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Personal carbon trading: Trade-off and complementarity between in-home and transport related emissions reduction

Abstract

Personal carbon trading is a downstream version of the cap and trade approaches to mitigating carbon emissions from individual energy use. Although there are studies that investigate the theoretical and implementation issues, there is little evidence over the potential ways people could reduce their emissions when subject to a PCT policy. Especially little is understood about how people make tradeoff between or complement reducing emissions from transport and in-home energy use. This paper addresses this gap by reporting the findings of a questionnaire survey of stated intentions under the policy. Results show that, more people (53.6%) preferred to reduce their emissions from both transport and in-home energy use compared to from only one of these. This shows the flexibility offered by a cap including transport and in-home energy use is more efficient compared to a PCT covering either of these separately. Nearly three-fourths (76.2%) opted to reduce their emissions following a PCT policy. However, among those with above-budget initial emissions, a large share (79.6%) still could not reduce their emissions to below the budget and opted to purchase at least some permits to cover their emissions, indicating the difficulty in reducing emissions at the personal and household level.

Keywords

Personal carbon trading; acceptability; questionnaire survey; transport emissions; domestic emissions; energy end use

1. Introduction

The reduction of greenhouse gas (GHG) emissions – of which carbon-dioxide is a major one – has been a major environmental goal for most governments in the developed world. The UK government is legally bound to reduce its GHG emissions by 80% by 2050. While some progress has been made in different sectors of the economy in reducing GHG emissions and fossil fuel derived energy use, domestic energy use continues to present a significant challenge. Households' direct consumption of energy in-home and for travel purposes is responsible for 57% of the carbon emissions in the UK (Fell and King 2012) and around one-third to one-half in the EU countries. At present, all existing policies address energy use and carbon emissions for residential and travel purposes separately. Most of these policies also do not regulate carbon emissions from a sector or from a household and instead primarily focuses on carbon intensity or energy efficiency. For example, vehicle carbon efficiency is governed at the European level (carbon efficiency standard), while electric vehicle grants encourage a switch from petroleum fuelled cars to electric ones. There are also soft policies to encourage users to switch from cars to more environment friendly modes such as buses, walking and cycling, all of which are less energy or carbon intensive. At the same time, there are policies in the housing sector to improve home energy efficiency and reduce carbon emissions, e.g. new-build housing efficiency standards or the Green Deal to retrofit houses in the UK. There is however an absence of potential policy instruments to address carbon emissions from transport and domestic energy use at the household level. This research investigates such an all-encompassing policy – personal carbon trading (PCT) – to reduce carbon emissions from the household end-use sector.

While there has been some literature on PCT (Section 2 below), there is a gap in understanding the responses of households to such a policy. The primary objective of this research is to explore the potential response pathways of individuals to a PCT policy. We are especially interested in understanding the trade-off and complementarity between carbon mitigation options from travel and in-home energy use, i.e. which of these areas offer the greatest flexibility in terms of reducing emissions and where do we expect to see the most of the reduction. Considering the heterogeneity of the responses of different people, we also identify the attitudinal, socio-demographic and economic factors that affect the choice of emissions reduction from transport and in-home use under a PCT policy.

The paper is laid out as follows. Section 2 discusses the literature on PCT, section 3 describes the survey and the modelling methods. Section 4 presents the results and discussion, while section 5 draws conclusions.

2. Review of literature

Numerous studies exist on tax and tradable permit (also known as cap and trade) systems to control environmental externalities using the market (e.g. Stavins 1998, Pizer 1999, Wadud and Guhnemann 2016; also see Tietenberg 2006). Theoretically, in the absence of transaction costs, taxes and tradable permits are equivalent in their efficiency and effectiveness, although important differences occur for practical application. Weitzman (1974) suggest that tradable permits are preferable over taxes, when there is an uncertainty over potential environmental damages, which is the case for climate change effects arising from carbon and GHG emissions. Tradable permits have become especially popular among policymakers and a number of emissions trading policies have been enacted: SO2 trading for clean air in the US, and carbon emission trading scheme of the European Union (EU-ETS) are two notable ones. Globally twenty regional or national carbon emissions trading markets are active at present (Wadud and Guhnemann 2016). However, all of these markets work on an upstream basis: only large polluters, which are often large manufacturers or utilities, are covered in these schemes.

Personal carbon trading (PCT) brings the concept of emissions trading to the downstream sector – among households. Essentially, in this policy every individual or household is allocated a specific amount of carbon allowances or permits, which the individual or household can use to emit the specified amount of carbon, sell the extra allowances if they do not use up the entire allowance, or buy permits from other households (who have extra) to cover more emissions beyond the original allocation of permits, which becomes the carbon budget or target emissions. First proposed by Fleming (1997), who called it Tradable Energy Quotas, there were subsequent exploration of personal carbon trading by various researchers. Although, in theory a PCT can include both direct and indirect (i.e. embedded) carbon emissions, nearly all studies investigate direct emissions from energy use, either for in-home purposes, or travel and, in very few cases, both.

A PCT is sometimes viewed as more effective in practice, given the presence of an absolute cap in emissions, which ensures certainty in carbon reduction. Researchers have also argued in favour of individual involvement in environmental policies – for example, Ahlheim and Schneider (2002) discuss of 'warm glow' effect that could make downstream trading more effective than upstream ones. Fawcett (2010) and Parag and Strickland (2011) also believe that PCTs could provide psycho-social incentives to change carbon and energy use behaviour, thus making them more effective than carbon taxes. However, Lockwood (2010 argues that PCTs may be less efficient compared to upstream carbon trading because of the transaction costs involved. Fan et al. (2015a, 2015b, 2016) and Li et al. (2017) investigate the theoretical properties of PCT scheme with respect to effectiveness, efficiency, stability of price and demand, etc. This stream of work primarily provides mathematical proofs of the suggestions made by other authors earlier.

Social acceptability of a PCT scheme – especially compared to a carbon tax – was studied early on by various researchers: Howell (2012), and Owen et al. (2008) conducted small focus group studies (30-90 respondents), while Bristow et al. (2010) conducted questionnaire surveys with a larger set of participants. The results were mixed, with neither policies acceptable by a majority, which is not unexpected as both tools would effectively raise the costs of using carbon-intensive energy sources. However, PCT consistently appeared to generate less negative views among the participants compared to a carbon tax. Bristow et al. (2010) concluded that the design features of each scheme are more important than the scheme itself and either could become acceptable to the majority of the population through appropriate design. Interestingly Bristow et al. (2010) and Zanni et al. (2013) also find that permit prices have little effect on the acceptability of PCT scheme.

Wadud (2011) suggested transportation is especially suited to a PCT scheme because of the difficulty to decarbonize this sector given its low sensitivity to a price signal and continued global growth in passenger-miles or freight-miles travelled. Wadud (2008, 2011), Wadud et al. (2008), Raux (2004), Raux and Marlot (2005) and McNamara and Caulfield (2013) investigate the introduction of PCT in the transportation sector and provide empirical insight on the potential distributional effects of such a policy in three countries: the US, France and Ireland. All of these studies estimate a fuel demand model or utilise existing elasticities of fuel demand and then use those elasticities to model the effects of PCT through the permit price mechanism. All found PCTs to be progressive in the transport sector and as such potentially politically and socially acceptable way of reducing carbon emissions from the transport sector.

Interestingly, the elasticity-driven approach in the transport sector was not applied to understand the effects of PCT on domestic energy use, although there were several studies that investigate the distribution of burden or benefits arising from such a policy. Unlike the transportation PCT studies, which incorporate a consumer response to the PCT policy (which reduces energy consumption or carbon emissions) studies on PCTs for domestic energy use generally use static incidence analysis approach (i.e. natural responses to PCT induced price increase are not included, only additional costs/benefits due to price increase included). In the UK, PCT was generally progressive for domestic energy use (in-home + transport), with nearly 71% of the households in the lowest income decile benefiting from the policy (DEFRA 2008). Despite this progressivity, Starkey (2012) argues that equal allocation of permits does not necessarily result in ‘fair’ allocation from environmental justice perspective. This is because the households who are losing out may have less realistic options to reduce their emissions. Different permit allocation strategies have also been studied to moderate such adverse effects on the disadvantageous and vulnerable groups (e.g. Burgess 2016, White and Thumin 2009, Wadud 2011).

Another stream of literature on PCT discusses the practicality of the policy: the advantages and disadvantages, barriers to implementation and potential ways to integrate PCT with existing policies. These include Fawcett (2010), Eyre (2010), Parag and Eyre (2010), Parag and Strickland (2011). While PCT gained much purchase as a downstream policy instrument in the UK during the early years of 2000, the Department for Environment, Food and Rural Affairs slowed its momentum substantially in 2008 when it concluded: “… while personal carbon trading remains a potentially important way to engage individuals…. it would nonetheless seem that it is an idea currently ahead of its time in terms of public acceptability and the technology to bring down the costs” (DEFRA 2008). One of the major concerns for any downstream policy addressing millions of consumers is monitoring and enforcement. However, because of rapid advances in technology in the past decade many of the previous barriers are coming down. For example, smart meters can be used not only for the utilities to balance load and use dynamic pricing, they can also easily keep track of and visually present energy usage of the consumer at small time slots. Web-based smart heating controls can be easily used to collect and store household's domestic energy use data. At the same time vehicle automation and GPS connectivity allow tracking of vehicles to monitor their energy use and carbon emissions. As such, at least the technological barriers to implementing a PCT scheme is substantially lower now than in 2008.

While various aspects of PCTs have been studied, quantitative studies investigating potential responses to a PCT scheme are relatively scarce. Raux et al. (2015) and Zanni et al. (2013) both conducted choice experiments to understand options for households in order to comply with PCT and carbon tax policies in the transport and domestic energy use context. Bristow et al. (2010) also conduct a choice experiment, but the primary objective was to understand the PCT and carbon tax design, rather than understanding potential responses. In all of these studies respondents were primarily given several choice scenarios and asked to choose one.

In theory, a PCT policy covering both transport and in-home energy use will offer more flexibility to the consumers to reduce their emissions, and as such will be more efficient (in the sense that emissions will be reduced at the least cost). As such, a policy covering all household-level emissions should be preferred compared to one covering only transport or only in-home emissions. An important aspect of PCT that did not receive much attention in literature is the various options in response to a PCT policy, especially the trade-off or complementarity between in-home and transport emission options. Only Zanni et al. (2013) suggested on the basis of a small survey (189 responses) that people prefer to reduce their in-home carbon emissions than emissions from transport. While Yang and Timmermans (2017) investigate the trade-off, it is not in the context to PCT. This paper addresses this gap in research further and explores the potential in-home and transport emissions reduction options under a PCT scheme using a stated preference questionnaire survey.

3. Methods

3.1 Survey design and data collection

We conduct a questionnaire survey to understand the intentions of respondents in response to a PCT policy. Carbon footprint calculator from carbon independent (carbonindependent.org) that takes into consideration the emissions from in-home energy consumption (in terms of electricity, gas and other means such as oil, coal, wood etc.) and emissions from transport (that includes car and aviation) were used to calculate household's current carbon emissions. The carbon budget was kept at 4t/yr following Bristow et al. (2010), i.e. each individual is allocated a free permit for up to 4t/yr of CO_2 emissions. If the emissions are beyond this limit, an individual has to buy the required permits and if the emissions are below this limit then an individual can sell the unused permits at a given price to others. Only transport and in-home direct energy use were included in the permit allocation and emissions calculation.

A web based survey questionnaire was designed to collect the data. The questionnaire was deliberately designed not to be a discrete choice experiment questionnaire with an intention not to force participants to a specific choice but to give more flexibility in terms of what they wanted to do to reduce carbon foot print. Also, with the number of options considered in the questionnaire it would have been very difficult to come up with an efficient discrete choice experiment. The survey questionnaire has four parts. The first part is the carbon footprint calculator to understand the respondents' current emissions and clearly show it to them. The second part consists of questions about individual's current travel patterns and attitudes towards climate change. The third part introduces the PCT scheme and questions around how and where (car, flight, in-home) they reduce their carbon emissions. The respondents were continuously shown the carbon budget, how far they were above or below the budget and its financial implications (amount spent in buying permits or gained by selling permits) after each action taken. They were also allowed to move back and forth between the options to offer flexibility in making their choices. The fourth part of the questionnaire consists of questions on socio-demographics and acceptability of the PCT policy. The format of the survey is quite similar to Zanni et al. (2013) although our main interest is in PCT and on the tradeoff and complementarity between in-home and transport related emissions reduction possibilities, rather than a comparison of PCT and carbon tax, as in Zanni et al. (2013).

A panel survey company was engaged to run the survey with a target of 1,000 interviews. The survey was administered in the second half of August 2016. We have deliberately sought for the recruitment of 25% non-car owners so that we can observe the intentions of a set of participants who have emissions below the set limit of 4t/year, although our sample consists a higher number of non-car owners, indicating this was not binding. The average time taken by the respondents to complete the survey was 13 minutes and there was a loss of 17% of the sample due to incorrect or missing entries.

3.2 Sample characteristics

Table 1 presents the descriptive statistics. The sample split between regular car users and non-car users is 59% and 41%. It is interesting to see that about 76% of the sample has full driving licence but only 66% own a car and even fewer 59% use car regularly. The gender split in the sample is 54% male and 46% female. Average household size is 2.3 with about half of the sample single and 80% of the households without any child. 62% of the sample own their house. Car is the main means of commuting to work for about 34% of the respondents. Just over half of the sample is employed either part time or full time. About 10% refused to disclose their income, rest of the income distribution is shown in Table 1.

Table 1. Sample descriptive statistics

Attribute	Levels	Share (%)
Gender	Male	54.2
Income	<20,000	34.0
	20,000-40,000	34.6
	40,000-75,000	17.1
	>75,000	4.7
	Did not answer	9.6
Employment	Full time employed or student	38.8
	Part time employed or student	16.5
	Unemployed	8.8
	Retired	27.4
	Home maker	8.6
Marital status	Single	37.2
	Married or co-habiting	61.4
Education	Below college	41.8
	College	22.0
	University	32.3
Children	Yes	20.0
Car ownership	Owns a car	66.3
Flying	At least one flight	18.0
Which single one of the following statements comes closest to your view?	Climate change is the result of man's activities and urgent action is required to reduce emissions	64.8
	Climate change is happening - but there is nothing we can do about it.	9.4
	Climate change is happening but it is overhyped by the media	21.9
	Climate change is not a problem	3.7
Individuals should take actions, alongside businesses, to reduce the emissions that contribute to climate change	Agree	81.9
	Disagree	6.3
	Don't Know	11.7
Were you surprised at the size of your carbon footprint	Yes, higher than I thought	44.7
	No, it was as expected	44.7
	Yes, lower than I thought	10.6
Did you make any changes to your lifestyle to reduce carbon footprint	Yes	36.6
	No	63.4
Do you think such a scheme would be effective in reducing CO2 emissions	Yes	23.3
	Not sure	44.9
	No	31.7
Do you think a PCT (personal carbon trading) scheme would change the way you use energy or fuel	Yes definitely	17.6
	Possibly, but depends	39.4
	Don't Know	16.8
	Unlikely	15.9
	Definitely not	10.3
Would a PCT (personal carbon trading) scheme be acceptable for you	Yes	23.4
	Not sure	42.7
	No	33.9
Permit Price	£50	31.8
	£100	34.7
	£150	33.5

The averages of personal, leisure and other car miles reported were 2353, 1276 and 679 per annum respectively. Only 18% of the respondents were making one or more flights with an average (within these 18%) emission of 3 tonnes from flying. About 45% of the respondents said they were surprised by their carbon footprint, 45% said their carbon footprints were as expected and the remaining felt that their carbon footprints were below their expectations.

3.3 Modelling

One of our primary goals is to investigate the various pathways respondents choose to reduce emissions using descriptive statistics. We also investigate through a set of modelling exercise the behaviour of participants towards their choices to reduce their emissions under a PCT policy, the amount reduced and the acceptability of the PCT scheme. We attempted to run random effects models throughout these regressions to account for individual heterogeneity. However, we report the random effects model only where the random effects were significant.

First of the set is a multinomial logit (MNL) regression model to understand the intention whether and how to reduce emissions. An MNL model is an extension of simple binary logistic regression but with the categorical dependent variable having more than two levels. The dependent variable in this model has four outcomes i.e. whether an individual does not reduce energy consumption or reduce only from transport, only from domestic uses or from both transport and domestic uses. The reference category is ‘do not reduce energy consumption’. The explanatory factors are sociodemographic characteristics, attitudes and current energy consumption behaviour. The multivariate multinomial model (Model 1) takes the form as expressed in equation 1.

$$\Pr(i) = \frac{\exp(Z_{ik,j})}{\sum_{l=1}^{j} \exp(Z_{ik,l})} \quad (1)$$

with $Z_{ik,j} = \alpha_{k,j} + \beta_{k,j} Xi + \varepsilon_{k,j}$ (2)

where, Pr(i) = Probability of membership in category ‘i’ at predictor level X, $\alpha_{k,j}$ are alternative and choice specific constant, $\beta_{k,j}$ is a vector of coefficients, x_i a vector of predictor variables and $\varepsilon_{k,j}$ error terms.

The second regression model (Model 2) measures the influence of sociodemographic characteristics, attitudes and current carbon emissions on the possible amount of carbon reduction. This is a random effects linear regression, where the dependent variable is the quantity of CO2 savings due to the scheme. The model takes the form as expressed in equation 3.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + u_0 + \varepsilon \quad (3)$$

where, Y is the emissions saved, βo is constant, β_1 to β_n are coefficients and X_1 to X_k are the predictor variables. u_0 is the deviation from the population average intercept. ε is the error term. All the continuous variables in this model are in logarithms. Model 2 is estimated on the subsample of only those who opted to reduce their emissions.

The third regression model is an ordered logit model (Model 3) for an ordinal response to measure the influence of sociodemographic characteristics, attitudes and current energy consumption on the acceptability of PCT scheme. The dependent variable had three ordinal categories – acceptable, not sure, unacceptable. The ordered logit model for an ordinal response Y_i with C categories is defined by a set of C-1 equations where the cumulative probabilities $g_{ci} = Pr(Y_i \leq y_c | X_i)$ are related to a linear predictor $\beta_i x_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$ through the logit function as

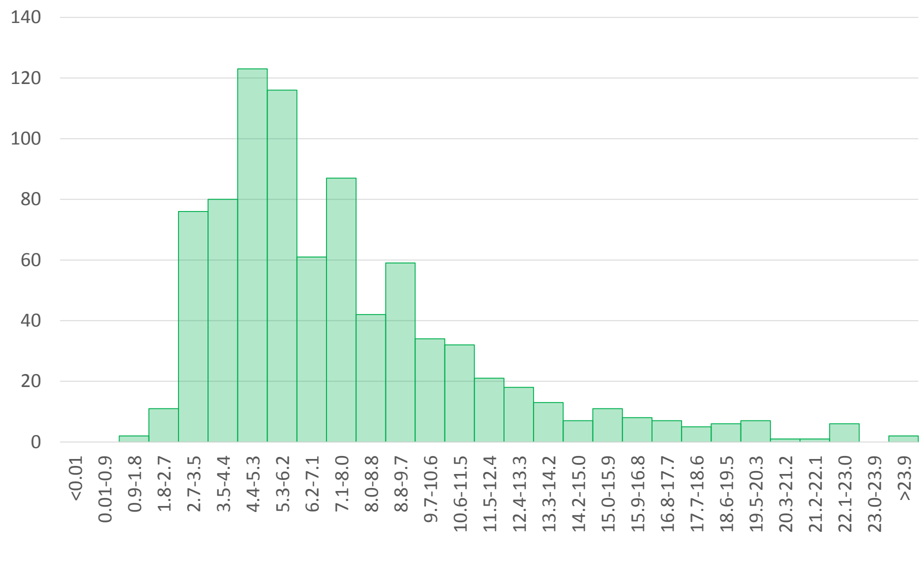
$$\text{Logit}(g_{ci}) = \alpha_c - \beta_i X_i \qquad (4)$$

Where α_c are thresholds or cutpoints separating the different categories. All of these linear and logistic regression models are estimated using STATA SE 14.

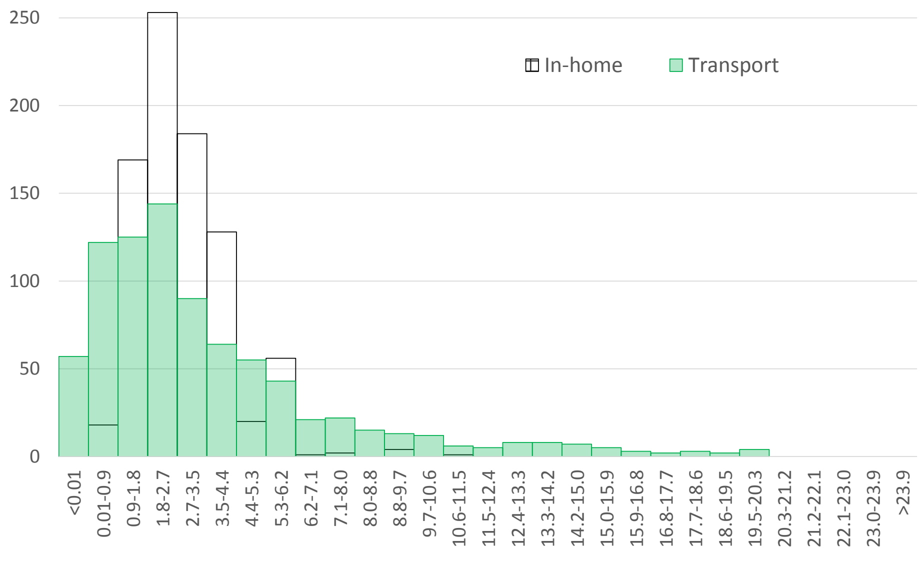
4. Results

4.1 Distribution of current emissions

Fig. 1 presents the distribution of total carbon emissions and emissions arising from travel activities and in-home energy use. As is possibly expected, there is a wide variation in the carbon emissions profile. The average emission over the whole sample is 6.4t/yr, of which emissions from transport is 3.6t/yr, and emissions from in-home energy use is 2.8t/yr. Before the implementation of the policy, 86.3% of the respondents emit more than 4t/yr, our initial allocation of carbon permits under the PCT policy (Fig. 1a). There are plenty of respondents with no carbon emissions from the transport sector, because these households do not own cars (Fig. 1b). For this research, we have ignored carbon emissions from the public transport modes. Still, nearly 30.8% respondents exceed their entire 4t/yr target through travel activities alone. Around 23.9% of respondents report in-home energy use greater than the total 4t/yr target. Fig. 1b also shows that the distribution for in-home energy use (cross-hatched pattern) is less dispersed (standard. deviation 1.45) than that for transport energy use (standard deviation 3.76), indicating a larger heterogeneity in how people travel compared to how they use energy in-home. About 6.2% of the respondents' transport emissions are more than 3 times the average transport emissions and less than 1% of the respondents' domestic emissions are more than 3 times the average domestic emissions. Around 18.3% of the sample flies once or more in a year and about one-fourths of them emit more than the permissible limit of 4t/yr from flying alone.



(a)



(b)

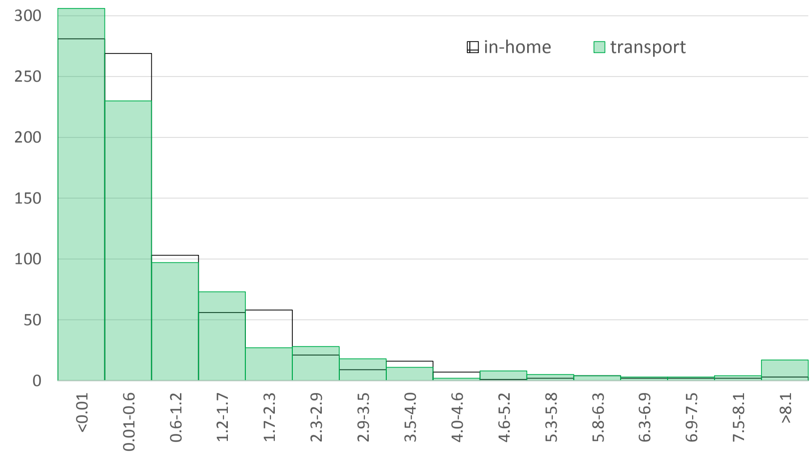
Fig 1. Distribution of (a) total personal emissions (sum of transport and in-home energy use), (b) personal transport and in-home emissions

4.2 Emissions reduction under PCT

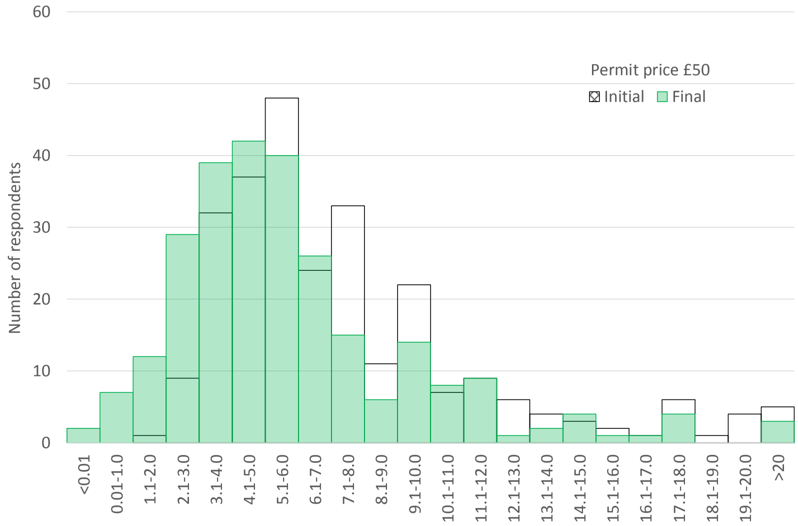
Over the whole sample around 76.2% of all respondents stated a reduction in emissions following the introduction of a PCT policy, and once the carbon permit prices and associated expenditure are shown to them. As expected, those who emit above the 4t/yr of initial allocation are more likely (78.5%, Table 2) to reduce emissions compared to those who emit below this quantity (61.7%). Once the policy is implemented, everyone benefits from reducing the emissions – since even those below the carbon budget can sell extra permits in the market, generating economic benefit. As such there is an incentive for those below the budget to reduce emissions too, which results in a relatively high share of respondents reducing emissions, even though they were under the PCT budget. Table 2 also shows the willingness to reduce and amounts reduced over the three different permit prices (£50, £100 and £250). There is an increasing willingness to reduce emissions at higher permit prices for those respondents emitting above the 4t/yr carbon budget, as can be expected from economic theory. For those emitting below the budget, the pattern is not as consistent, possibly indicating 'selling extra permit' is less of an incentive compared to 'buying extra permits'. Such asymmetric responses – whereby people value the losses more compared to similar gains – have been evidenced in other areas of consumer behaviour as well (Kahnemann and Tversky 1973, Wadud 2017).

Fig. 2 presents the distribution of stated reductions in emissions in response to the PCT policy and resulting final emissions for all three permit prices combined. It is clear from Fig. 2 (b) – 2(d) that the distribution of post-PCT intended emissions shifts to the left of the original distribution for each of the three permit prices. Further exploration shows that among the respondents who were emitting above 4t/yr initially (86.3%), 20.4% could reduce their emissions to below 4t/yr under a PCT scheme, i.e. these respondents will no longer have to purchase additional permits from the market. As such, 68.5% of the total respondents (79.6% of those above budget) still have emissions above 4t/yr and opted to purchase some permits. This indicates the difficulty in reducing emissions under a fixed budget for these households.

Our key interest is on reductions from transport and in-home energy use. On average, over the whole sample and each of the three permit prices, respondents could reduce their transport related emissions more as compared to their in-home emissions. A PCT policy would enable the respondents to reduce 0.98t/yr from transport and 0.75t/yr from home use (Table 2), with a total reduction of 1.73t/yr, on average, over the whole sample. Interestingly, the share of respondents who said they would reduce emissions from in-home use is marginally larger (66.4%, Table 2) than those who stated a reduction from the transport sector (63.4%). Considering the reduction over only those respondents who stated a reduction, transport reduction was 1.55t/yr, while reduction from in-home energy use was 1.12t/yr. Therefore, in absolute terms, respondents were able to reduce more emissions from the transport sector on average. This finding is noticed separately for three different permit prices too. Further analysis reveals that nearly 53.6% respondents showed intention to reduce emissions from both transport and in-home energy use, 9.7% would reduce from transport only, and 12.8% would reduce from domestic energy use only. This clearly shows that respondents prefer to optimize their emissions reduction through reducing emissions from both option. Also, further investigation shows that most of the large reductions in emissions in Fig. 2 (a) come from respondents with large transport emissions, who were flying more often than the rest.



(a)



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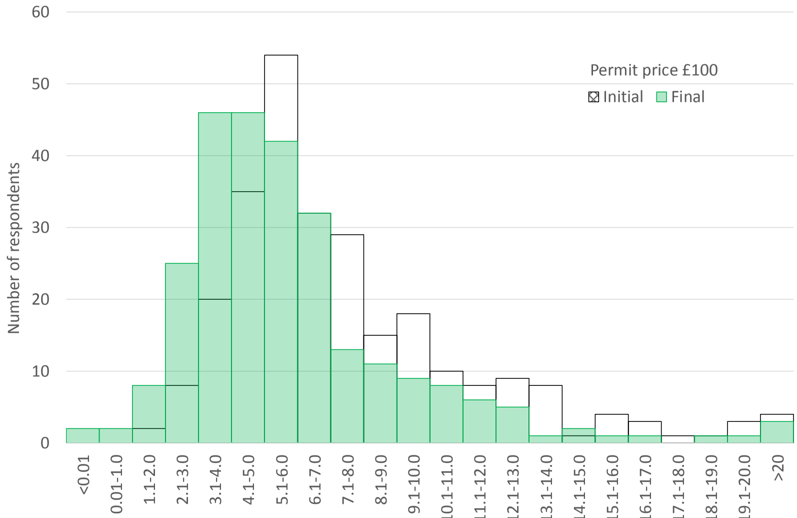
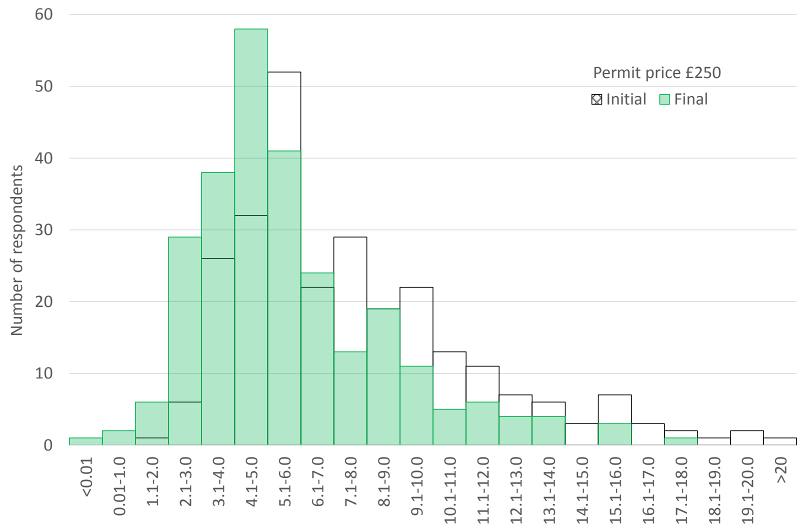


(c)



(d)

Fig. 2 (a) Stated reduction of emissions under a PCT scheme; and Initial and final emissions at permit prices (b) £50/ton (c) £100/ton and (d) £250/ton

Table 2. Stated reductions in carbon emissions and average reduction in different sectors

Subsample	% reducing emissions	% reducing emissions from transport	% reducing emissions from in-home use	Average reduction from transport		Average reduction from in-home use	
				Whole sample	Only those reducing	Whole sample	Only those reducing
Above 4t	78.5	68.6	68.0	1.12	1.63	0.78	1.15
@permit price £50	63.5	62.2	61.8	1.06	1.70	0.64	1.05
@permit price £100	80.4	71.8	69.4	1.05	1.46	0.80	1.15
@permit price £250	82.6	71.1	72.3	1.25	1.76	0.88	1.22
Below 4t	61.7	31.3	56.5	0.08	0.28	0.51	0.91
@permit price £50	63.41	34.1	58.5	0.097	0.28	0.67	1.14
@permit price £100	61.11	30.6	58.3	0.111	0.37	0.45	0.77
@permit price £250	60.53	28.9	52.6	0.052	0.18	0.40	0.77
Overall	76.2	63.4	66.4	0.98	1.55	0.75	1.12
@permit price £50	70.68	57.9	61.3	0.91	1.57	0.65	1.06
@permit price £100	78.01	66.7	68.0	0.93	1.40	0.76	1.11
@permit price £250	79.64	65.4	69.6	1.08	1.66	0.82	1.17

4.3 Model for willingness to reduce emissions

The group-wise comparisons above offer a broad picture, however they miss the differences in other relevant factors or the correlation among the factors that could affect the intended responses or reduction arising from a PCT policy. Especially, given different respondents were given a different permit price, these averages have somewhat limited usefulness. As such we run a MNL model to understand how different socio-demographic, attitudinal and emissions related factors affect the likelihood to reduce emissions under a PCT scheme, as described earlier. The explanatory factors build upon those used by Zanni et al. (2013), but are complemented further by additional attitudinal factors and initial carbon emission conditions. The respondents are categorized into four groups: reducing emissions from only transport, from only in-home energy use and from both; and not reducing at all. Table 3 presents the results of the parameter estimates of the MNL model for the probability of the respondents falling into the three groups, compared to the base group (those who do not reduce emissions at all).

The probability of a respondent reducing emissions from transport, in-home energy use or both decreases if the respondent is male or highly educated. Gender differences in a variety of pro-environment behaviour is well documented (e.g. Dietz et al. 2002) and support our finding. The effect of education appears counter intuitive, yet Akter and Bennett (2011) also found that highly educated respondents were less likely to reduce their carbon emissions. In our context, income could be correlated with education and as such the education variable may have picked up that effect, or highly educated respondents may be involved in a job which requires them to travel more frequently and farther distances (e.g. flying), which might make them less inclined to reduce emissions. Age of respondent, employment status or presence of children in the household does not affect the probability of reducing emissions from any of the three options. Low income also does not have a statistically significant effect on the probability to reduce emissions, although this may also be a result of collinearity with other similar variables in the model. Home ownership status also does not statistically affect the choice of emissions reduction.

Current emissions profile has a significant effect on the reduction choices. As one may expect, the probability to reduce emissions increases if the respondent's emissions are above the initially allocated amount of 4t/yr. This follows from the earlier finding using descriptive statistics too. A larger share of transport emissions in overall emissions profile has a positive impact on reducing emissions from transport (from transport alone, or along with in-home emissions), but decreases the probability to reduce emissions from in-home emissions only. A car user is less likely to reduce emissions in the domestic front only. Conversely, non-car users are more likely to reduce emissions from in-home energy use, as is possibly expected.

Attitudes and actions related to climate change and receptiveness about the PCT policy have substantial effects on the probability to reduce emissions. If respondents believe that climate change is a result of human actions then they are more likely to reduce emissions. Those who believe individuals should act to reduce emissions are more likely to reduce emissions from both transport and in-home energy use. Respondents who found their emissions were larger than expected are more likely to reduce emissions from both transport and in-home energy use. On the other hand, those who made some changes to their lifestyle in mitigating carbon emissions are more likely to reduce emissions from transport only, and are less likely to reduce emissions from in-home energy use. This possibly reflects the relative inflexibility in reducing carbon emissions from in-home energy use, once some actions are taken already. Belief that PCT is an acceptable policy increases the probability of reducing emissions from any of the three means. Those who believe PCT would be an effective policy are more likely to reduce emissions from in-home energy use.

Table 3 Parameter estimates for the choice to reduce emissions (multinomial logit model)

	From Transport Only		From Domestic Only		From Transport & Domestic	
Parameter	Coeff.	s.e	Coeff.	s.e	Coeff.	s.e
Constant	-2.143	1.394	4.000***	1.220	0.721	0.961
Child(ren) in household	-0.532	0.411	-0.445	0.430	-0.426	0.278
Emissions above budget	1.025**	0.527	0.624**	0.379	1.009***	0.331
Owns home	-0.496	0.307	-0.362	0.311	0.240	0.224
Car User	0.168	0.304	-2.692***	0.467	0.398	0.218
Climate change is result of human actions	0.887***	0.346	1.250***	0.352	0.754***	0.230
Individuals should act to reduce emissions (Agree)	0.107	0.408	-0.121	0.395	0.618***	0.270
CO_2 higher than expected	0.200	0.294	-0.233	0.303	0.555***	0.207
Already made some changes to lifestyle	0.610***	0.306	-0.647**	0.341	0.001	0.221
Employed full time	0.315	0.338	0.075	0.344	0.132	0.236
Male	-1.010***	0.291	-0.560**	0.294	-0.759***	0.206
Have university degree	-0.683***	0.293	-0.517**	0.289	-0.378**	0.204
Low income	0.205	0.327	-0.288	0.325	-0.043	0.231
Permit Price per tonne	0.002	0.002	0.004***	0.002	0.002**	0.001
Share of transport emissions in total	2.591***	0.681	-1.504***	0.664	2.502***	0.482
Age of participant	0.008	0.013	-0.014	0.013	-0.004	0.009
PCT would be effective (Yes)	0.357	0.492	-0.989***	0.432	-0.719***	0.329
PCT acceptable (Yes)	-1.156***	0.458	-0.786**	0.438	-0.872***	0.338
Number of Observations	834					
Mc Fadden R^2	0.236					
Log Likelihood	-743.36					

, * significant at 90% and 95% level respectively

Permit prices also affect the choices. Table 3 shows that a higher permit price increases the probability of reducing emissions from either in-home energy use or both transport and in-home energy use, but it does not affect reduction solely from transport. This is not surprising, demand for transport fuel has been known to be quite price inelastic (Wadud et al. 2009, 2010).

4.4 Model for intended reduction in emissions

The average reductions in Table 2 also have the same limitations as mentioned in 4.3. As such we run a second regression model – as described in 3.3 – which correlates the factors that affect the quantity of emissions reduction for respondents who opted to reduce emissions, the results of which are presented in Table 4. Among the socio-economic characteristics only age, gender, low income indicator and home ownership have statistically significant effect on the amount of CO_2 reduction. Interestingly, although male respondents are less likely to reduce emissions (Table 3), those who do reduce, reduce more compared to female respondents. This possibly reflects the use of larger cars that could be downsized, presence of discretionary activities that could be cut down or a willingness to engage in domestic retrofitting type activities by men. Low income respondents reduce less compared to others, which possibly suggests lack of alternatives to carbon-intensive travelling or unaffordability of energy technology measures. Emissions reduction decreases with increasing respondent age. Respondents who own their homes reduce more, compared to those who do not, possibly reflecting better opportunities to reduce in-home emissions. Permit prices have no statistically significant effect on the amount reduced, supporting previous literature (Bristow et al. 2010). As expected, respondents who emit above the initially allocated carbon budget reduce more compared to those who do not. Positive attitude toward climate change results in a larger reduction, too. Also, respondents who found that their carbon footprint was larger than what they expected reduced more.

Table 4. Parameter estimates for the overall amount of emission reduction (random effects model)

	Random Effects Regression	
Explanatory factors	Coeff.	s.e
Constant	0.442	0.890
Reduce only transport emissions	-1.277***	0.140
Reduce only in-home emissions	-0.635***	0.150
Age of participant (log)	-0.465***	0.190
Permit Price per tonne (log)	0.017	0.070
Emissions above budget	0.624***	0.161
Owns home	0.187**	0.105
Child(ren) in household	-0.001	0.124
Car User	0.145	0.108
Climate change is result of human actions	0.105	0.115
Individuals should act to reduce emissions (Agree)	0.301**	0.153
CO_2 higher than expected	0.229***	0.093
Already made some changes to lifestyle	0.232***	0.097
Employed full time	0.189**	0.107
Male	0.236***	0.093
Have university degree	0.074	0.096
Low income	-0.218**	0.109

PCT would be effective (Yes)	0.161	0.124
PCT acceptable (Yes)	0.014	0.127
Random-effects Parameter		
Variance(Residual)	1.286***	0.072
No. of observations	635	
Loglikelihood	-980.90	

, * significant at 90% and 95% level respectively

Our key interest for this model is to understand the reductions through various options chosen: from transport only, from in-home only and from both. After controlling for the other factors, respondents who reduce from transport only or in-home only, reduce less (both negative parameter estimates) compared to the respondents that reduce emissions from transport and in-home energy use. Respondents who reduce emissions from in-home energy use only reduce more (less negative) than those who reduce from transport only. This may appear contradictory to the averages in Table 2, but can be explained by – a) Table 2 numbers include respondents who reduce from both transport and in-home energy use and b) Table 2 numbers do not control for other factors that also differ between the groups.

4.5 Current emissions and ease of reduction under PCT

In addition to modelling the willingness to reduce emissions and amount of reduction, we are interested in understanding the mechanisms behind the reduction or willingness to reduce. As such we asked the respondents not only how they would reduce emissions, but also how easy or difficult they think it would be to reduce emissions from transport and in-home energy use. We also separate the in-home carbon reduction measures into two categories: short run behavioural means (e.g. through switching off lights, not using half-loaded washing machines etc.) and long run technological means (e.g. replacing an existing boiler with a more energy efficient one, insulation of the roof, etc.). Fig. 3 presents the summary responses, categorized against current emissions (whether above or below 4t/yr) across three different means of reducing emissions. No substantial differences are observed between the above- and below-budget groups of respondents for transport emission reductions. However, for in-home energy use reductions through behavioural means, 33.6% of the higher emitting respondents would find it easy or very easy, compared to 28.7% emitting below that amount. Similarly, a larger share of high-emitting respondents (30.2%) will be able to easily install energy efficiency or renewable energy technologies compared to those emitting below (26.1%). The share who would find it difficult remains the same between the above and below groups for both in-home reduction choices. Although the share of respondents who find the reduction to be easy or very easy are roughly similar for all three broad options, the share is larger for those who find it difficult or very difficult to reduce their transport energy use (25.8%) compared to in-home energy use (17.3%

and 16.7%). This indicates that more than one-fourths of all respondents are possibly captive transport users with little options to reduce their transport-related carbon emissions, highlighting the differences among respondents opportunities to reduce emissions.

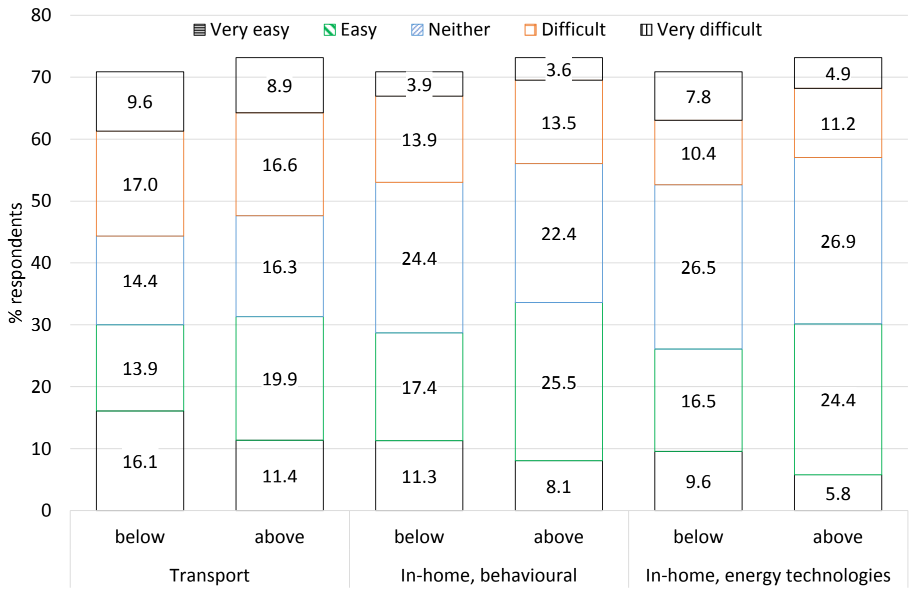


Fig. 3 Ease of reducing emissions from three broad options: transport and in-home through behavioural and energy technologies measures

4.6 Reduction in transport emissions under PCT

Table 5 investigates the reduction possibilities in transport in more detail, with respect to the share of transport emissions, share of emissions from flying and car ownership. A larger share (29.6%) of high transport emitters (those having transport emissions more than half of total emissions) find it difficult to reduce their transport emissions, compared to low transport emitters. However, those high emitters who can reduce their transport emissions, reduce significantly more (1.68t/yr on average) compared to low emitters (0.34t/yr).

Further exploration shows that around 9% of the respondents have flying responsible for more than one-quarter of their emissions. More than half of them (51.4% in Table 5, or 4.6% of total sample) find it easy or very easy to reduce emissions from transport. Overall, respondents with large flying emissions, on average, can reduce 5.46t/year, which represents 66% of their total (transport + in-home) emissions on average. Flying is a very carbon-intensive activity and as such air travel makes up a large share of emissions for these respondents. The large reduction is possible as air travel is likely discretionary that can be foregone or substituted easily.

Table 5. Stated reduction in transport emissions under a PCT policy for different groups

	Total>4t budget?		Transport>50%		Flying>25%		Owns car?	
	Yes	No	Yes	No	Yes	No	Yes	No
Net transport saving	1.12	0.08	1.68	0.34	5.46	0.53	1.26	0.43
Transport saving as % of average transport emissions	23.96	15.65	25.75	17.96	66.29	17.23	26.42	12.35
Share of respondents finding it difficult to reduce transport emissions	-	-	71.2	67.2	48.6	69.5	71.7	63.8
Share of respondents finding it very easy /easy to reduce transport emissions			28.8	32.8	51.4	30.5	28.3	36.2

Share of respondents who find it difficult to reduce emissions from the transport related energy use are similar (25.2-26.2%), irrespective of whether they own a car or not. Further investigation shows that a smaller share of car owners (28%) find it easy to reduce transport emissions compared to those who do not own a car (36.2%). After the carbon permit prices were shown and the respondents were informed of the saving or additional costs, car owners opted to reduce their transport emissions by 1.26t/yr on average, which is around 26.4% of average total emissions. Those who do not own a car (but could still have flying emissions and/or use cars as second drivers) could reduce only 0.43t/yr., the saving coming from reducing flying. This indicates that although a lower share of car owners could reduce emissions easily, they could reduce substantially more in quantity compared to non-car owners. This is possible since car owners have two different set of opportunities to reduce emissions – by reducing car travel (mode switch, work from home, etc.) and by driving more efficiently (purchase a hybrid or an electric or a fuel efficient car, drive smoothly, etc.) compared to non-car owners who can only reduce their travel by a limited amount (no opportunities for substantial mode switch). For example, Fig. 4 presents the substitute travel options preferred by the respondents in reducing their travel. Clearly a smaller share of non-car owning respondents can choose these opportunities compared to car owners. Among car owning respondents above the 4t/yr budget and opting to reduce at least a part of their emissions, more than 55% said that they would drive more smoothly and maintain vehicle and monitor tyre pressure regularly to reduce carbon emissions. 39.6% also opt to purchase a more fuel efficient vehicle while 18.8% show an inclination toward a hybrid or electric vehicle for their next purchase. None of these options to reduce emissions are available to non-car owners.

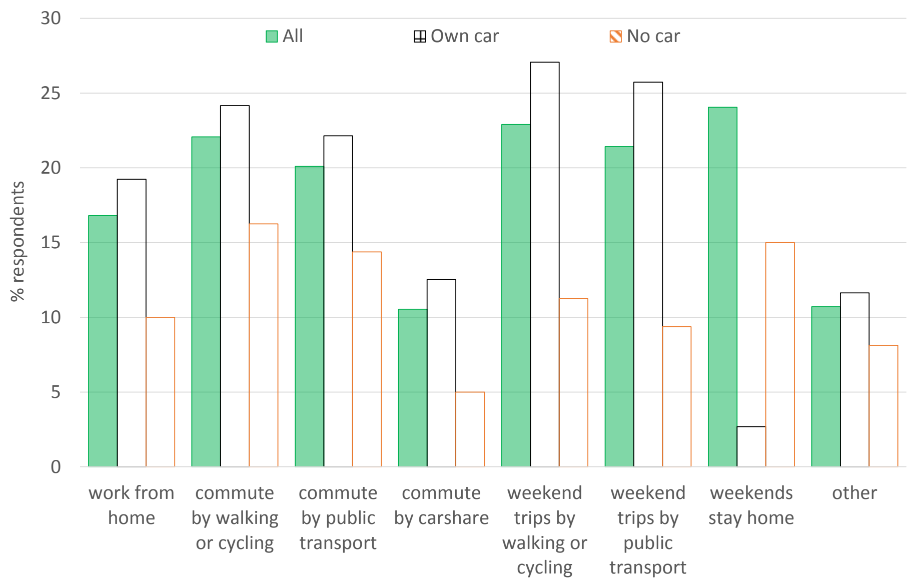


Fig. 4 Alternate measures taken to reduce travel related carbon emissions

4.7 Reduction in in-home emissions under PCT

Table 5 presents the reduction possibilities in the in-home sector in more detail – both for short term behavioural adaptations and longer term energy technology related reductions. In general, average reductions from technology related measures are between three to four times larger than those from shorter term behavioural options, although a lower share of respondents opted for longer term measures (38.1%) compared to short term measures (60.7%). This is expected given the smaller potential to reduce emissions by behavioural means (e.g. switching off lights, not using washing-machines at half-load, etc.). Respondents above the 4t carbon budget are inclined to reduce their emissions substantially more (0.29t/yr) compared to those below the budget. Although the low emitting respondents would not have to buy additional permits, some still opted to reduce emissions – this could be a result of the PCT policy's so-called psychological impact or of the economic effect that by reducing further, the households can sell extra permits.

Savings through behavioural means do not vary substantially for different groups defined by the share of in-home emissions or ownership of properties – between 0.12t/yr to 0.16t/yr. However, respondents who own their properties reduce their emissions using energy technology measures marginally more than those in rented properties. This follows the expectation that people would not be willing to invest in technologies or have the authority to install technologies in rented properties. Similarly, marginally smaller number of property owners find is difficult to reduce emissions through energy technologies, compared to the others.

Table 6. Stated reduction in in-home emissions under a PCT policy for different groups

	Total>4t budget		In-home>50%		Property ownership		
	Yes	No	Yes	No	Owned	Rented	Other
Short term, behavioural savings	0.17	0.11	0.15	0.16	0.16	0.16	0.12
Long term, technology related savings	0.67	0.38	0.61	0.57	0.63	0.54	0.44
All in-home savings	0.84	0.49	0.76	0.73	0.79	0.70	0.56
Short term, behavioural saving as % of average domestic emissions	6.07	3.93	5.36	5.71	5.71	5.71	4.29
Long term, technology related saving as % of average domestic emissions	23.93	13.57	21.79	20.36	22.50	19.29	15.71
All in-home savings as % of average domestic emissions	30.00	17.50	27.14	26.07	28.21	25.00	20.00
Share of respondents finding it difficult to reduce in-home emissions through behavioural means	-	-	17.0	18.8	17.4	16.9	20.0
Share of respondents finding it difficult to reduce in-home emissions through energy technology	-	-	15.8	17.8	15.8	17.6	22.5

4.8 Model for acceptability of the PCT policy

Although around three-fourths (76.2%) of the respondents reduced their emissions in response to the policy, that does not mean the policy was popular or acceptable. Descriptive statistics show that among the respondents who were emitting more than the allocated amount of permits, only 18.9% found it acceptable, and 37.6% found it unacceptable. The acceptance rate was naturally larger for those below the initial allocation, but still only 36%, which is somewhat surprising as these households would benefit from the policy. There were also around 24% of respondents with below 4t/yr emissions, who found the PCT policy to be unacceptable. Note that the question on acceptability was asked after the respondents have been shown the permit prices and after they have made the necessary adjustments in their energy consumption behaviours.

The acceptability of the PCT policy is explored further in Table 6, which presents the results of an ordered logistic regression, where the dependent variable has three ordinal categories – acceptable, not sure, unacceptable. Results show that those who found their emissions were larger than the allocated 4t/yr are less likely to find the policy acceptable. Respondents who were surprised by their emissions (to be higher than they expected) were more likely to find the policy acceptable. This indicates the importance of accurate knowledge of one’s carbon footprint. Respondents who believe climate change is an issue, agree that immediate action is required, or have made some lifestyle changes already are more receptive to the PCT policy. Those who have children are more likely to accept the policy, but other socio-economic characteristics such as education, employment, gender do not have any statistically significant impact on the acceptability of the policy. This is not surprising, given many of these variables possibly form the attitudes about climate change, which are already included in the model.

Table 7. Acceptability of the PCT policy (ordinal logistic regression)

Explanatory variable	Coeff.	s.e
Child(ren) in household	0.342**	0.187
Emissions above budget	-1.181***	0.223
Owns home	-0.183	0.152
Car User	-0.012	0.151
Climate change is result of human actions	0.949***	0.165
Individuals should act to reduce emissions (Agree)	0.634***	0.202
CO_2 higher than expected	0.332***	0.140
Already made some changes to lifestyle	0.492***	0.146
Employed full time	0.226	0.161
Male	-0.009	0.139
Have university degree	0.044	0.139
Low income	0.078	0.162
Age of participant	-0.007	0.006
Permit Price per tonne	0.000	0.001
Share of transport emissions in total	-0.154	0.318
Thresholds		
Between unacceptable & not sure	-0.691	0.467
Between not sure and acceptable	1.489***	0.470
No. of observations	834	
LR chi2(15)	175.93	
Prob > chi2	0.00	
McFadden R^2	0.098	
Log likelihood	- 803.96	

, * significant at 90% and 95% level respectively

5. Conclusions

This paper investigates the potential carbon reduction pathways from households under a personal carbon trading policy. As opposed to previous studies, which primarily investigate transport or in-home emissions separately, our focus was on a PCT covering both these emissions, which offers more flexibility and thus provide more efficient reduction. Around three-fourths of all the survey respondents opted to reduce their emissions, and the share is higher (nearly four-fifths) for those emitting more than the target allocation amount. Across all respondents over the three permit prices average intended reduction was 23%, which is larger than what a previous study has found (13.3% in Zanni et al. 2013, which had a very small sample).

Despite reducing some emissions, a large share (79.6%) of the respondents above the allowance limit still had to purchase some permits to cover at least part of their emissions, indicating the limits to reducing emissions for these respondents. However, this also points to the advantage offered by the

PCT policy whereby respondents can opt to choose their optimum amount of reduction and then buy permits to cover the rest.

Our primary focus was on how people trade-off or complement their emissions reduction options from transport and in-home energy use, when subjected to a PCT policy covering both. The least amount of reduction came from those reducing from transport only, followed by those reducing from in-home energy use only. These respondents were clearly constrained in reducing emissions from in-home energy use or transport energy use respectively. A PCT policy addressing only in-home (or transport) emissions would have put these respondents in a difficult position. On the other hand, the majority (53.6%) of the respondents opted to reduce emissions from both transport and in-home energy use activities. These respondents could also reduce their emissions the most. This clearly hints at the flexibility offered by a PCT covering both transport and in-home energy use, and reinforces the benefits of covering both the emissions together, compared to covering them separately under a PCT scheme.

On average car-owners could reduce their transport emissions substantially more compared to non-car owners. Similarly, a large share of respondents who fly a lot could reduce their transport emissions substantially. This indicates the relative ease for these respondents to substitute or reduce car trips or flights to reduce transport emissions. At the same time, around one-fourth of the respondents find it difficult or very difficult to reduce emissions from their transport energy use. This again reflects the differences in opportunities or flexibility to reduce carbon emissions among the respondents. An equal permit allocation therefore may not necessarily be the fairest allocation.

For emissions reduction from in-home energy use, longer term energy efficiency or renewable energy technologies result in larger reductions, compared to short-term behavioural responses to PCT. As such, although a smaller share of the respondents are inclined to reduce their emissions using the capital intensive energy technology options, their average intended reduction is much higher compared to those from short term, primarily behavioural, responses.

Permit prices have a small effect on the choice to reduce emissions but did not have any influence on the amount reduced afterwards. Gender appears to be the only demographic factor that affects both the choice to reduce emissions and also the amount reduced. In general, attitude toward climate change appears more important in reducing emissions while responding to a PCT policy.

While nearly three-fourths of the respondents expressed a willingness to reduce their emissions, the policy was not universally popular. Even among the respondents who had emissions below the initial allocation, i.e. those who would financially benefit from PCT, only around a third found the policy acceptable, while one-fourths still found it unacceptable. This is especially important since distributional burdens are often used as a measure of public acceptability of a policy and all the households below the initial allocation would have been assumed to be in favour of the policy using this metric (e.g. Wadud 2011). Our results show that such a simplified metric for acceptability could lead to incorrect conclusions.

Closely connected to the PCT scheme is the issue of embedded carbon. So far in this study, we have included only the direct emissions from personal transport and in-home energy use activities. However, it is possible (albeit resource-intensive) to calculate the embedded carbon of every consumption good and as such including them in a PCT scheme. Especially including food choices within the PCT scheme could give the consumers further options to reduce their consumption-based emissions, given the large carbon footprint of meat products (Audsley et al. 2009). While the design, monitoring and administration of a PCT covering all embedded and direct emissions would most likely be more challenging compared to a direct emissions approach, such a policy would clearly offer even more flexibility to the consumers in reducing their emissions.

One element of personal tradable permits that needs further investigation is the effects of permit prices and the potential for its increase. A substantial share of respondents reduce their emissions and still purchase permits from the market. This indicates that people prefer to reduce emissions initially, however as the easier options to reduce emissions are exhausted, they start to buy permits. The increased demand combined with the fixed supply of permits would likely increase prices of the permits further and induce some further reduction. This important feature has not been included here (or in any past studies) and future experiments should be designed in a way such that every respondent's action affects the combined market price of the permits.

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