partly comparable) quantity pledges (Weitzman, 2014).

Ultimately, though, we concur with Stiglitz (2021 p.610) that we need to move beyond the reliance on a single carbon price and instead consider a 'more nuanced policy where carbon prices were supplemented by regulations and other government interventions and might vary across time, location, and uses'. Along these lines, our study proposes the use of levies that increase with intensity of consumption. Such interventions provide a strong price signal that excessive consumption is not socially desirable, and this signalling effect is critical in the context of hard-to-decarbonise sectors with huge inequalities of consumption such as air travel (Carmichael, 2019). Despite the challenges in implementing more nuanced policies such as the FFL, we propose that this policy may eventually become an example for other areas of environmental policy.

6. Conclusion and policy implications

This paper examined whether there is a trade-off between progressivity and effectiveness associated with the introduction of flat-rate pricing environmental policies compared to policies imposing excessive consumption levies. To do this, the paper compared the distribution of consumer welfare impacts and cost-effectiveness of an air travel carbon tax and a frequent flyer levy to mitigate carbon dioxide emissions.

An important background to this analysis is that the wealthy have dominated and continue to heavily dominate the use of air travel – see Fig. 1 (and Banister, 2019, Gössling and Humpe, 2020; O'Garra and Fouquet, 2022). Since the birth of the aviation industry, the affluent (i.e., the top income quintile) have benefitted relatively ten times more and were responsible for eighteen times more climate damage from air travel compared to the poor (i.e., the bottom income quintile). While air travel has mostly benefitted the rich until now, the demand for air travel is steadily increasing as income levels rise. The implication is that

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[24] The airline industry has been lobbying the British government to abolish the APD (Frontier Economics, 2019).

[25] If data privacy is an issue, one solution (suggested to us by Yari Baars) is that, instead of a FFL, a high flat levy is imposed on all flights and then a full refund on the levy is offered for the first flight (or distance band), a partial discount on the levy is offered on the second flight (or distance band), with increasingly smaller discounts for subsequent flights (or distance bands). Customers that want the refunds and discounts would then need to register with their passport and be on the database. Customers who objected to revealing information about travel plans would be protected, but at the expense of paying the full levy.

[26] As noted by the Association of Accounting Technicians (AAT, 2021) in response to the HM Treasury Consultation on Aviation tax reform in March 2021, many of the supposed problems associated with the introduction of FFL are 'greatly exaggerated'.

carbon emissions – and other aviation-related pollutants – are set to rise under business-as-usual scenarios for air travel. Furthermore, air travel has generally been promoted through regional development policies with almost no policies aiming to restrain behaviour for environmental reasons. This unchecked behaviour generates low marginal benefits among the affluent who fly excessively, whilst posing environmental burdens on the rest of society who fly less. In this context, it becomes imperative to find ways to stabilise emissions in this sector, whilst ensuring that distributional impacts are minimised.

To our knowledge, this is the first in-depth analysis of the incidence of carbon pricing policies for passenger air travel – since our original analysis (Fouquet and O'Garra, 2020), Chapman et al. (2021) and Cass et al. (2022) have also looked at the expenses incurred associated with a FFL across income quintiles, but have not considered consumer welfare implications. Specifically, we compared the impact of a carbon tax with a frequent flyer levy (FFL) which targets excessive emissions through consumption reductions, rather than by directly pricing emissions. Results indicate that the FFL is both more progressive and more effective than a carbon tax. One might expect a trade-off between effectiveness and equity, especially since a carbon tax ensures that marginal costs of abatement are minimised.[27] However, by avoiding charging consumers for low levels of consumption, there is no trade-off between progressivity and effectiveness when using a FFL. The evidence also indicates that, as demand grows over time, the FFL remains a more progressive and effective policy. Also, importantly, both policies become less progressive over time, reflecting the growing demand for air travel amongst the lower income quintiles. To address the erosion in progressivity over time, it is critical that policies start off as highly progressive.

Although our intention in this paper is to focus on the potential for ex ante pricing mechanisms to address emissions and equity simultaneously, we acknowledge that ex post revenue recycling may improve the progressivity of carbon taxes; however, revenue recycling may be similarly applied to frequent flyer levies, further increasing their progressivity. In particular, revenue recycling approaches involving lump sum transfers might be attractive due to their simplicity to administer, their efficiency and potential fairness. However, unless transfers are made regularly, the benefits will be felt less keenly than the costs (of paying carbon taxes) for lower-income groups due to high discount rates. In addition, uncertainties (or trust issues) regarding the impact of the policy may reduce the expected utility (Stiglitz, 2019). Lump sum transfers may also be considered less fair to low-income individuals who receive the same amount as high-income individuals. As noted in Klenert et al. (2018 p.672) "they might be seen as unnecessarily giving out money to the rich". All these factors may reduce welfare among lower income groups and negatively impact the public acceptability of carbon taxes.

Ultimately, public acceptability is critical. A survey undertaken by 10:10 Climate Action (2019) indicated that the UK public considered a FFL as the preferred potential air travel policy option over fuel taxes and other options (although carbon taxes were not explicitly considered). Having the public's support, especially in the context of taxation, substantially reduces the intangible costs of implementation. Previous studies have shown that acceptability of a carbon tax depends on clear communication strategies about the progressive effects of the tax and its impacts at the individual level (Carattini et al., 2017; Klenert et al., 2018). If more nuanced revenue recycling approaches are used (e.g., transfers targeted according to need), then fairness and public acceptability of carbon taxes may be more assured, but the trade-offs between administration costs and impacts become more substantial, as needs-based systems are more costly to administer. Taking these considerations in mind – especially the importance of public acceptability in determining policy implementation - we consider it necessary to assess ex ante measures that are designed to be fair from the moment of consumption; as noted in the introduction, these can be considered complementary to revenue recycling.

In sum, our analysis indicates that there are potentially large reductions in emissions to be achieved at relatively low cost to the consumer. Inevitably, this analysis and results depend on a set of assumptions, which have their limitations (see Appendix G for details). However, these limitations do not affect the conclusions drawn. In addition, further research is needed to understand how the supply-side would respond to either policy, including the long run incentives to improve fuel efficiency (Gosnell et al., 2020) and reduce the carbon content of fuel (Baumeister et al., 2017), as well as on the issues related to implementing such policies, including the challenges of data privacy and the role for revenue recycling. These may create trade-offs not included in the main analysis.

A key insight from the analysis is the value of achieving behavioural reductions while minimising monetary expenses. At the margin, affluent consumers appear to not suffer greatly from reducing their travel, but the poor suffer from paying more to cover the environmental costs. Since travellers pay more for each kilometre travelled, a carbon tax leads to a lower effectiveness ratio (i.e., emissions-reduction-to-consumer-welfare-loss ratio). A FFL manages to achieve a higher ratio, because it does not charge an environmental cost for the first flight a person takes in a year. Thus, the analysis highlights the potential benefits of environmental policies that achieve behavioural and emission reductions without imposing large additional expenses on consumers; not only are such policies more fair but public (and political) acceptability is likely to be higher for these same reasons.

To conclude, this paper shows that energy policies targeting excessive consumption can achieve multiple purposes. In addition to reducing emissions, they can reduce the inequality of energy consumption. This paper indicates that an excessive consumption policy would be especially successful for air travel, perhaps because the inequality of consumption is so acute. Further research is needed to explore the application of excessive consumption environmental policies to other consumer behaviour, such as clothing, household goods, energy and other modes of transport (Cass et al., 2022). It is possible that the use of excessive consumption levies may not work as effectively in all consumer markets. Thus, future research should investigate the conditions under which a trade-off between progressivity and effectiveness exists. In time, this understanding could help develop a new generation of policies that both improve environmental quality and social equity.

CRediT authorship contribution statement

Roger Fouquet: Conceptualization, Investigation, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Tanya O'Garra:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing.

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[27] From a theoretical perspective, it is important to stress that a FFL does not equalise the marginal costs of abatement, as a carbon tax does. A carbon tax works on the basis that all carbon dioxide emissions have equal impact, are equally worthy of abatement and the tax creates the incentive for individuals to reduce their emissions until their marginal costs of abatement are equal to the tax. Instead, the FFL starts from the premise that not all emissions are 'equal' (Benoit, 2020); a tonne of carbon emitted by someone on their eighteenth flight to their villa in Malaga in any year might not be considered equal to a tonne of carbon generated by a family on their annual holiday. By emitting substantially higher emissions than most of the population (O'Garra and Fouquet, 2022), frequent flyers impose an additional cost to society, so the priority is to target these excessive emissions specifically, especially as their marginal benefits are likely to be lower - Benoit (2020 p.2) argues that these 'discretionary extravagant activities' generate little utility. Hence, the introduction of a FFL would not equalise marginal costs of carbon abatement; instead, it would aim to create incentives to equalise the social marginal costs of consumption (i.e., private costs plus climate impacts plus social burden from excessive consumption) with the marginal benefits of consumption; a more formal analysis would be an interesting avenue for future research.

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.enpol.2022.113278.

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