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Unequal emissions – unequal policy impacts: how do different areas of CO_2 emissions compare?

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Abstract

Distributional implications of climate change mitigation policies are of interest to social policy scholars because they relate to important questions about fairness: which groups bear the highest burdens – or receive the greatest assistance – from these policies and how does this relate to their contribution to emissions? It is already well established that general carbon taxes are likely to have regressive impacts – placing higher relative burdens on poorer than on richer households – and it is often argued that these effects can be reversed, for example through rebate schemes or equal per capita carbon allowances. But does this equally hold for all areas of household CO2 emissions such as home energy, transport, and total emissions? And which role do household characteristics other than income and household size play for the distribution of benefits and burdens from mitigation policies? This chapter provides an overview of mitigation policies and examines potential distributional implications across different emission domains. The analysis is based on a dataset of household CO2 emissions that the authors derive from UK expenditure data. It shows that mitigation policies that only target home energy emissions are least fair from a distributional point of view, not only in terms of differences among income groups but also in relation to other household characteristics.

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1 Introduction

It is increasingly clear that radical policies to mitigate anthropogenic climate change (hereafter "mitigation policies") are urgently required as its impacts are already threatening food security, damaging ecological systems and creating new social inequalities, e.g. related to severe weather events. Such impacts are set to worsen and contribute to mass migration, resource conflicts and other catastrophic outcomes if greenhouse gas emissions from human activities continue to accelerate. An important element of mitigation policies will be to reduce the combustion of fossil fuels, and thus the release of carbon dioxide (CO_2), the greenhouse gas which contributes the most to current warming.

From a social policy perspective, an important question is how mitigation policies can be designed such that unjust distributional effects are, so far as possible, avoided. This requires proportionality in terms of people's financial capacities to bear burdens of mitigation policies as well as in terms of their relative contribution to emissions. Such proportionality is important both from a fairness perspective and for the public acceptability of such policies. Acceptability is likely to influence the likelihood that governments adopt them, as is borne out by the available policy research (Bristow et al., 2010).

It needs to be emphasised, that any such policies are unlikely to be implemented without a new global agreement on climate change mitigation. The current UNFCCC process would only implement such an agreement by 2020 at the earliest under the "Doha Gateway" set up at the latest COP meeting (Ritter and Casey, 2012). Nonetheless, there are a range of policy instruments which could be used to reduce CO_2 emissions. Their distributional implications may differ depending on their design and the area of emissions that they target.

Carbon taxes are generally perceived to be regressive – putting larger burdens on poor than on rich households relative to their income – because this is a general feature of taxes levied on consumption (Johnstone and Serret, 2006; Metcalf and Weisbach, 2009). While several previous studies (AEA and Cambridge Econometrics, 2008; Boyce and Riddle, 2007; DEFRA, 2008) have shown that regressive effects can be reversed through equal per capita carbon trading schemes or schemes in which revenues from mitigation policies are redistributed to the population, others have questioned the fairness of these schemes (Posner and Weisbach, 2010: ch. 6; Starkey, 2008). In particular, they highlighted the possibility that some groups in society might have higher emissions due to "structural circumstances" rather than "expensive tastes" (Dworkin, 1981a, b; Starkey, 2012: 15)[2], e.g. a need for higher indoors temperatures if someone is feeling the cold more or lives in a colder area. From a social policy perspective, this is relevant in several ways: firstly, which household

[2] The distinction between needs and wants or tastes is notoriously difficult and outside of the scope of this chapter. See Starkey (2008) and Druckman and Jackson (2010) for a discussion on emissions needs.

characteristics other than income are important for the responsibility or "need" for emissions? If there are groups with higher emission "needs", would this justify additional support to these groups, e.g. in form of infrastructure investment or financial compensation to cope with the cost of emission reduction? We address these questions by examining potential distributional implications of mitigation policies, considering a range of household characteristics whilst controlling for income and household size.

Furthermore, little is yet known about how this differs across emission domains as most studies that examine distributional implications of mitigation policies for a several of household characteristics usually just focus on one area of emissions or, if emission areas are compared, only provide descriptive analysis that does not control for income or other factors (e.g. Brännlund and Nordström, 2004; DEFRA, 2008; Feng et al., 2010; Halvorsen, 2009; Hassett et al., 2009; Klinge Jacobsen et al., 2003; Labandeira and Labeaga, 1999; White and Thumim, 2009). A comparison of emission domains is also important for examining questions such as: how does the regressiveness of carbon taxes differ in direct comparison? Can equal per capita rebates reverse regressiveness equally for all areas of emissions? By directly comparing potential distributional implications within one study, one can be more confident to separate out what is really distinctive about an emissions category as peculiarities of particular studies arising from differences in data sources and time periods are avoided.

The chapter is structured as follows. Section two will provide a brief overview of mitigation policies and debates around distributional implications. Section three describes the data and methods applied. Section four examines and compares potential distributional implications of different hypothetical mitigation policies. Here the focus lies on a simple £100 per tonne of carbon tax scheme and a 'tax and 100% rebate' scheme which re-distributes the tax revenue on a *per capita* basis. Section five concludes and discusses limitations.

2 Background: mitigation policies and distributional implications

In economic terms, climate change is market failure caused by anthropogenic greenhouse gas emissions, which are "negative externalities" (costs falling on third parties) arising from production and consumption. Hence governance is required to reduce emissions, usually seen as intervention by a national government. Here, one can distinguish traditional regulation from economic instruments (Helm, 2005). For many commentators, economic instruments are an essential part of policy to reduce greenhouse gas emissions because they offer increased flexibility and scope, and, hence, cost-efficiency over a purely regulatory, "command and control" approach. However, economic instruments are sometimes criticized because they put a price on a commons, the earth's atmosphere. That is, they create property rights over what was previously unowned and freely accessed by all. Another point of contention is that some rich people will be able to maintain their high carbon lifestyles as they are able to pay a higher price for their consumption. However, within schemes that set a strict overall cap on emissions this will not be possible for the generality of the rich. For the bulk of emission reductions would need to be based on a cut-back of their consumption, which is disproportionately responsible for emissions. In short, we acknowledge considerable ethical concerns about, and potential shortcomings of, market-based mitigation policies. However, it is plausible that they form a part of any viable plan to avoid dangerous climate change, since emissions cannot be regulated away overnight.

Carbon taxes and cap and trade schemes are the two main classes of economic instruments discussed. Both effectively put a price on emissions. In theory, then, both schemes create financial incentives to switch to low-impact lifestyles and production methods. The key difference between the two is that environmental taxes – often termed 'Pigouvian taxes' – levy a charge on environmentally damaging activity, whereas cap and trade fixes the amount of the activity. For example, suppose less petrol needs to be sold in order to reduce the emissions its burning causes. A tax would be raised on sales, in the expectation that the resulting price increase would reduce consumption. The price increase will equal at most the value of the tax. However, it is uncertain how consumers respond to the tax: will they substantially reduce their consumption of petrol or will they just pay a higher price? The resulting reduction in emissions is thus unknown. In contrast, the cap part of cap and trade would limit the annual amount of petrol available to the economy whilst the price would depend on the level of consumer demand.

Mitigation instruments can apply at different levels of economic activity: up-, mid- or downstream in the chain of production running from natural resource extraction down to the end user. An upstream scheme would apply a tax or emissions cap to the production and / or import of fossil fuels into the economy, thus achieving broadest coverage whilst minimising the number of actors included in the scheme and the related administrative costs. Examples are the proposals for upstream carbon taxes (Hansen 2009), Cap and Dividend (Barnes 2003), Cap and Share (AEA and Cambridge Econometrics 2008; FEASTA 2008) or the Kyoto2 scheme (Tickell 2008). A mid-stream scheme would apply to companies outside the primary energy sector producing goods and services. The largest existing cap scheme, the European Union Emissions Trading Scheme (EU ETS) is an example, which applies, broadly, to energy using facilities above a certain size. Downstream schemes apply to individuals, and in some variants businesses, who would have carbon accounts and trade permits themselves (DEFRA 2008a; Fleming 2007).

Within cap and trade schemes, several options exist as to how emission permits are allocated to the participants – all of which have different distributional impacts. Initial Carbon budgets can be allocated to the participants in the scheme either free of charge, through auctioning, or through a mix. For example, in the European Union Emissions Trading scheme (EU ETS), permits have largely been given away for free to companies in the participating sectors, depending on their previous and estimated future emissions. This approach is called 'grandfathering'. It is widely believed that this leads to windfall profits for companies as they will pass the opportunity cost of using a permit onto customers, or sell a considerable volume of their allocated permits. In other words, grandfathering is likely to have regressive effects (Shammin and Bullard 2009; Sijm et al. 2006). In contrast, auctioning the permits makes the polluters pay whilst the distributional effects depend on the capabilities of the targeted industries to pass on the costs and the availability of alternatives to these goods for consumers. Furthermore, auctioning emission permits to the participants creates a revenue stream for the government or organisation that issues the permits. We will discuss below how those revenues can be used to counter-balance possible regressive effects of mitigation policies.

2.1 Distributional implications

Regressivity is a general feature of taxes on consumption, and therefore one would expect carbon taxes to be regressive. This expectation also carries through to various types of cap and trade schemes. Overall, the literature on the distributional effects of mitigation policies confirms this prior view (Dresner and Ekins 2006; Metcalf and Weisbach 2009; Parry 2004; Serret and Johnstone 2006, to name but a few). However, there are exceptions to this rule depending on the source of pollution that is targeted and how the revenue arising from the policy is used. We will review results from previous studies on carbon taxes, before discussing the ways in which revenue from mitigation policies can be used and their distributional implications.

There is a general consensus that taxes on home energy use are regressive if the revenue from those taxes or charges is not redistributed to the citizens (Baranzini, et al. 2000; Barker and Köhler 1998; Dresner and Ekins 2006). The effects of such taxes, covering electricity and heating fuels, are particularly regressive because home energy use is relatively evenly distributed across income deciles (at least in industrialised countries) as shown below in the results section. This means that low income households spend much higher shares of their income on home energy than richer households (Dresner and Ekins 2006; Druckman and Jackson 2008; Wier et al. 2005).

Schemes which put a price on carbon emissions further upstream, for example through a tax on total carbon emissions or a cap and trade scheme that applies only to those who introduce fossil fuels into the market, have an effect not only on downstream energy prices but also on *all* other goods and services due to the higher price of the energy used in their production. Since overall expenditure including consumer goods generally increases less than proportionally with income (see, for example, ONS (2009), table A9, for the UK case), upstream mitigation policies are therefore likely to have additional regressive effects. These will be substantial because indirect emissions comprise around half of UK households' overall emissions (52.9 per cent in our study) However, a complication is that upstream mitigation policies will have weaker regressive effects than downstream policies if companies that are affected by the upstream policies are not able to fully pass on the costs of the tax to customers (e.g. Baranzini et al., 2000; Wier et al., 2005).

The results are more varied when it comes to carbon taxes on transport or motor fuels. Several studies state that motor fuel taxes place higher burdens on middle income households than on poor or rich households (Blow and Crawford, 1997; Poterba, 1990). For the UK, Dresner and Ekins (2004) found that taxes on motor fuels or vehicles have progressive effects for the whole population but regressive effects amongst motorists; (see also Klinge Jacobsen et al., 2003; Tiezzi, 2005)).

Some studies compare the distributional effects of energy or mitigation policies for different domains such as home energy and transport. These find that taxes on home energy emissions are more regressively distributed than taxes on transport emissions. However, they often only concentrate on distribution over income. For example, Barker and Köhler (1998: 398) provide regressivity ratios separately for taxes on home energy, petrol and total CO2 emissions for 11 EU countries including the UK; Hassett and Mathur (2009) examine the distribution of tax burdens over income groups separately for CO_2 taxes on direct and indirect emissions in the United States; and Wier et al. (2005) compare the distribution of burdens from an upstream CO2 tax to one on direct energy only over income groups for Denmark but none of these studies considers other household characteristcs. Klinge Jacobsen et al. (2003) compare impacts of a motor fuel and home energy tax for Denmark using Gini coefficients and distributions over different household groups but without controlling for income.

The literature summarised above shows that if the revenue from carbon taxes or carbon trading schemes are not earmarked for redistribution to citizens, they are highly likely to have regressive effects, with the possible exception of schemes that only include transport emissions. But the distributional outcomes of mitigation policies crucially depend on how the revenues are used and distributed. Revenues arise, for example, through carbon taxes or if emission permits within trading schemes are (partly) auctioned. Three options for redistributing revenues are salient in the literature, though such options could also be combined in different proportions.

1) The revenue can be used to finance measures that further reduce greenhouse gas emissions or support behavioural adaptation, as proposed by Tickell (2008). For example energy efficiency measures through home insulation programmes, investments into renewable energy or public transport subsidies, training and R&D can be supported. The distributional effects depend on who is benefiting from those programs. For example, means tested home insulation programmes like the Warm Front programme in the UK benefit low income households, and subsidies for public transport currently primarily benefit low income urban households. Policies that aim to expand renewable energy, in contrast, can have regressive effects if they work through financial incentives to (already wealthy) homeowners (e.g. see Monbiot, 2010 on the distributional implications of the feed-in tariffs for solar electricity).

2) The revenue from taxes or auctions under cap and trade schemes can be partly or fully redistributed to the population and / or industry by reducing other existing taxes. This is frequently discussed in the environmental economics literature as the 'double dividend' hypothesis of 'green taxes'. This is the proposition that environmental taxes generate dual benefits. Whilst the tax creates incentives to reduce the activities which give rise to negative externalities, that is, the revenue generated can be 'recycled' for any other purpose, including the reduction of taxes on income or capital, which are often held to discourage economic activity, or VAT which is regressive. If we return to our example on petrol, the tax would not only set an incentive for customers to buy less petrol, but the raised revenue could be used to offset other tax burdens, for example income tax. From a mainstream economics perspective, this would limit market distortions that those taxes might imply, for example reduced work incentives. If the entire revenue is earmarked to decrease/remove other taxes, the tax reform is termed 'revenue neutral', meaning that the costs of the new source of revenue are completely compensated through the reduction of other taxes or charges. However, one problem with the "double dividend" hypothesis is that the revenue from green taxes should decline over time if the tax incentive is working, e.g. if carbon emissions are reduced. If this is the case, total government revenue would be shrinking, creating a need to increase other types of taxes.

Studies on the effects of reducing social security contributions, taxes on income, or VAT so far show mixed results, demonstrating that distributional implications of such measures cannot be generalised but depend on the specifics of the existing tax and benefit system and "double dividend" reforms introduced. For example, a study on the German "eco tax" demonstrated that the reduction of the contribution to pension insurance increased previous regressive effects as the reduction mainly benefited middle income households but disadvantaged low income, unemployed and pensioner households (Bach et al., 2002; Bork, 2006). Conversely, studies on the reduction of income tax report progressive effects if taxes on low incomes are reduced more than those on higher incomes (e.g. Grainger and Kolstad, 2008; Metcalf, 1999; Metcalf and Weisbach, 2009). Labandeira et al.'s (2009) study of a revenue-neutral reduction of VAT as a compensating mechanism also showed progressive effects. A second option is for the revenue to be returned to citizens by increasing specific social security benefits, for example, child benefit or means-tested benefits such as tax credits or income support. With this option, regressive effects can be considerably reduced or even reversed as several studies have demonstrated (Baranzini et al., 2000; Dresner and Ekins, 2006; Ekins and Barker, 2001; Ekins and Dresner, 2004).

3) A final option is to return the revenue from mitigation policies directly to individuals or households as a lump sum. There is a substantial literature discussing this option (Barker and Köhler, 1998; CEC, 1992; Dinan and Rogers, 2002; Ekins and Barker, 2001; Parry, 2004; West and Williams, 2002). In the United States, a 'carbon tax and 100% dividend' proposal has recently been promoted by climate scientist James Hansen (2009). An equal per capita rebate or free allocation of emission permits (which is distributionally equivalent) is also integral to Personal Carbon Trading (PCT) (DEFRA, 2008), Cap and Share and Cap and Dividend proposals (Barnes, 2003; FEASTA, 2008). Under PCT, individuals receive equal per capita tradable carbon allowances. Under Cap and Dividend, an independent climate trust would auction off the permits to upstream fossil fuels producers or importers and redistribute equal per capita rebates to the citizens. Under Cap and Share, an independent trust would allocate each citizen with an equal share of the nation's emission permits which they can then sell via banks or post offices. Fossil fuel producers or importers would have to buy the permits to cover the carbon content of the products that they intend to sell on the market.

Studies which examined the distributional effects of equal per capita permit or rebate schemes usually conclude that this option has strongly progressive effects on average when applied to total or direct emissions (AEA and Cambridge Econometrics, 2008; Barker and Köhler, 1998; DEFRA, 2008; Dinan and Rogers, 2002; Parry, 2004; Starkey and Anderson, 2005). This means that low income households will gain more (lose less) as a share of their income than high income households. For example, in a Cap and Share or Cap and Dividend scheme, any individual who consumes less than the capped level of emissions will financially gain from the rebate/revenue (AEA and Cambridge Econometrics, 2008; Boyce and Riddle, 2007). As low income households usually generate relatively low emissions, they may gain financially from the scheme. Even if gains were equal across the income distribution, they would be larger as a share of income for poorer than for richer households. If poorer households gain more in absolute terms than richer households, the distributional effect will be strongly progressive in relative terms.[3] However, questions have been raised regarding the fairness of equal per capita schemes as they are not taking higher "needs" for emissions that some people in society may have into account (e.g. Posner and Weisbach, 2010: ch. 6; Starkey, 2008; Starkey, 2012). Whilst a discussion about a distinction between needs and wants when it comes to emissions goes beyond this chapter, our analysis of relationships between a whole range of household characteristics and emissions will help identify potential groups with higher emission needs which may need to be addressed through complementary policies.

Furthermore, the studies outlined above estimate effects of mitigation policies either within a single area or for total emissions. There are no studies we are aware of that compare the distributional implications, taking a range of household characteristics into account, of per capita rebate schemes for different areas of emissions. Do equal per capita schemes reverse regressiveness in all areas? What are potential implications for different types of households arising from equal per capita schemes related to different areas of emissions? We will examine this question below.

3 Data and limitations

3.1 Data

For the UK there is currently no representative CO2 emissions dataset at the household level available. Research on the distribution of emissions across households thus relies on other data sources to estimate household emissions. In this paper, we convert rich information on households' expenditure into CO2 estimates. Our household expenditure data derive from the UK Living Costs and Food Survey (LCF) for the years 2008 and 2009 and its predecessor, the Expenditure and Food Survey (EFS), for the years 2006 and 2007 which, merged, provide us with a total household sample size of 24,446. The LCF/EFS is an annual survey, covering detailed information on expenditure for a large number of consumer items and services according to the UN *Classification of Individual Consumption According to Purpose* (COICOP) and a range of socio-economic variables. We convert households' expenditure into CO2 emission estimates using the following methods.

[3] The distributional effects of lump-sum rebate schemes also depend on the level of the cap. PCT or Cap and Share/Dividend schemes will be progressive as long as low income households generally consume less than their initial allocation of emissions/energy. If a scheme applies internationally with the same per capita allocation across the whole scheme, its distributional effects are likely to be regressive in highly developed countries. For example, a global scheme which allocated a budget of 4 tonnes of CO_2 per year to each citizen in 2006, slightly below the then world average of 4.39 tonnes CO_2 per person, would have regressive effects in most industrialised countries as their average per capita emissions are much higher (in the UK, annual per capita emissions were 9.37 tonnes CO_2, in the US 19 tonnes CO_2 in 2006, according to the World Bank Development Indicators.). However, those schemes would be extremely progressive in less developed countries. See Wakeford (2008) and Sharan (2008) on the impact of a Cap and Share scheme on South Africa and India respectively.

For *home energy* we use Tables 2.2.3 and 2.3.3 of the Quarterly Energy Prices statistics by the Department for Energy and Climate Change (DECC, 2011a, b) providing us with information on annual domestic electricity and gas prices per kWh, including standing charge and VAT, for three payment methods and each electricity/gas region. Since the LCF/EFS include variables on payment method and region, we can estimate units of energy consumption separately for piped gas and electricity. In addition, our home energy CO2 estimates include emissions from heating oil, bottled gas, coal and wood which comprise 9.8 per cent of the UK households' CO2 home energy emissions estimate. Here we use Sutherland (2012) tables to convert expenditure into units of consumption.

For *transport CO2 emissions* we estimate litres of <u>motor fuel</u> (petrol and diesel) consumed using AA statistics (AA, 2006-2009) of monthly motor fuel prices for each government region. For <u>public transport</u> we estimate kilometres travelled employing information on average annual passenger miles for train, tube, bus and coach journeys from the National Travel Survey for Great Britain (DfT, 2011: table NTS0305) and the Northern Ireland Travel Survey for Northern Ireland (DRDNI, 2011: table 3.1). Flight emissions are estimated by approximating <u>flight kilometres</u> merging information from the LCF/EFS survey on the number of person flights per household within the UK, Europe and outside Europe with average mileage for flights to these destinations calculated using the NTS and the International Passenger Survey.

DECC CO2 conversion factors (DECC and DEFRA, 2011) provided for different fuels and modes of transport are then applied to units of consumption of home energy, litres of motor fuels and kilometres travelled by mode of transport to estimate CO2 emissions.

To estimate *indirect emissions* we use the Resources and Energy Analysis Programme (REAP) database which provides estimates of total CO2 emissions arising from consumption by UK households of 56 COICOP categories in 2006 (Paul et al., 2010). These data are used to generate CO2 per pound expenditure factors for 50 consumption categories which we apply to household expenditure to estimate emissions. Expenditure data for 2007-9 are deflated to 2006 prices using Consumer Price Index Statistics for each of the consumption categories. For further details see Büchs and Schnepf (2013, forthcoming).

3.2 Limitations

Estimating emissions based on household expenditure is limited in several ways. Firstly, the data available to us in the LCF/EFS and external statistics cannot account for some of the heterogeneity of emissions in the "real world". For example, neither the LCF/EFS or the DECC home energy price statistics provide information on the tariff that a household is subscribed to; for public transport tickets and flights the provider of the service and type of ticket (first or second class or reductions for pre-booking or railcards) are unknown; and for other consumer items we have no information on brands. This might also lead to a slight overestimation of emissions by rich people because they might, on average, purchase more expensive products even though the actual product has similar or even lower emissions (e.g. local organic produce from the farmers market compared to that from a supermarket, shipped round the world and cooled over long periods) (Girod and De Haan, 2010).

Another limitation results from the 'infrequency of purchase problem'. The LCF collects expenditure data through a survey covering quarterly or annual expenditure for more infrequent purchases such as electricity and gas bills, cars, season tickets and package holidays. However, some more frequent expenditure items are only collected through two-week diaries kept by each household member. For all these expenditures, expenditure estimates might be affected by the 'infrequency of purchase' problem. For some items we can estimate the extent of the problem, for example, we know that only 1.2% of households have an expenditure on flights, whilst 41% of households state in the survey that they had at least one flight in the past 12 months (consequently, we use the survey, not the expenditure data, to estimate flight emissions). Furthermore, we know that 18.2% of households with a vehicle have not purchased any petrol during the diary window whilst data from the National Travel Survey indicate that only around 0.1% of households with a vehicle have not driven their car within the last year.

For our *CO2 transport estimate* this problem most clearly affects motor fuels and public transport which contribute 74.3 per cent of our total transport CO2 estimate (the rest deriving from flights for which we use the survey measure) and 16.2 per cent of our total CO2 UK estimate. For *home energy* the problem is less relevant with heating fuels collected through the diary such as oil, bottled gas, coal, wood and peat contributing only 2.6 per cent to total emissions and prepayment electricity only used by 15.0 and gas pre-payments by 12.2 per cent of households with access to mains gas. All *indirect CO2 emission* estimates are based on diary data. Whilst proportions of households with zero expenditure can be high for individual categories, none of the households has zero expenditure on items that are included in indirect emissions (see Table 1).

Does the infrequency of purchase problem affect our analysis? All previous studies using expenditure data for estimating CO2 emissions implicitly or explicitly (DEFRA, 2008: 13) assume that CO2 estimates based on diary data provide unbiased estimates of population *mean values*, as zero expenditure from infrequently purchased items should be compensated by expenditures higher than the actual consumption rate of those households who stock up during the diary period. However, *measures of dispersion* and inequality such as standard deviation and Gini coefficients are likely to be overestimated. For this reason, we use ratios of mean emissions comparing different income quintiles rather than the gini coefficient for examining emissions inequality and distributional implications of mitigation policies. In the last section, we present OLS regression results. Since the measurement error relates to the dependent variable, we need to be aware that standard errors of coefficients are likely to be inflated.

4 Results

4.1 CO2 emissions in the UK by emission area

Table 1 shows mean and median household CO2 emissions for our pooled sample. Median UK total household emissions are 17.1 tonnes of CO2 emission per year whilst the mean is as high as 20.2 tonnes, demonstrating a positively skewed distribution. Home energy emissions constitute 25 per cent of total emissions. 22 per cent of total household emissions originate from transport, including flight emissions that contribute as much as 6 per cent on average to households' total emissions (equating to only 0.6 private flights per person per year or 1.3 flights per household). The remaining 53 per cent consist of indirect emissions incorporated in other goods and services.

4.2 Inequality of emissions

We know from previous research that emissions are unequally distributed across UK households (see review above) but how does this compare for different areas of emissions? Table 2 shows measures of variation and inequality for home energy, transport, indirect and total emissions. The coefficient of variation (CV), which is a standardised measure of the dispersion of a variable around the mean, shows that total, home energy and indirect emissions show similar levels of dispersion with CVs of 61.8, 63.5 and 66.8 respectively, whilst transport emissions vary more around the mean, particularly if 'zero' emissions are included, with a CV of 102.2. However, since the coefficient of variation is sensitive to the infrequency of purchase problem, it is likely to be inflated, particularly for transport emissions. Column 4 shows mean emissions for households in the lowest income quintile which can be compared with mean emissions for households in the highest income quintile in column 5. Since sample sizes are fairly large with almost 4,900 households per quintile we can assume that these mean figures are not substantially influenced by infrequency of purchase. Column 6 shows the ratio of mean emissions for the highest and lowest income quintiles, demonstrating that transport emissions are most unequally and home energy emissions most equally distributed.

Figures 1 and 2 graph the distribution of emissions over equivalised income deciles, confirming that emissions in all areas are unequally distributed and rise with rising income, but mostly so for transport emissions. The 25% of households with the lowest incomes only emit 11 per cent of all transport emissions, 14 per cent of indirect and 15 per cent of total emissions, whilst the richest emit 42, 38 and 37 per cent respectively. However, for home energy, the poorest 25% emit

20% of all emissions, whilst the richest 25% emit 30%. These inequalities illustrate the vast contribution that rich households make to overall emissions: If all households restricted themselves to CO2 emissions equal to those of the poorest 25 per cent, average UK household emissions would decrease from 20.2 to about 12.1 tonnes and total annual UK household emissions from 513 to 306 million tonnes. If achieved by 2020 and compared to a baseline of 586 million tonnes in 1990 (DECC, 2012), this would equate to a reduction by 48 per cent to the 1990 baseline - much more drastic than the currently envisaged reduction of 20 per cent by 2020 that the European Union subscribed to. Again, this relates back to policy implications of carbon reduction policies, highlighting issues around fairness if low income households are penalised.

4.3 Distributional implications of mitigation policies

To examine potential distributional implications, we first calculated the tax burden from a hypothetical tax of £100 per one tonne of carbon dioxide emission. The tax burden is expressed as a proportion of equivalised household income. Figure 2 suggests that taxes are regressively distributed for all emission domains, apart from transport where they appear to be near neutral. Households in the lowest equivalised income decile would lose 5.6 per cent of their income from taxes on home energy, 7.6 for indirect, 2.0 for transport and 15.3 per cent for taxes on total emissions. This compares to 1.1 per cent, 2.9 per cent, 1.4 per cent and 5.3 per cent respectively for households in the highest equivalised income decile.

As discussed above, it is assumed in the literature that the regressiveness of carbon taxes can be reversed, for example by redistributing the tax revenue to the population on a per capita basis. To estimate distributional implications we estimate "net rebates" as a proportion of annual disposable income per household. This is achieved by substracting the tax burden from the rebates that each household received (based on the number of adults or adults and children in a household) and expressing this as a proportion of disposable household income. The net rebates have a mean of zero. Figure 3 shows the estimated distributional outcome of such as scheme and suggests that regressive effects can indeed be reversed for total, indirect and transport emissions whilst income effect seem very marginal for home energy emissions across the income distribution.

This can be examined further using the Suits index for tax progressivity which compares the cumulative distribution of the tax burden to the cumulative income distribution (Suits, 1977). Since the Suits index can be calculated based on mean emissions and mean income per income decile, it is less affected by the infrequency of purchase problem than the Gini coefficient that is sometimes used to examine changes in income inequality before and after a tax or benefit reform. The Suits index reaches from -1 (extreme regressivity) to +1 (extreme progressivity). Results are presented in table 3: The Suits index confirms that taxes on home energy have most regressive effects, followed by taxes on total emissions. Conversely, taxes on transport emissions are near neutrally distributed or even progressive for flight emissions. The remainder of the table presents the *change* of the income ratio comparing the highest and lowest income quintiles *after* different mitigation policies are applied, including the £100 carbon tax, an equal per adult tax and rebate (T&R) scheme and an equal per adult T&R scheme that also includes half a rebate per child. Positive figures indicate that income inequality rises after the policy is applied and vice versa. To achieve comparability, the changes in income ratios are scaled up based on the proportion that they contribute to total emissions in the right-hand side of the table (e.g. since home energy emissions constitute 25 per cent of total emissions, the ratio change is scaled up by a factor of 4).

Results suggest that T&R schemes on home energy reduce income inequality only very marginally whilst those applied to transport emissions have stronger progressive effects. This is an interesting result as it may question the effectiveness of equal per capita home energy allowances (DEFRA, 2008; Parry and Williams, 2010). Furthermore, the scheme that includes allowances for children suggests stronger progressive effects across all emission domains than the scheme that only distributes rebates to adults.

Most of the existing work on distributional implications of mitigation policies focusses on income. However, household characteristics other than income may well play an important role in influencing distributional outcomes of mitigation policies, including age, employment status, education and rural/urban location. To examine the relationship between other household characteristics and distributional impacts, we estimated mean net rebates from a £100 per tonne of CO2 adult-only T&R scheme and tested whether means differ for specific groups (see table 4). First, the different role of household size for different areas of emissions becomes evident: whilst two-adult households lose significantly more from adult-only T&R schemes on total and transport emissions than one-adult households, the opposite is true for home energy. However, economies of scale also become relevant for total and transport emissions for households with three or more adults. Households with children also receive significantly lower net rebates than households without children who 'gain' on average for all schemes. This pattern reverses if the scheme allocates each child half of the lump sum rebate (results not shown).

The results also show an interesting relationship between age and distributional outcomes. Previous research has shown that the relationship between age and emissions takes on an inverse u-shape, apart from home energy emissions which still rise with high age (Buchs and Schnepf, 2013). This is confirmed when we compare mean net rebates: on average, households with reference persons aged 35-65 receive significantly lower rebates, and those with reference persons aged 65+

significantly higher ones, compared to households with reference persons under 35. In contrast, the oldest age group 'loses' more than the other two groups for home energy schemes. Education also makes a difference to the financial implications of this scheme: Those with highly educated reference persons (defined as attending full-time education for 16 or more years) receive significantly lower net rebates than households in which no-one attended full time education for more than 11 years.

Rural households (defined as those in settlements of fewer than 10,000 inhabitants) receive lower net rebates than 'urban' households (households in all other areas), apart from schemes that apply to flights and public transport only, when there is no significant difference. Workless households (defined as households with at least one person of working age but without any working age person in employment) receive significantly higher net rebates than households in which at least one person of working age is in employment. Female headed households receive significantly higher net rebates than male headed households for schemes that apply to total and transport emissions, but lower rebates for schemes that apply to home energy emissions. Whilst households with 'non-white' reference persons receive significantly higher rebates than other households in most cases, they 'lose' out from schemes that only apply to flights. Finally, whilst poor rural households with vehicles 'lose' on average from T&R schemes that apply to motor fuels and home energy, they 'lose' significantly less than rich rural households with vehicles and they 'gain' from all other schemes.

Even though some groups are estimated to 'gain' on average from T&R schemes as demonstrated above, a certain proportion of households with these characteristics will still 'lose' from these schemes as they emit more than the rebate that they are allocated. Table 5 provides an overview of the estimated proportion of households in each group 'losing' from an adult-only T&R scheme across the different emission domains. This confirms that, on average, considerably lower proportions of low income, older, childless, female headed low educated, urban and workless households 'lose' from these schemes than their counterparts. However, the proportion of households 'losing' from these schemes can still be considerable, for example, amongst low income households 21.1 per cent are estimated to 'lose' from a scheme on total emissions, 42.5 per cent in relation to a home energy emissions scheme 18.7 per cent within a scheme targeting motor fuels. Furthermore, there are some exceptions to the general pattern that higher proportions of well-situated households 'lose' from T&R schemes, particularly for schemes on home energy emissions for which higher proportions (around half) of households with older reference persons, female headed households and 'low educated' households 'lose' than their counterparts.

Clearly, many of these household characteristics are related, such as high income and high education or rural location and car ownership. Which characteristics still make a significant difference to households' estimated net rebates from a T&R scheme after income and other factors are held constant can be examined applying multivariate regression analysis. In the remainder of this chapter we present results from OLS regression of net rebates from a £100 per tonne T&R adult-only scheme on total, home energy and transport.[4]

The first three columns show models that only include income and household size as independent variables, columns 4 to 6 present models that include a range of other household characteristics and columns 7 and 8 show results for total and home energy emissions, also controlling for type of dwelling and heating type. Missings are excluded in all models to make the results comparable. Robust standard errors to address heteroskedasticity as well as sampling weights are applied in all four models. Error terms were not perfectly normally distributed but results were robust against exclusion of regression error outliers without significant changes in coefficients. The models presented here include regression outliers.

The results confirm that an increase in income is related to 'losses' from a T&R scheme (here measured as annual disposable income divided by 10,000). A comparison of results after standardizing the values of the dependent variables confirmed that effect sizes are greatest for schemes on total emissions and lowest for home energy (results not shown). Results in table 6 also show that each additional adult in the household is associated with further 'gains' from and adult-only T&R scheme whilst additional children tend to be associated with 'losses' from these schemes compared to households without children. If children receive half an allowance each, each additional child is associated with a significantly higher allowance compared to households without children even after controlling for other factors (regression results for these models not shown).[5]

Interestingly, high education remains associated with significant 'losses' (compared to households in which none of the members attended full time education for more than 11 years) from T&R schemes across all emission domains even after controlling for income and other factors.

Female headed households 'lose' significantly more from schemes on total and home energy emissions than male headed households. Workless households tend to 'win' from schemes on total and transport emissions compared to households in employment but do not significantly differ from their counterparts in relation to home energy schemes.

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[4] The net rebate variables are divided by 1000 to rescale coefficient sizes. The 1st and 99th percentile of the net rebate and income distribution are excluded from the regression analysis to minimise the influence of outliers.

[5] All other patterns described above remain very similar in the model which allocates half an allowance to every child, apart from ethnic minority households' rebates on transport emissions which are no longer significantly different to 'white' households, probably related to the significantly higher number of children in ethnic minority households (1 child on average (se 0.03) compared to 0.5 (se 0.01) for "white" households).

Rural households ‘lose’ from all types of T&R schemes, suggesting that they use more energy for heating their homes and for travelling than urban households even after controlling for income, education, housing and vehicle ownership. However, rural location is no longer significant in the full model that also controls for dwelling and heating type as well as home ownership. This suggests that higher home energy emissions of rural households are largely accounted for by a higher proportion of detached houses and oil central heating. As one would expect, additional numbers of bedrooms and owning a car ‘reduce’ rebates from T&R schemes on all types of emissions because they relate to higher emissions from home energy and transport. The ‘full’ model of rebates on total and home energy emissions also indicates that owning an accommodation outright or through a mortgage ‘reduces’ the rebate compared to households who are renting.

5 Conclusion and Discussion

Comparing estimated distributions of burdens from carbon taxes and net rebates from T&R schemes across emission domains in the UK provides several insights. According to income ratios, transport emissions were most unequally distributed in the sample, followed by indirect, total and home energy emissions. We also found that carbon taxes on transport are less regressive than taxes on total or home energy emissions, confirming findings from other studies (e.g. Barker and Köhler, 1998; Klinge Jacobsen et al., 2003). Taxes on flight emissions were slightly progressive based on the Suits index and near neutral using changes in income ratios whilst taxes on motor fuels remained to be more regressive. This contrasts to findings by Barker and Köhler (1998: 398) and Dresner and Ekins (2004) who found taxes on motor fuels to be neutral or progressive in the UK. This may well be because car ownership amongst low income households was much lower in the mid to late 1990s. In 1995 NTS data record just under 40% of sampled households in the lowest income quintile as owning cars, but by 2008 this had risen to 60% (Stokes and Lucas, 2011). In our data, by 2009 car ownership was an estimated 48% in the lowest income decile.

Our results also confirm that T&R schemes, generally speaking, have progressive distributional effects, based on a comparison of income inequality before and after applying the T&R schemes. However, this was less clear for the home energy scheme which was surprising given that per capita schemes have been advocated for reversing regressive effects of home energy taxes (DEFRA, 2008; Parry and Williams, 2010). T&R schemes on total and transport emissions also appeared to be slightly more progressive if allowances for children were included.

Furthermore, employing multivariate analysis suggests that household characteristics other than income and household size have important, independent associations with distributional outcomes and may thus need to be considered in the design of mitigation or other complementary policies as they may indicate greater emissions “needs” or responsibilities for emissions – including rural location, type of heating and dwelling, age, worklessness, gender and high education. This add weight to the point so far most forcefully raised by Starkey (2008; 2012) that equal per capita allowances or rebates may not be fair as they do not take these responsibilities and/or "needs" into account. Whilst per capita schemes are perhaps least costly from an administrative point of view, they may need to be complemented by additional schemes that offer compensation to people who have higher emissions due to circumstances beyond their own choice.

Due to several limitations, results presented in this chapter need to be treated with caution:

- Distributional implications across emission domains are compared by applying the same tax rate in each area. If the degree of regressiveness or progressiveness is compared across emission domains, results might differ if different tax rates are applied to different areas.
- We only applied a very simple method of simulating distributional outcomes by focussing on the change in household income after the tax or T&R scheme is applied. More detailed simulation exercises would also introduce the complexities of the existing tax and benefit system and could examine how changes based on mitigation policies interact with other changes in the tax and benefit system.
- In relation to T&R schemes we referred to 'gains' and 'losses' from these schemes. However, if a declining upstream cap on emissions was set (which is necessary if emission reduction targets are to be met), financial 'gains' from these schemes would not translate into overall higher consumption or increases in material living standards. This is because the economy would be shrinking overall to the extent that alternative energy sources and efficiency gains are not fully substituting for fossil energy. Monetary income from the scheme might not be falling because of the increased scarcity value of fossil fuels, but money is, ultimately, only a claim on goods and services produced. The limitation of our analysis here is intrinsic to static microsimulation, which allows a detailed analysis of instantaneous effects at the cost of assuming unchanged behaviour.
- Due to the infrequency of purchase problem outlined above, some measures of distribution or inequality are likely to be inflated, particularly for transport related emissions.

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Unequal emissions – unequal policy impacts: How do different areas of emissions compare?

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TABLES and FIGURES

Table 1: Mean and median annual household CO2 emissions in tonnes, per cent of total emission and per cent of households not having emissions by emission area

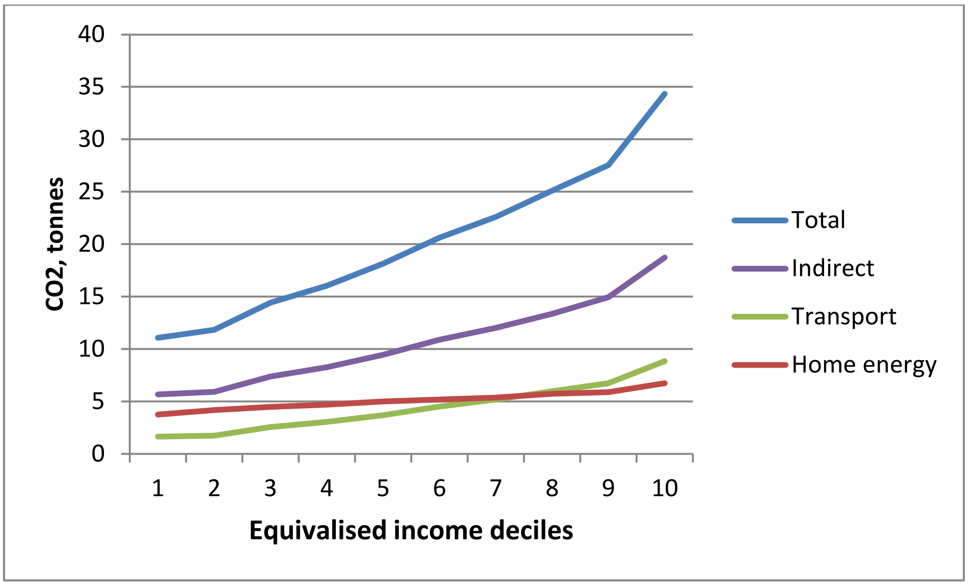
	Median CO2, tonnes	Mean CO2, tonnes	Standard error mean, tonnes	Per cent of total CO2 emissions	Per cent of households without emissions
Home energy total of which	**4.48**	**5.11**	**0.03**	**25.3**	**5.7**
Gas	2.35	*2.49*	0.02	12.3	22.8
Electricity	1.84	*2.09*	0.01	10.4	8.1
Other home energy	0.00	*0.53*	0.03	2.6	93.2
Transport total of which	**2.97**	**4.40**	**0.04**	**21.8**	**15.2**
Motor fuels	1.60	*2.38*	0.03	11.8	36.4
Flights	0.00	*1.13*	0.02	5.6	59.0
Public transport	0.00	*0.89*	0.02	4.4	50.2
Indirect total of which	**8.69**	**10.67**	**0.08**	**52.9**	**0.0**
Indirect home energy and motor fuel emissions	2.23	*2.60*	0.02	12.9	9.0
Food	1.33	*1.53*	0.01	7.6	0.7
Catering/hotels	0.69	*1.11*	0.01	5.5	11.6
Cars & repairs	0.05	*0.4*	0.01	2.0	39.5
Recreation	0.33	*0.77*	0.03	3.8	3.7
Clothing	0.23	*0.66*	0.01	3.3	32.6
Furniture, appliances, tools	0.13	*0.67*	0.01	3.3	32.1
Personal care	0.17	*0.38*	0.01	1.9	12.3
Other indirect	1.53	*2.54*	0.03	12.6	0.0
Total	**17.13**	**20.18**	**0.13**	**100.0**	**0.0**

Table 2: CO2 emissions and inequality

	1 **Mean**	2 **Median**	3 **CV**	4 **Mean CO2 low income**	5 **Mean CO2 high income**	6 **20/80 ratio**
Total	20.18	17.13	72.42	11.47	30.94	2.70
Indirect	10.67	8.69	86.69	5.79	16.84	2.91
Home energy	5.11	4.48	77.97	3.97	6.32	1.59
Transport	4.40	2.97	113.21	1.70	7.79	4.57

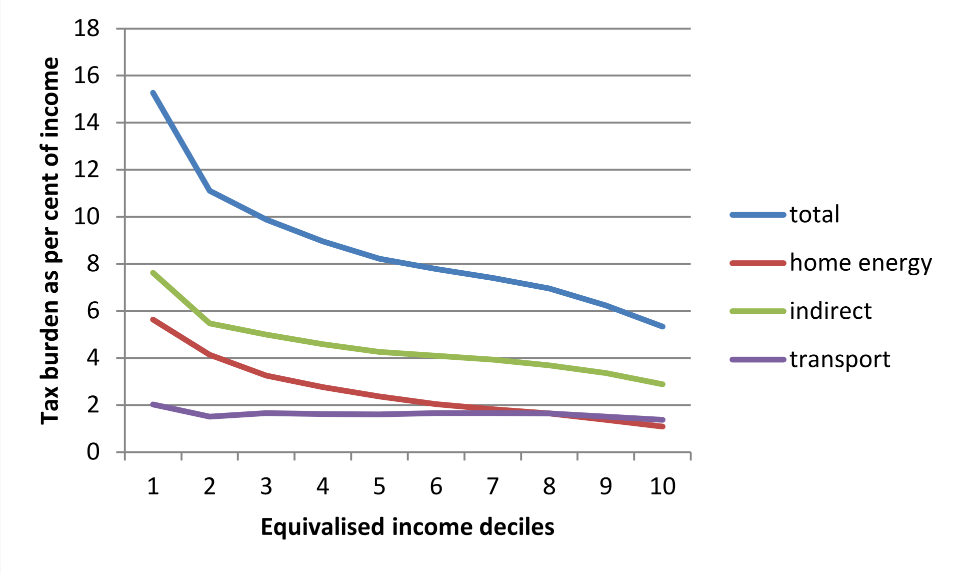
Note: CV stands for coefficient of variation. Column 4 shows mean emissions for the lowest income quintile, based on equivalised income. Colum 5 shows mean emissions for the highest income quintile. Column 6 shows the ratio of mean emissions of the top and bottom income quintiles.

Figure 1: Distribution of annual household emissions over equivalised income deciles



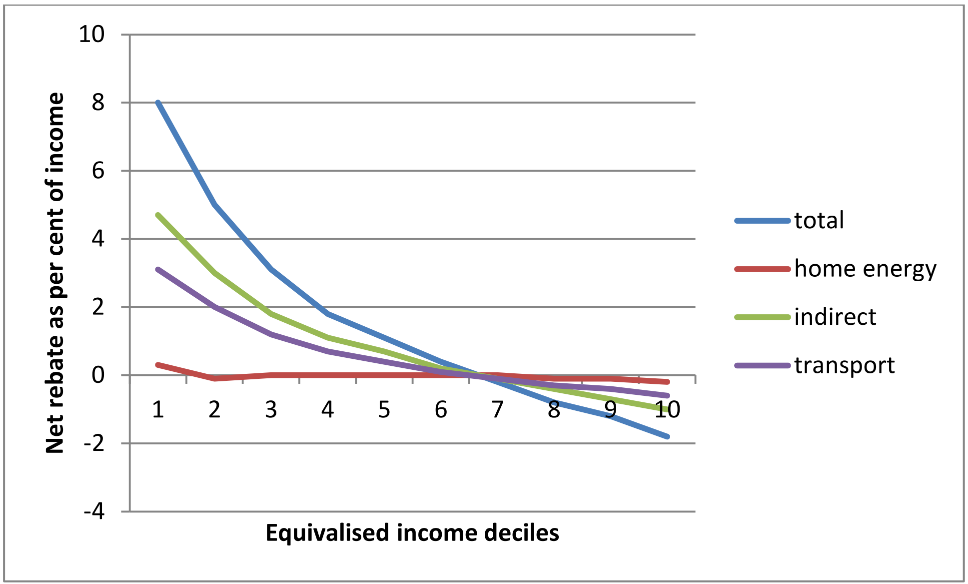
Note: Sample size 24,446

Figure 2: The distribution of annual CO2 tax burdens over equivalised income deciles



Note: The 1st and 99th percentile of the income distribution are excluded to reduce bias from income outliers. The tax burden relates to carbon taxes of £100 per tonne, expressed as per cent of annual disposable household income.

Figure 3: the distribution of net allowances from a carbon tax and rebate scheme, per cent of disposable income



Note: the 1st and 99th percentiles of the income distribution are excluded to minimise bias from income outliers. The net rebates are calculated by subtracting the CO2 tax to be paid by each household from their equal per adult allocation of tax rebates. The net rebate is expressed as per cent of annual disposable household income.

Table 3: change of the gini coefficient of income inequality before/after tax and 'tax and rebate' (T&R) schemes; Suits index for the CO2 taxes.

	Suits index	**Difference of 20/80 income ratio after policy**						
		Unscaled			Scaled			*Scaling factor*
	Tax	Tax	T&R adult	T&R 0.5 child	Tax	T&R adult	T&R 0.5 child	
total	-0.08	1.20	-0.54	-0.64	1.20	-0.54	-0.64	*1.0*
indirect	-0.06	0.48	-0.35	-0.41	0.91	-0.66	-0.77	*1.9*
home energy	-0.19	0.39	-0.01	-0.04	1.55	-0.05	-0.16	*4.0*
transport	0.02	0.08	-0.24	-0.26	0.38	-1.10	-1.21	*4.6*
motor fuels	-0.01	0.06	-0.12	-0.13	0.48	-1.01	-1.12	*8.5*
public transport	0.04	0.01	-0.05	-0.05	0.33	-1.13	-1.25	*22.7*
flights	0.07	0.01	-0.07	-0.08	0.23	-1.26	-1.36	*17.9*

Note: The Suits index compares the distribution of income to the distribution of the tax burden over equivalised income deciles. A negative sign means the tax is regressive, a positive sign means it is progressive, 0 is neutral. It reaches from 1 to -1.
Changes in income inequality in response to mitigation policies are examined by comparing the ratio of mean income of the highest income quintile to that of the lowest income quintile after deducting tax burdens or net rebates from equivalised household income. Positive figures indicate an increase in income inequality, negative figures a decrease. The scaled 20/80 income ratio changes are multiplied by a factor reflecting the proportion of an emissions sub-category of total emissions. For example, home energy emissions make up about 25% of total emissions. The income ratio difference is thus multiplied by 4 to make it comparable to the one for total emissions.

Table 4: Comparison of mean net annual rebates of a £100 per tonne of CO2 adult-only scheme, £ pounds

	total	*se*	he	*se*	transport	*se*	mf	*se*	flights	*se*	pt	*se*
adult 1	-49.3	10.3	-95.1	3.7	54.3	3.3	31.2	2.1	16.3	1.5	6.8	1.6
adult 2	**-140.2**	16.7	**-7.1**	4.4	**-51.2**	5.5	**-22.1**	3.1	**-19.2**	2.9	**-9.9**	2.4
adult 3	**442.8**	35.3	**189.1**	9.6	32.9	13.3	**-3.4**	9.1	23.8	6.9	12.4	5.4
children	-305.0	22.7	-36.7	5.9	-69.8	7.6	-49.0	4.4	-13.9	4.2	-6.8	3.2
no children	**126.1**	12.3	**15.2**	3.7	**28.8**	4.0	**20.3**	2.5	**5.7**	2.0	2.8	1.7
age <35	55.9	22.0	**80.2**	6.0	-22.1	8.2	2.4	4.9	-15.5	4.2	-9.1	3.5
age 35-65	**-169.5**	16.7	**-9.1**	4.4	**-64.1**	5.5	**-40.3**	3.4	-14.6	2.8	-9.2	2.3
age > 65	**314.0**	16.5	**-42.2**	5.8	**152.0**	3.9	**83.0**	2.4	**42.6**	2.0	**26.4**	1.8
low income	487.2	14.8	21.4	5.7	180.2	4.2	92.8	2.8	51.7	2.3	35.7	1.4
high income	**-807.6**	23.8	**-68.1**	6.8	**-269.7**	8.5	**-111.3**	5.3	**-92.1**	5.1	-66.4	4.4
high edu	-475.2	29.3	-15.5	7.7	-183.6	9.5	-65.9	5.7	-77.8	5.4	-39.9	4.5
low edu	**219.6**	13.3	5.9	4.1	**83.3**	4.2	**34.6**	2.7	**32.6**	1.9	**16.1**	1.8
rural	-302.7	25.1	-100.5	9.1	-65.3	7.9	-79.3	5.2	5.8	3.7	8.2	3.0
urban	**92.7**	13.7	**33.5**	3.3	**17.9**	4.5	**23.6**	2.5	-3.2	2.4	-2.4	1.9
workless	442.7	21.9	37.5	7.6	158.5	6.4	93.7	3.8	41.0	3.5	23.8	2.6
in employment	**-62.7**	12.7	**-5.3**	3.6	**-22.5**	4.1	**-13.3**	2.5	**-5.8**	2.2	**-3.4**	1.8
female	51.1	13.9	-26.7	4.5	46.8	4.7	32.3	2.8	14.2	2.3	0.3	2.1
male	**-32.1**	15.9	**16.8**	4.2	**-29.4**	5.0	**-20.3**	3.1	**-9.0**	2.7	-0.2	2.1
"white"	-32.5	12.4	-7.1	3.5	-2.3	4.0	-5.2	2.4	3.7	2.0	-0.7	1.6
ethnic minority	**382.3**	38.5	**83.9**	11.4	27.8	13.7	**62.9**	8.4	**-43.5**	7.9	8.4	5.2
poor rural motorists	113.7	46.6	-110.3	22.7	79.5	14.3	-12.7	9.7	53.4	7.0	38.8	6.8
rich rural motorists	**-1172.4**	52.3	**-194.4**	18.4	**-347.3**	17.0	**-220.5**	11.2	**-75.6**	8.9	**-51.2**	8.3

Note: Figures in bold are significantly different to the comparator group (always the first line within each group)

Table 5: Percentage of households 'losing' from an adult only tax and rebate scheme

	Total	Energy	Trans-port	Motor fuel	Flights	Public transport	n
Average	*41.87*	*44.71*	*37.34*	*38.81*	*26.06*	*24.45*	*24,446*
Low income	21.1	42.5	15.2	18.7	10.3	15.5	6,112
High income	70.7	50.2	64.7	57.3	44.0	39.6	6,112
Children in hh	54.4	49.2	44.4	48.7	26.5	28.5	7,151
No children hh	36.7	42.9	34.4	34.7	23.6	25.1	17,295
Age <= 35	43.6	34.4	41.8	40.2	27.9	30.4	4,836
Age 36 to 64	48.9	46.1	44.8	46.9	28.5	28.4	13,294
Age>=65	25.8	49.7	18.2	20.8	13.4	17.7	6,316
Education>=16	58.9	44.4	57.0	51.3	40.8	35.5	5,743
Education<11	33.3	44.7	28.1	31.9	16.6	21.8	9,405
Rural area	50.1	51.2	44.8	51.5	23.4	23.3	4,713
Urban area	39.2	42.6	35.3	35.0	25.0	26.9	17,374
Workless hh	24.1	40.3	18.7	20.7	12.6	19.4	3,035
In employment	44.4	45.3	40.0	41.4	26.1	27.0	21,411
Female head	40.5	50.4	31.5	32.4	20.8	25.7	9,434
Male head	42.7	41.1	41.0	42.8	26.7	26.3	15,011
Not white	34.4	36.7	36.1	29.4	35.2	28.0	1,908
White	42.5	45.4	37.4	39.6	23.5	25.9	22,530
Poor rural motorists	36.6	50.8	29.2	42.7	10.7	13.6	637
Rich rural motorists	76.6	58.0	71.6	70.6	41.6	34.6	1,422

Note: Low income households have equivalised household income equal or below the 25th percentile, high income households are situated at or above the 75th percentile of the equivalised income distribution.

Table 6: OLS regression results of an adult-only £100 per tonne of CO2 Tax and Rebate scheme

VARIABLES	(1) Total	(2) Home energy	(3) Transport	(4) Total	(5) Home energy	(6) Transport	(7) Total	(8) Home energy
Income	-0.327***	-0.032***	-0.102***	-0.246***	-0.020***	-0.075***	-0.230***	-0.016***
	(0.005)	(0.001)	(0.002)	(0.006)	(0.002)	(0.002)	(0.006)	(0.002)
adult2	0.629***	0.177***	0.103***	0.780***	0.210***	0.150***	0.784***	0.215***
	(0.013)	(0.005)	(0.005)	(0.013)	(0.005)	(0.005)	(0.013)	(0.005)
adult3	0.663***	0.163***	0.127***	0.737***	0.200***	0.135***	0.695***	0.186***
	(0.027)	(0.009)	(0.011)	(0.026)	(0.008)	(0.011)	(0.026)	(0.008)
adult4	0.584***	0.198***	0.049*	0.626***	0.219***	0.056**	0.606***	0.210***
	(0.060)	(0.018)	(0.027)	(0.058)	(0.017)	(0.026)	(0.057)	(0.017)
adult5+	0.619***	0.082	0.116*	0.594***	0.109*	0.101	0.557***	0.098*
	(0.188)	(0.056)	(0.065)	(0.182)	(0.057)	(0.063)	(0.181)	(0.055)
child1	-0.151***	-0.020***	-0.009	-0.113***	-0.041***	0.026***	-0.124***	-0.044***
	(0.018)	(0.006)	(0.008)	(0.019)	(0.006)	(0.008)	(0.018)	(0.006)
child2	-0.207***	-0.054***	-0.039***	-0.142***	-0.029***	-0.024**	-0.136***	-0.028***
	(0.025)	(0.008)	(0.011)	(0.024)	(0.008)	(0.011)	(0.024)	(0.008)
child3+	-0.038	-0.052***	0.025	-0.049	-0.040***	0.016	-0.080**	-0.049***
	(0.035)	(0.013)	(0.016)	(0.033)	(0.012)	(0.015)	(0.033)	(0.012)
age				-0.026***	-0.006***	-0.008***	-0.021***	-0.005***
				(0.002)	(0.001)	(0.001)	(0.002)	(0.001)
age2_100				0.024***	0.004***	0.009***	0.021***	0.003***
				(0.002)	(0.001)	(0.001)	(0.002)	(0.001)
agetop				-0.004	-0.016*	-0.002	0.011	-0.015*
				(0.021)	(0.009)	(0.008)	(0.021)	(0.009)
Female				-0.037***	-0.015***	0.002	-0.046***	-0.017***
				(0.012)	(0.004)	(0.005)	(0.012)	(0.004)
Education 16+				-0.201***	-0.025***	-0.060***	-0.174***	-0.019***
				(0.018)	(0.006)	(0.008)	(0.018)	(0.006)
Education 12-15				-0.122***	-0.022***	-0.023***	-0.097***	-0.015***
				(0.014)	(0.005)	(0.006)	(0.014)	(0.005)
Edu missing				0.048***	0.006	0.019***	0.050***	0.006
				(0.017)	(0.007)	(0.006)	(0.016)	(0.007)
Workless				0.062***	0.012*	0.030***	0.042**	0.005
				(0.016)	(0.006)	(0.006)	(0.016)	(0.006)
Ethnic minority				0.144***	-0.005	-0.020*	0.120***	-0.016*
				(0.024)	(0.008)	(0.010)	(0.023)	(0.008)
Rural				-0.110***	-0.036***	-0.032***	-0.060***	-0.005
				(0.014)	(0.005)	(0.006)	(0.014)	(0.005)
Rural missing				-0.299***	-0.153***	-0.015*	-0.103***	-0.032**
				(0.023)	(0.010)	(0.008)	(0.035)	(0.015)
Bedrooms				-0.182***	-0.078***	-0.023***	-0.130***	-0.053***
				(0.007)	(0.002)	(0.003)	(0.008)	(0.003)
No vehicle				0.385***	0.046***	0.149***	0.323***	0.021***

				(0.012)	(0.005)	(0.005)	(0.012)	(0.005)
Own outright							-0.137***	-0.047***
							(0.016)	(0.006)
Mortgage							-0.176***	-0.047***
							(0.016)	(0.006)
Missing own							-0.096**	-0.067***
							(0.042)	(0.016)
Detached							-0.166***	-0.095***
							(0.023)	(0.008)
Semid							0.001	-0.045***
							(0.018)	(0.006)
Terraced							0.055***	-0.027***
							(0.017)	(0.006)
Flat conv.							-0.062**	-0.026***
							(0.031)	(0.010)
Elec heat							0.168***	0.064***
							(0.017)	(0.006)
Oil heat							-0.233***	-0.147***
							(0.036)	(0.016)
Other heat							0.182***	0.048***
							(0.020)	(0.008)
Constant	0.507***	-0.027***	0.215***	1.291***	0.364***	0.293***	1.072***	0.300***
	(0.009)	(0.004)	(0.004)	(0.061)	(0.021)	(0.026)	(0.061)	(0.021)
Observations	22,990	22,990	22,990	22,990	22,990	22,990	22,990	22,990
R-squared	0.325	0.138	0.188	0.409	0.233	0.240	0.426	0.261

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. 1st and 99th percentiles of the net rebate distributions and of income are excluded to reduce influence of outliers. Error terms are not perfectly normally distributed but regression results were robust against exclusion of error outliers with no significant differences of coefficients. The results presented include regression outliers.

Independent variables: “Income” represents annual disposable income divided by 10,000. “Adult2” identifies households with at least 2 adults, “adults3” identifies households with at least 3 adults and so forth, the same logic applies to the variables “child2” and following. “Age” provides age in years. Since the relationship between age and emissions has an inverse u-shape, an age-squared term is also used (‘age2/100 – age squared divided by 100). “Agetop” is coded 1 for households with reference persons aged 80 and over and 0 otherwise. “Education 16+” is coded 1 if at least one household member attended full time education for 16 or more years. “Education 12-15” is coded 1 if at least one household member attended education for 12 to 15 years and 0 otherwise, “Edu missing” is coded 1 if information on education is missing. “Rural” is coded 1 for households in settlements with less than 10,000 inhabitants. “Rural missing” is coded 1 if information on rural location is missing which is mainly for households in Northern Ireland. Own outright means that the household owns the property without mortgage, “mortgage” means the property is owned through a mortgage. “Missing own” denotes that information is not available, control household is renting the property. Control household for type of dwelling is a household in a purpose build flat and the control household for the heating variables has central gas heating.

References

AA, 2006-2009. Fuel Price Reports. The Automobile Association.

AEA, Cambridge Econometrics, 2008. A Study in Personal Carbon Allocation: Cap and Share. A Report to Comhar SDC Sustainable Development Council, Ireland, AEA Energy & Environment and Cambridge Econometrics.

Bach, S., Kohlhaas, M., Meyer, B., Praetorius, B., Welsch, H., 2002. The effects of environmental fiscal reform in Germany: a simulation study. Energy Policy 30, 803-811.

Baranzini, A., Goldemberg, J., Speck, S., 2000. A future for carbon taxes. Ecol. Econ. 32, 395-412.

Barker, T., Köhler, J., 1998. Equity and Ecotax Reform in the EU; Achieving a 10 per cent reduction in CO2 emissions using excise duties. Fiscal Studies 19, 375-402.

Barnes, P., 2003. Who Owns the Sky?: Our Common Assets and the Future of Capitalism. Island Press, Washington D.C.

Blow, L., Crawford, I., 1997. The distributional effects of taxes on private motoring. London: Institute for Fiscal Studies.

Bork, C., 2006. Distributional effects of the ecological tax reform in Germany: an evaluation with a microsimulation model, in: Serret, Y., Johnstone, N. (Eds.), The Distributional Effect of Environmental Policy. Edward Elgar / OECD, Cheltenham, UK, pp. 139-170.

Boyce, J., Riddle, M., 2007. Cap and Dividend: How to Curb Global Warming while Protecting the Incomes of American Families. Working Paper Series Number 150, Amherst: Political Economy Research Institute, University of Massachusetts.

Brännlund, R., Nordström, J., 2004. Carbon tax simulations using a household demand model. European Economic Review 48, 211-233.

Bristow, A.L., Wardman, M., Zanni, A.M., Chintakayala, P.K., 2010. Public acceptability of personal carbon trading and carbon tax. Ecol. Econ. 69, 1824-1837.

Buchs, M., Schnepf, S.V., 2013. UK households' carbon footprint: a comparison of the association between household characteristics and emissions from home energy, transport and other goods and services, S3RI Working Paper, University of Southampton.

Büchs, M., Schnepf, S.V., 2013, forthcoming. Expenditure as proxy for UK household emissions? Comparing three estimation methods, S3RI working paper, University of Southampton.

CEC, 1992. European Economy: The climate challenge - economic aspects of the Community's strategy for limiting CO2 emissions. European Economy 51, Commission of the European Communities, Luxembourg: Office for Official Publications.

DECC, 2011a. Average annual domestic electricity bills for selected towns and cities in the UK and average unit costs (QEP 2.2.3). Department of Energy and Climate Change.

DECC, 2011b. Average annual domestic gas bills for selected towns and cities in the UK and average unit costs (QEP 2.3.3). Department of Energy and Climate Change.

DECC, 2012. UK Emissions Statistics. 2010 final UK figures. Department of Energy and Climate Change.

DECC, DEFRA, 2011. 2011 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. London: Department for Environment, Food and Rural Affairs and Department for Energy and Climate Change.

DEFRA, 2008. Distributional Impacts of Personal Carbon Trading. London: Department for Environment, Food and Rural Affairs.

DfT, 2011. Average distance travelled by mode, Great Britain, since 1995/97. Department for Transport, available from http://www.dft.gov.uk/statistics/tables/nts0305/, last accessed 21 July 2012.

Dinan, T., Rogers, D.L., 2002. Distributional effects of carbon allowance trading: How government decisions determine winners and losers. National Tax Journal 55, 199-221.

DRDNI, 2011. Travel Survey for Northern Ireland. In-Depth Report 2007-2009. Department for Regional Development Northern Ireland.

Dresner, S., Ekins, P., 2004. The distributional impacts of economic instruments to limit greenhouse gas emissions from transport. PSI Research Discussion Paper 19, London: Policy Studies Institute.

Dresner, S., Ekins, P., 2006. Economic instruments to improve UK home energy efficiency without negative social impacts. Fiscal Studies 27, 47-74.

Druckman, A., Jackson, T., 2010. The bare necessities: How much household carbon do we really need? Ecol. Econ. 69, 1794-1804.

Dworkin, R., 1981a. What is equality? 1. Equality of welfare. Philosophy & Public Affairs 10, 185-246.

Dworkin, R., 1981b. What is equality? 2. Equality of resources. Philosophy & Public Affairs 10, 283-345.

Ekins, P., Barker, T., 2001. Carbon taxes and carbon emissions trading. J. Econ. Surv. 15, 325-376.

Ekins, P., Dresner, S., 2004. Green taxes and charges. Reducing their impact on low-income households. Joseph Rowntree Foundation.

FEASTA, 2008. Cap & Share. A fair way to cut greenhouse emissions. Dublin: The Foundation for the Economics of Sustainability (FEASTA).

Feng, K., Hubacek, K., Guan, D., Contestabile, M., Minx, J., Barrett, J., 2010. Distributional Effects of Climate Change Taxation: The Case of the UK. Environmental Science & Technology 44, 3670-3676.

Girod, B., De Haan, P., 2010. More or Better? A Model for Changes in Household Greenhouse Gas Emissions due to Higher Income. Journal of Industrial Ecology 14, 31-49.

Grainger, C., Kolstad, C., 2008. Who Pays for a Carbon Tax? University of California (conference paper).

Halvorsen, B., 2009. Conflicting Interests in Environmental Policy-making? Environmental & Resource Economics 44, 287-305.

Hansen, J.E., 2009. Carbon Tax & 100% Dividend. Testimony of James E. Hansen to Committee on Ways and Means, United States House of Representatives, 25 February 2009, http://www.columbia.edu/~jeh1/2009/WaysAndMeans_20090225.pdf, download 22 July 2009.

Hassett, K.A., Mathur, A., Metcalf, G.E., 2009. The Incidence of a US Carbon Tax: A Lifetime and Regional Analysis. Energy Journal 30, 155-178.

Helm, D., 2005. Climate-change policy. Oxford University Press, Oxford.

Johnstone, N., Serret, Y., 2006. Distributional effects of environmental policy: introduction, in: Serret, Y., Johnstone, N. (Eds.), The Distributional Effect of Environmental Policy. Edward Elgar / OECD, Cheltenham, UK, pp. 1-19.

Klinge Jacobsen, H., Birr/Pedersen, K., Wier, M., 2003. Distributional implication of environmental taxation in Denmark. Fiscal Studies 24, 477-499.

Labandeira, X., Labeaga, J., 1999. Combining input-output analysis and micro-simulation to assess the effects of carbon taxation on Spanish households. Fiscal Studies 20, 305-320.

Labandeira, X., Labeaga, J.M., Rodriguez, M., 2009. An integrated economic and distributional analysis of energy policies. Energy Policy 37, 5776-5786.

Metcalf, G.E., 1999. A distributional analysis of green tax reforms. National Tax Journal 52, 655-681.

Metcalf, G.E., Weisbach, D., 2009. The design of a carbon tax. Harvard Environmental Law Review 33, 499-556.

Monbiot, G., 2010. Are we really going to let ourselves be duped into this solar panel rip-off? The Gurardian, 1 March 2010

ONS, 2009. Family Spending. A Report on the 2008 Living Costs and Food Survey. Palgrave Macmillan, Basingstoke.

Parry, I.W.H., 2004. Are emissions permits regressive? Journal of Environmental Economics and Management 47, 364-387.

Parry, I.W.H., Williams, R.C., 2010. What are the Costs of Meeting Distributional Objectives for Climate Policy? B E Journal of Economic Analysis & Policy 10.

Paul, A., Wiedmann, T., Barrett, J., Minx, J., Scott, K., Dawkins, E., Owen, A., Briggs, J., Gray, I., 2010. Introducing the Resources and Energy Analysis Programme (REAP). Stockholm Environment Institute.

Posner, E.A., Weisbach, D.A., 2010. Climate Change Justice. Princeton University Press, Princeton.

Poterba, J., 1990. Is the gasoline tax regressive? NBER Working Paper 3578: National Bureau of Economic Research.

Ritter, M., Casey, M., 2012. UN Conference Accepts Extension of Kyoto Protocol. Business Week. December 8th 2012. http://www.businessweek.com/ap/2012-12-08/un-talks-nearing-weak-deal-on-climate, accessed 1 Feb 2013.

Sharan, A., 2008. Potential Impacts of a Global Cap and Share Scheme on India. Dublin: FEASTA.

Starkey, R., 2008. Allocating emissions rights: Are equal shares fair shares? Working Paper 118, Tyndall Centre for Climate Change Research, www.tyndall.ac.uk/sites/default/files/twp118.pdf (last download 20 Feb 2013).

Starkey, R., 2012. Personal carbon trading: A critical survey Part 1: Equity. Ecol. Econ. 73, 7-18.

Starkey, R., Anderson, K., 2005. Domestic Tradable Quotas: A policy instrument for reducing greenhouse gas emissions from energy use. Technical Report 39, Tyndall Centre for Climate Change Research.

Stokes, G., Lucas, K., 2011. Poverty and travel behaviour in Great Britain – what the National Travel Survey tells us. Transport Studies Unit Working Paper 1053, University of Oxford.

Suits, D.B., 1977. Measurement of Tax Progressivity. The American Economic Review 67, 747-752.

Tiezzi, S., 2005. The welfare effects and the distributive impact of carbon taxation on Italian households. Energy Policy 33, 1597-1612.

Wakeford, J., 2008. Potential Impacts of a Global Cap and Share Scheme on South Africa. Dublin: FEASTA.

West, S.E., Williams, R.C., 2002. Estimates from a consumer demand system: implications for the incidence of environmental taxes. Cambridge, MA: National Bureau of Economic Research, Working Paper 9152, http://www.macalester.edu/~wests/NBER9152.pdf.

White, V., Thumim, J., 2009. Moderating the distributional impacts of personal carbon trading. A report to the Institute for Public Policy Research, Bristol: Centre for Sustainable Energy.

Wier, M., Birr-Pedersen, K., Jacobsen, H.K., Klok, J., 2005. Are CO2 taxes regressive? Evidence from the Danish experience. Ecol. Econ. 52, 239-251.