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Missing carbon reductions? Exploring rebound and backfire effects in UK households

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Abstract

Households are expected to play a pivotal role in reducing the UK's greenhouse gas (GHG) emissions, and the UK Government is encouraging specific household actions to help meet its targets. However, due to the rebound effect, only a portion of the GHG emission reductions estimated by simple engineering calculations are generally achieved in practice. For example, replacing short car journeys by walking or cycling reduces consumption of motor fuels. But this frees up money that may be spent on, for example, purchasing extra clothes or flying on vacation. Alternatively, the money may be put into savings. Since all of these options lead to GHG emissions, total GHG savings may be less than anticipated. Indeed, in some instances, emissions may increase – a phenomenon known as 'backfire'. We estimate that the rebound effect for a combination of three abatement actions by UK households is approximately 34%. Targeting re-spending on goods and services with a low GHG intensity reduces this to a minimum of around 12%, while re-spending on goods and services with a high GHG intensity leads to backfire. Our study highlights the importance of shifting consumption to lower GHG intensive categories and investing in low carbon investments.

Keywords: *Rebound effect; Sustainable consumption; Household savings.*

1 Introduction

The UK has a target to reduce greenhouse gas (GHG) emissions by at least 80% below 1990 levels by 2050 (HM Government 2008). It is relying on households to play a pivotal role in meeting this target by encouraging a range of measures including, for example, household energy efficiency improvements.

It is commonly assumed that historical improvements in energy efficiency have reduced energy consumption and associated GHG emissions below the level at which it would have been without those improvements. Nevertheless, before the recession, it was apparent that such improvements failed to reduce energy consumption in absolute terms. Thus while the energy intensity of industrial economies steadily fell, absolute energy consumption attributable to UK households continued to rise, along with the associated carbon emissions (Druckman et al. 2008; Wiedmann et al. 2008; Druckman and Jackson 2009a).

The most common explanation for the failure to decouple energy consumption and carbon emissions from economic growth is that we haven't tried hard enough: energy and carbon prices are too low and policies to encourage energy efficiency and/or lifestyle changes are often small-scale, under-funded, poorly designed and ineffectual. In this view, the appropriate solution is to reinforce these policies - namely, to introduce more regulations, standards, financial support and information programmes alongside the pricing of carbon emissions.

But an additional explanation for the failure to reduce energy consumption is that many of the potential energy savings have been 'taken back' by various behavioural responses which are commonly grouped under the heading of *rebound effects*. While generally neither anticipated nor intended, these effects reduce the size of the energy savings achieved. An example of a rebound effect would be the driver who replaces a car with a fuel-efficient model, only to take advantage of its cheaper running costs to drive further and more often. Some authors argue that these effects lead to *increased* energy demand over the long term – an outcome that has been termed 'backfire' (Saunders 1992; Brookes 2000).

Since energy efficiency improvements reduce the effective price of energy services such as travel, the consumption of those services may be expected to increase, thereby offsetting some of the predicted reduction in energy consumption. This so-called *direct rebound effect* was first studied by Khazzoom (1980) and has since been the focus of much research (Greening et al. 2000; Sorrell and Dimitropoulos 2007; Sorrell and Dimitropoulos 2008; Sorrell et al. 2009). But even if there is no direct rebound effect for a particular energy service (e.g. even if consumers choose not to drive any further in their fuel efficient cars), there are a number of other reasons why the economy-wide reduction in energy consumption may be less than simple 'engineering' calculations suggest. For example, the money saved on motor-fuel consumption may be spent on other goods and services that also require energy to provide. Depending upon the nature, size and location of the energy efficiency improvement, these so-called *indirect rebound effects* can take a number of forms (Sorrell 2007).

The *overall* or *economy-wide* rebound effect from an energy efficiency improvement represents the sum of these direct and indirect effects and is normally expressed as a percentage of the expected energy savings. Hence, an economy-wide rebound effect of 20% means that one fifth of the potential energy savings are 'taken back' through one or more of the above mechanisms. A rebound effect that exceeds 100% means that the energy efficiency improvements 'backfire': in other words, they *increase* overall energy consumption.

The quantification of rebound effects is difficult, owing to limited data, endogenous variables, uncertain causal relationships, trans-boundary effects and other factors (Sorrell 2007). As a result, the existing literature is patchy and most studies focus upon only a subset of the relevant effects measured over relatively short time horizons (Sorrell 2007). While rebound effects are most commonly estimated in relation to energy consumption, they may equally be estimated for carbon dioxide emissions or greenhouse gas (GHG) emissions. The percentage effect may not be the same in each case, owing to variations in the energy, carbon dioxide and GHG intensity of different goods and services. In this paper, we estimate rebound effects in relation to GHG emissions, since we consider the reduction of these emissions to be the primary policy goal.

Most studies of rebound effects focus upon household energy services such as heating and lighting and examine the effect of improving the *efficiency* of delivering those services - for example, using less electricity to provide the same level of lighting through the replacement of incandescent bulbs with compact fluorescents. However, an entirely analogous effect may occur when individuals choose to change their consumption patterns, with the primary or secondary aim of reducing their environmental impacts or 'carbon footprint'. For example, individuals may choose to walk or cycle rather than using a car, or to turn off the lights in unoccupied rooms. In these circumstances, the money saved by reduced consumption of the relevant energy service(s) will generally be spent on *other* goods and services. However, there will be energy consumption and carbon emissions associated with the purchase of these other goods and services. In other words, there will be *indirect* rebound effects that will offset some (or in extreme cases all) of the intended energy and emissions savings. However, there will not be any *direct* rebound effects in these circumstances as the household has voluntarily chosen to consume less of that specific energy service.

In this paper, reducing consumption of a particular good or service is termed an *abatement action*. This is distinct from improving the *efficiency* of providing a particular energy service which frequently leads to increased consumption of that service and hence a direct rebound effect. So while efficiency improvements lead to both direct and indirect rebound effects, abatement actions lead to only indirect rebound effects. In both cases, these rebound effects are unintended and usually unacknowledged, but their net effect will be to reduce the environmental benefits of the relevant action. Since abatement actions are visible, simple and low cost they are widely promoted by government bodies and non-governmental organisations (NGOs) as an effective means of reducing GHG emissions, as well as being widely practised by individual households. But the indirect rebound effects associated with these actions remain largely unexplored.

This study makes some preliminary estimates of the rebound effects associated with representative abatement actions that may be taken by an average UK household. We consider three actions that have the primary or secondary objective of reducing GHG emissions, namely:

- reducing internal temperatures by 1^{o}C by means of lowering the thermostat;
- reducing food expenditure by one third by eliminating food waste; and
- walking or cycling instead of using a car for trips of less than 2 miles.

We assume that expenditure avoided due to these actions is either re-spent on other goods and services or is saved. Savings may either be treated as deferred consumption or as a source of funds for investment, but in either case, they will also be associated with GHG emissions. In this paper we treat them as investment funds. We set up a generalised framework in which we can vary the proportion of avoided expenditure that is re-spent or saved, and also vary the expenditure categories in which the re-spending is carried out. The latter may either be in accordance with the estimated expenditure elasticities for the relevant good or service (see below), or determined exogenously in order to estimate upper and lower bounds of the rebound effect.

Four features of this study should be noted. First, unlike other rebound studies, our study takes account of the impact of household savings and investments. This allows us to investigate situations where households put aside rather than re-spend money saved through reduced consumption. Second, we focus specifically on household actions that do not require capital outlay, thereby removing the need to account for the financial and energy consequences of capital investment. Third, we investigate abatement actions involving reduced consumption rather than improved energy efficiency which means that we can focus solely upon 'income effects' and ignore any price-induced 'substitution effects'.[1] Finally, we also ignore any 'general equilibrium' effects that may result from the abatement actions, such as changes in the price of energy that may induce behavioural changes by other households.

We therefore expect our estimates of the size of rebound effects to be relatively conservative. The rationale for these choices is to produce a simple and transparent study which clearly demonstrates the importance of such effects. Modelling additional dimensions of the rebound effect is the focus of ongoing work.

Our paper is organised as follows: in Section 2 we present the background to estimating the rebound effect, and review relevant studies. Section 3 is the Methodology and we present our results in Section 4. Consideration of the limitations of the study are given in Section 5. In the concluding section (Section 6) we summarise our findings and discuss their implications for sustainable consumption policy-making.

2 Background

Two sets of information are required to estimate the rebound effects from energy efficiency improvements and/or abatement actions by households: First, estimates of the energy consumption and/or GHG emissions that are associated with different categories of household goods and services, and investments; Second, estimates of how the share of expenditure on different goods and services, and the level of savings, varies as a function of prices, income and other variables. The former may be derived from Environmentally-Extended Input-Output analysis, Life Cycle Analysis or some combination of the two, while the latter may be derived from the econometric analysis of survey data on household expenditure.

Econometric models of household behaviour can take a wide range of forms and represent behaviour at varying levels of complexity (Deaton and Muelbauer 1980). Of particular importance is the choice of categories for grouping household expenditure and the level of aggregation of those categories. For example, are all travel-related expenditures grouped into a single category, or is this disaggregated into sub-categories such as petrol, maintenance, public transport and so on? The choice typically depends upon the nature of the data source, the relevant sample size and the associated degrees of freedom.[2]

While there are quite a few studies estimating direct rebound effects, estimation of indirect rebound effects appears to be in its infancy, and only a handful of studies are currently available (Sorrell 2007; Sorrell and Dimitropoulos 2007; Sorrell 2010).

The most widely cited study is Brännlund et al. (2007) who examine the effect of a 20% improvement in the 'energy efficiency' of personal transport (all modes) and space heating in Sweden.[3] They estimate an econometric model[4] of household expenditure on non-durables in which the share of expenditure for thirteen types of non-durable goods or services is expressed as a function of total expenditure on non-durables, the price of each good or service and an overall price index. This allows the own-price, cross-price and expenditure elasticities of each good or service to be estimated. Energy efficiency improvements are assumed to reduce the cost of transport and heating and lead to substitution and income effects that change overall demand patterns (e.g. improvements in transport efficiency are estimated to increase demand for clothes but to decrease demand for beverages). By combining these estimated changes in demand patterns with relevant emission coefficients, Brännlund et al. estimate that energy efficiency improvements in transport and heating lead to total rebound effects (in carbon terms) of 120% and 175% respectively (i.e. they backfire). Indeed, their results suggest that the direct rebound effects alone for these energy services exceed 100%. The latter result appears questionable since it contradicts the results of numerous studies that estimate the direct rebound effect for personal travel and household heating to be less that 30% (Sorrell 2007; Sorrell and Dimitropoulos 2007).

Mizobuchi (2008) follows a similar approach to Brännlund et al for Japanese households and finds broadly similar rebound effects, despite differences in estimation procedures. When the estimated capital cost of efficiency improvements is included, the rebound effect reduces to around 27%. However, there are difficulties in the way Mizobuchi incorporates capital costs which both raise questions about this result and make comparison with the Brännlund *et al.* study problematic (Sorrell 2010).

A second Swedish example is Alfredsson (2004) who calculates the direct and indirect energy consequences of 'greener' consumption patterns - including both efficiency improvements, such as buying a more fuel-efficient car, and abatement actions such as car sharing. In the case of greener food consumption (e.g. shifts towards a vegetarian diet), the total energy consumption associated with food items is reduced by around 5% and total expenditure on food items is reduced by 15%. But the re-spending of this money on a variety of items, notably travel and recreation, leads to indirect energy consumption that more than offsets the original energy savings (i.e. backfire). The results for a shift towards 'greener' travel patterns are less dramatic, but the re-spending reduces the overall energy savings by almost one third. A comprehensive switch to green consumption patterns in travel, food and housing is estimated to have a rebound effect of 35%.

In a more recent study, Carlsson-Kanyama et al (2005) used a similar model and approach to Alfredsson, but employing Swedish rather than Dutch data on energy intensity. They found that a shift to 'green' food consumption could reduce overall energy consumption. Closer examination reveals that this result follows largely from the assumption that greener diets are more expensive (owing to the higher cost of locally produced organic food), thereby leading to a negative rebound effect.

The importance of variations in the price and quantity of individual products is also emphasised by Girod and de Haan (2009), who find that Swiss households with low GHG emissions are characterised by relatively more spending on high-quality goods and services, along with less spending on mobility and more spending on leisure. In a related paper, Girod *et al* (2010), illustrate the sensitivity of the rebound effect to the pattern of re-spending and the importance of other constraints on the household such as the availability of time and space.

Lenzen and Dey (2002) also explore the consequences of a 'greener diet', but in an Australian context. Their green diet involves less food consumption in weight terms, a 30% reduction in total food expenditure and significant reductions in food-related energy consumption and GHG emissions. However, once the re-spending effect is allowed for, the net effect is to increase overall energy consumption by 4 to 7%, although GHG emissions are still reduced by around 20% as a result of reduced livestock emissions. They find that the rebound effect varies from 112 to 123% for energy consumption and from 45 to 50% for GHGs.

Thiesen et al. (2008) examine the specific example of two Danish cheese products that are broadly comparable in terms of taste and quantity, but differ in packaging - with one having a 'traditional' packaging and the second a 'convenience' packaging. Since the convenience product is 8.6% more expensive, purchasers of the traditional product will save money that can be spent upon other goods and services. Thiesen et al. use Life-Cycle Analysis (LCA) to compare the environmental impact of the two cheeses and combine household survey and Input-Output data to estimate the environmental impact of re-spending the cost savings. On the basis of the LCA analysis alone, the cheaper cheese has three times the global warming impact of the convenience cheese, but this increases to seven and half times when the re-spending is allowed for. Their results provide a very strong case for including rebound effects within life-cycle appraisals.

The results from such studies appear sensitive to the methodology and assumptions used, as well as the types of household analysed and the particular shifts in consumption patterns that are explored. It is evident that the potential for estimating indirect rebound effects has yet to be fully explored and that existing studies differ substantially in terms of data sources, methodology, level of commodity aggregation, technical and/or behavioural changes examined, rebound effects covered, and the magnitude of effects found (Sorrell 2010). In particular, none of the studies examine the implications of saving or investing the avoided expenditure. Thus, while existing work suggests that indirect rebound effects may be sizeable, considerably more research is required to address methodological weaknesses and to examine a wider range of independent variables.

3 Methodology

The approach taken in this study is straightforward. We first identify three simple actions that an average UK household may take to reduce the emissions attributable to its expenditure, based on suggestions from websites sponsored by the UK government[5]. From these we estimate the expected (hoped for) annual reduction in GHG emissions (ΔH), and approximate annual expenditures (Δy) that are likely to be avoided. We assume that the latter are either re-spent on other goods and services or saved (invested). This leads to additional GHG emissions (ΔG) that offset some or all of the anticipated GHG savings (ΔH). Hence, the actual emission reductions are given by ΔH-ΔG.

We define the rebound effect as:

$$\text{Rebound Effect} = \frac{\text{(Potential Savings) - (Actual Savings)}}{\text{Potential Savings}} = \frac{\Delta H - (\Delta H - \Delta G)}{\Delta H} = \frac{\Delta G}{\Delta H}$$

As discussed earlier, estimation relies on having information on the GHG intensity of different categories of goods and services, and the expenditure elasticities of those goods and services. In this study we make use of two models developed within RESOLVE[6] at the University of Surrey. The first is the Surrey Environmental Lifestyle MApping (SELMA) framework from which we obtain GHG intensities 1992-2004. The second is the Econometric Lifestyle Environmental Scenario Analysis (ELESA) model from which we obtain estimates of income elasticities and GHG emissions for 2008. These are described below.

3.1 Underlying models: SELMA and ELESA

SELMA estimates the GHG emissions[7] that arise in the production and distribution of goods and services purchased by UK final consumption (households, government and investment). This is known as accounting from the 'consumption perspective'.

This perspective is based on the premise that it is the demand for goods and services which drives the production processes that consume resources (including energy resources) and emit pollutants (including carbon dioxide and other GHGs) (UNCED 1992; Daly 1996; UN 2002; HM Government 2005). Using this perspective, estimates include emissions from direct energy use, such as for personal transportation and space heating, as well as 'embedded' emissions, which are the emissions that arise in supply chains in the production and distribution of goods and services purchased in the UK. An important feature of SELMA is that it takes account of all emissions incurred as a result of final consumption in the UK, whether they occur in the UK or abroad. To do this, the estimation of embedded emissions is carried out using a Quasi-Multi Regional Environmentally-Extended Input-Output sub-model incorporated within SELMA. Details of SELMA's methodology, data sources, assumptions and limitations are provided in Druckman and Jackson (2008; 2009a; 2009b).

As mentioned above, 'investment' is one of the three final demand categories to which UK GHGs are attributed in consumption perspective accounting, as carried out using standard Environmentally-Extended Input-Output analysis (Leontief 1986; Miller and Blair 2009). Investment here refers to general UK investment[8] and we assume this to be representative of household savings. Accordingly, we use the GHG intensity of general UK investment as a proxy for the GHG intensity of household savings. It is estimated by dividing the GHG emissions attributed to investment by the monetary value of the investment.

Emissions due to household expenditure, obtained from SELMA, are classified into 16 categories based upon the COICOP[9] classification scheme (see Table 1). The rationale for these categories is explained in Druckman and Jackson (2009b). The GHG intensity of each of the 16 expenditure categories is estimated by dividing GHG emissions by corresponding expenditure.

Table 1: Expenditure categories used in this study

Category	COICOP Classification	Description
1	1	Food & non-alcoholic beverages
2	2	Alcoholic beverages, tobacco, narcotics
3	3	Clothing & footwear
4	4.4.1	Electricity
5	4.4.2	Gas
6	4.4.3	Other fuels
7	4.1 to 4.3	Housing [a]
8	5	Furnishings, household equipment & routine household maintenance
9	6	Health
10	7.2.2.1 & 7.2.2.2	Personal transport fuels
11	Remainder of 7	Other transport
12	8	Communication
13	9	Recreation & culture
14	10	Education
15	11	Restaurants & hotels
16	12	Miscellaneous goods & services

[a] This includes household rent, maintenance, repair, and water supply.

ELESA is an econometric scenario modelling tool in which a Structural Time Series Model (STSM) (Harvey 1989) is used to independently estimate household expenditure equations for each of the 16 categories presented in Table 1, using UK quarterly time series data for 1964:q1 to 2009:q1. This allows examination of the relationship between household expenditure, income, prices, temperature[10] and a stochastic (rather than deterministic) underlying trend which is arguably important when estimating the elasticities (Hunt and Ninomiya 2003). The underlying trend is likely to be affected by technical progress, changes in tastes, consumer preferences, socio-demographic and geographic factors, lifestyles and values, which are not easily measured, and therefore difficult to obtain any suitable data. The stochastic underlying trend aims to capture the aggregate effect of above factors (Chitnis and Hunt 2009; Chitnis and Hunt 2010b; Chitnis and Hunt 2010a).

The year of focus for this study is 2008. This is chosen as it is the end of estimation period for the expenditure functions from which income elasticities are obtained in ELESA. This enables use of the most up-to-date information available on consumer preferences (as indicated by income elasticities). GHG emissions and intensities for 2008 for each of the 16 expenditure categories and the savings category are modelled within ELESA using STSM based on data for 1992-2004 from SELMA, as presented in Chitnis and Hunt (2009).

ELESA models total UK households. In this study, in order to model an average UK household, the results from ELESA in terms of GHG emissions and expenditures are divided by the estimated total number of households in the UK (DCLG 2009: Table 401).

3.2 GHG abatement actions

We consider very simple GHG abatement actions advocated by UK Government-sponsored websites in the areas of household energy use, food, and private transportation. These actions are chosen specifically as they do not involve capital expenditure and are therefore simpler to model with few assumptions being required.

a) Household energy reduction

Many household actions, such as switching off lights in unoccupied rooms, can reduce energy use through simple behavioural changes. Here we use guidance from the UK government ActOnCO_2 campaign: "*Turning your thermostat down by 1ºC could reduce CO_2 emissions and cut your fuel bills by up to 10 per cent*" [11].

This estimated reduction is in terms of total household energy usage, but reducing internal temperatures only affects energy used for space heating. Gas, for example, is used for hot water heating and cooking in addition to space heating, and similarly electricity is also used for lighting, cooking and powering appliances. According to DECC (2009: Table 3.7) in 2007 68% of Gas, 12% of Electricity and 74% of Other fuels were used for space heating. Hence, in order to simulate a 10% reduction in total household energy bills with the reductions allocated to the portion of each fuel that is devoted to space heating, we reduce expenditure on Gas by 12%, Electricity by 2%, and Other fuels by 13%[12]. Assuming linearity[13] between expenditure on fuel and the quantity purchased in line with the ActOnCO_2 statement above, we reduce the GHG emissions in each category by the same percentage.

b) Food

The scope for studying the rebound effects that may arise due to changes in food consumption and diet is very wide, depending on the precise changes made and the level of commodity disaggregation available within the model. As a very simple illustration, we take the broad finding that an average UK household throws away one third of the food purchased[14] (WRAP 2008). Therefore, we simply assume a reduction in food and non-alcoholic drink expenditure of 33%, and a corresponding 33% reduction in food and non-alcoholic drink related GHG emissions.

c) Travel

Many opportunities are available to reduce expenditure on personal transportation fuels such as through 'smarter driving' techniques or replacing vehicles by more fuel efficient models. Here, we use the example of replacing all journeys under 2 miles that were taken by car by either walking or cycling. Based on data from DfT (2009: Table 3.5) for 2008 we estimate that this would reduce expenditure on personal transportation fuel, as well as the GHG emissions from personal transportation fuel, by 23%.

3.3 Estimating the rebound effect under varying conditions

In this section we first outline the general framework used for estimating rebound effects due to household GHG abatement actions.

As shown above, the rebound effect is defined as the ratio of GHG emissions due to re-use of avoided expenditure (ΔG), to the expected (hoped for) reduction in GHG emissions (ΔH). Sources of ΔH are explained in Section 3.2. ΔG depends on how avoided expenditure Δy is re-used, and sources of Δy are also explained in Section 3.2. In this study we assume that Δy is re-spent on goods and services in categories 1 to 16 of household expenditure, and/or is saved (invested). The proportion of avoided expenditure that is saved is determined by the savings ratio. We estimate ΔG using the GHG intensity of each category of expenditure and also the intensity of household investment, both taken from ELESA as explained in Section 3.1. Full details of this general framework are provided in the Appendix.

Using this general framework, we can estimate the rebound effect under a variety of circumstances:

- for each of the three GHG abatement actions either one at a time or in combination;
- for a variety of different assumptions concerning re-spend;
- for a variety of savings ratios;

There is therefore a range of possible scenarios for which the rebound effect may be estimated. We focus on combinations that are considered realistic, as well as those likely to give worst and best (or 'least worst') case rebound effects.

In order to estimate the most probable size of the rebound effect we assume that avoided expenditure Δy is analogous to an increase in disposable income, and that re-spend occurs in line with the estimated income elasticities of expenditure obtained from ELESA. We refer to this as the 'behaviour as usual' case.

The worst-case rebound effect will occur when all the re-spend is in the most GHG-intensive expenditure category (or invested, if this is more GHG intensive than the most GHG-intensive expenditure category). Conversely, the best-case (or 'least-worst-case') will occur when all the re-spend is in the least GHG-intensive expenditure category (or invested, if this is the least GHG-intensive category). While both outcomes are unlikely in practice, they provide upper and lower bounds of the rebound effect.

The savings ratio (r) is generally estimated by ELESA. However, in order to explore how the rebound effect is influenced by the proportion of avoided expenditure that households place in investments, we exogenously change the savings ratio to examine the effect of:

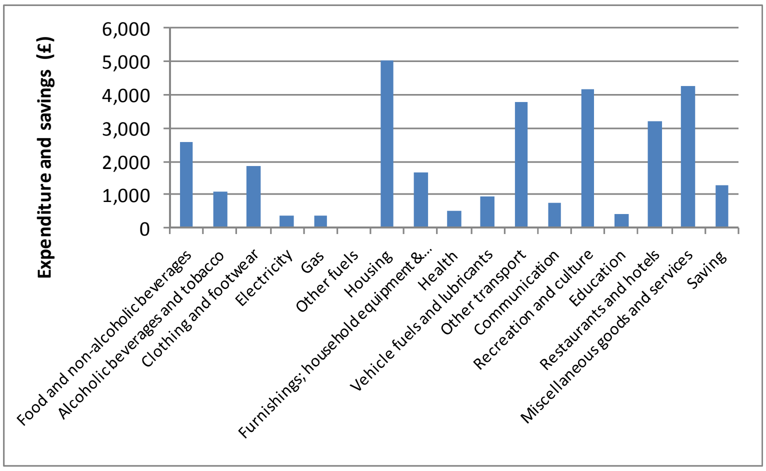
- a low savings ratio[15]. For this we use the lowest value observed in the UK during the period 1964-2009;
- a high savings ratio. As an example for this we take the highest rate observed recently in China form Ma and Yi (2010);
- saving (investing) all of the avoided expenditure.

4 Results

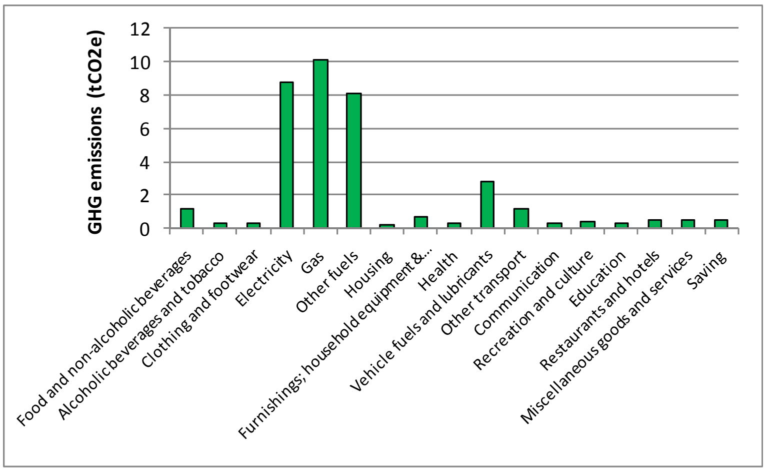
4.1 Household GHG emissions

To set the scene we first examine the estimated expenditure and GHG emissions of an average UK household in 2008. Figures 1a-1c illustrate that whereas, for example, gas accounts for only around 1% of total expenditure, it is one of the categories with the highest GHG emissions. The savings category, in contrast, has a relatively low GHG intensity.

(a)



(b)



(c)

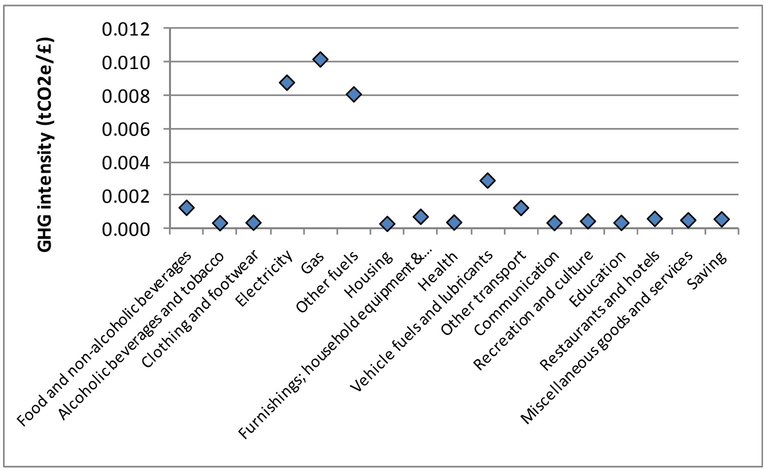


Figure 1. Average annual UK household (2008)
(a) Expenditure and investment (b) GHG emissions (c) GHG intensities

4.2 Estimation of rebound under varying conditions

The 'behaviour as usual' rebound is estimated by assuming that avoided expenditure is spent and invested in line with current behaviour patterns (as given by Equation 13 in the Appendix). Figure 2 shows the estimated rebound for each of the different abatement actions, and for all the actions carried out in combination. The figure shows the expected (hoped for) GHG emissions (ΔH) and the emissions due to re-spend/investment of the avoided expenditure (ΔG). The rebound effect is the ratio of the two, as explained above.

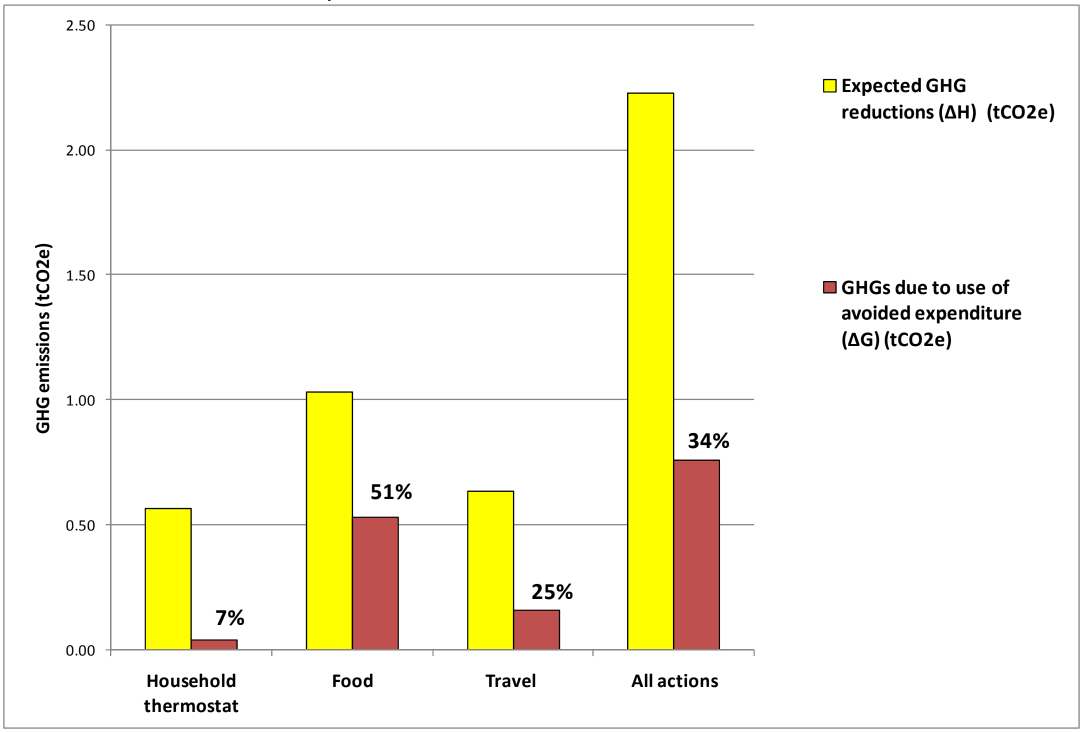


Figure 2. Rebound effect for different actions

Figure 2 shows that the estimated rebound effect is lowest (7%) for lowering the household thermostat, and highest (51%) for reducing food waste. The higher rebound for food is expected as expenditure on food is relatively less GHG intensive than expenditure on household fuels and personal transport fuels, and therefore the re-spend/investment of the avoided expenditure will be relatively more GHG intensive. Where all three abatement actions are carried out in combination, the rebound is estimated to be 34%.

In the discussion which follows we focus on the rebound effect due to all three actions in combination. We next examine how different choices for using the avoided expenditure affect the size of the rebound effect, to explore its upper and lower bounds.

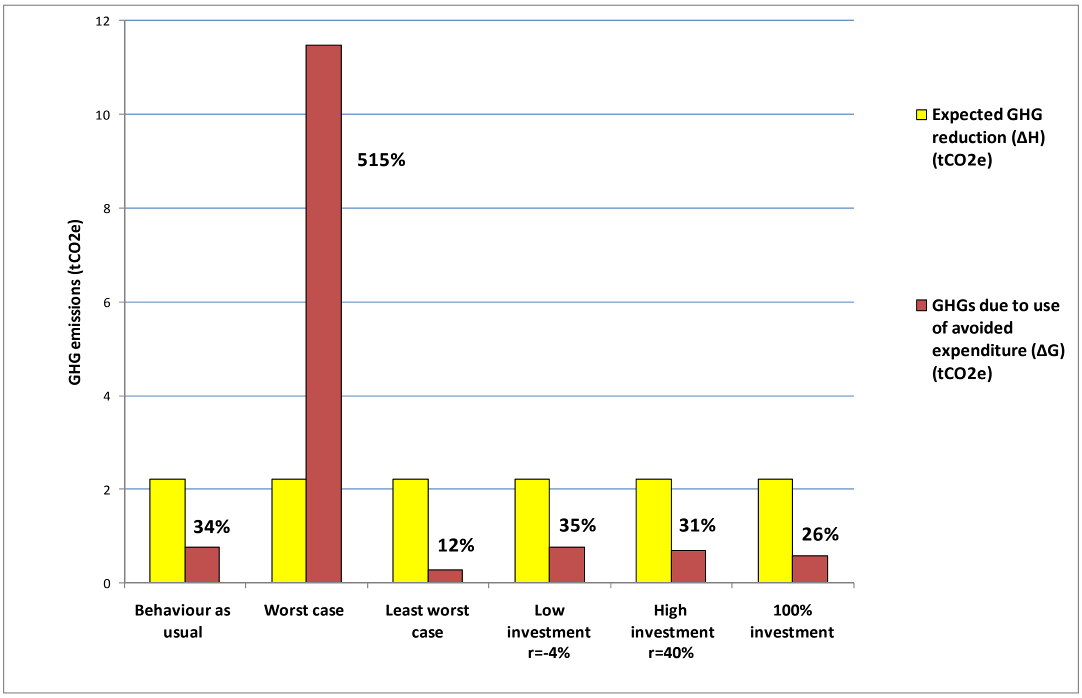


Figure 3. Rebound effect for all actions with varying assumptions concerning re-use of avoided expenditure

The 'least-worst' case is where households are assumed to re-spend all the avoided expenditure in the least GHG intensive category, which is 'Housing'[16]. In this case the rebound effect is estimated to be 12% (Figure 3). In the worst case we assume that all the avoided expenditure is spent in the most GHG intensive category which, using the expenditure classifications used in this study, is gas (this might be used for, say, heating water for extra hot showers). In this case, the GHG emissions due to the re-spend on gas far outweigh the expected GHG saving from the actions, and rebound of 515% is estimated (extreme backfire).

In order to investigate how the proportion of income that households invest influences the rebound effect, we exogenously vary the household savings ratio (r)[17] to look at extreme cases[18]. As an example of an economy with a low savings ratio we used lowest level observed in the UK between 1964 and 2009 which was r=-4%[19]. The negative value indicates that, rather than putting aside money into savings, households were withdrawing from savings. As expenditure has generally higher GHG intensity than savings, the estimated rebound is higher. However, the effect is small, giving a rebound of 35%.

As an example of an economy with a high savings ratio we use r=40%, which is the highest ratio observed in China during recent years (Ma and Yi 2010). In this case rebound is estimated at 31%. This slightly lower rebound effect is expected as investment (saving) has a relatively low GHG intensity.

A further possibility is that all the avoided expenditure is saved (invested) rather than re-spent. In this case the rebound effect is estimated to be 26%, as indicated by "100% investment" in Figure 3.

4.3 Comparison of results with other studies

As mentioned in Section 2, the size of rebound depends on the precise details of the study. Currently there are very few comparable studies, and those that do exist give widely varying estimates. The closest study to ours is Alfredsson's (2000; 2004) 'greener' consumption study for Sweden. Alfredsson estimated that a comprehensive switch to green consumption patterns in travel, food and housing would have a rebound of 35%. This finding, agrees well with the 34% estimate in our study for all three abatement actions carried out in combination. However, this is largely accidental since Alfredsson's study includes both direct and indirect rebound effects whereas our study is confined to indirect effects.

Our study is consistent with others in that it highlights that the rebound effect will generally be smaller where the abatement action reduces consumption in a highly GHG-intensive category, and where the cost savings are re-spent in less GHG intensive categories – and vice versa (Nässén and Holmberg, 2009). There is considerable scope to explore this basic insight further though undertaking more detailed studies.

5 Limitations of the study

The abatement actions investigated above have been specifically chosen for their simplicity, in that they do not require household capital expenditure and do not lead to any price-induced substitution effects. This makes estimation of the rebound effect simpler and more transparent. Nevertheless, the study has a number of important limitations.

A major limitation of the study is the relatively small number of expenditure categories modelled. These are based on the 12 major COICOP categories which are further sub-divided to separate out the most important categories in terms of GHG emissions. There is, however, likely to be considerable disparity in the GHG intensities of commodities *within* each category which could have an important effect on the results. For example, a highly GHG intensive category that we were not able to isolate is personal aviation - which is currently included within 'Other transport'. It would be valuable to explore the effects of re-spending within this and similar categories. Furthermore, we cannot take account of the effects of substitution between luxury and non-luxury[20] goods (Girod and de Haan 2009).

A second limitation is the use of 'UK average' households. This precludes investigating how rebound effects vary between different income groups or between groups with different demographic characteristics. Studies of this type require more detailed survey data on household expenditures.

A third limitation is that the study neglects other contributing mechanisms to the overall rebound effect – many of which operate over the longer term. For example, if many households carry out the actions modelled, then aggregate demand for gas, electricity, personal transport fuels and food may fall, together with the price of those commodities. This in turn could encourage other households to increase their consumption of these goods and services and thereby increase overall GHG emissions (Alcott 2008). To capture these broader price and quantity adjustments would require Computable General Equilibrium (CGE) or macroeconometric modelling. However, CGE models, for example, are based upon numerous assumptions that, arguably, have little empirical foundation and are often criticised for their lack of transparency (Clarete and Roumasset 1986; Scrieciu 2007). Since the inclusion of economy-wide effects would most probably increase our estimate of the total rebound effect, our estimates are likely to be conservative.

In addition to these limitations, there are also many assumptions and limitations involved in modelling the emissions embedded in goods and services purchased by UK households using SELMA. For details the reader is referred to Druckman et al (2008) and Druckman and Jackson (2009a; 2009b).

Despite these limitations, the study demonstrates how the size of the indirect rebound effect depends upon the relative GHG intensities of expenditure and savings categories, and choices concerning re-use of avoided expenditure.

6 Discussion

Behavioural changes by households are anticipated to make an important contribution to reducing UK GHG emissions. But while policy-makers are increasingly recognising that rebound effects will offset some of the anticipated emission reductions, the empirical evidence on the size of such effects remains very poor. Our study therefore aims to estimate the size of the rebound effect for a set of simple GHG abatement actions advocated by the UK government. These actions have no associated capital costs and are achieved purely through behavioural change.

We estimate that under conditions of 'behaviour as usual', the rebound effect is around 34% for the suite of three 'green' household abatement actions studied (reducing internal temperatures by 1^{o}C by means of lowering the thermostat; reducing food purchased by one third by eliminating food waste; and walking or cycling instead of using a car for trips of less than 2 miles). This means that only two thirds of the anticipated GHG emissions reductions are likely to be achieved.

It is vital that policy-makers become aware of the possible best and worst cases. In our estimation the lowest rebound effect that may be hoped for is around 12%, meaning that, even under the best conditions, only about 88% of any 'engineering' based calculated GHG emissions reductions might be achieved. This result is, however, sensitive to the disaggregation of expenditure categories used in the analysis. The use of higher levels of disaggregation may allow categories of expenditure with lower GHG intensities to be identified (such as fine art). If all the re-spend was assumed to be within this category then the rebound might reduce to nearly zero.

The worst case rebound is more serious - although perhaps unlikely in practice. We estimate that if households were to confine their re-spending to the most GHG-intensive category (which, in this study, is gas), then backfire is very likely to occur.

This means that rather than the hoped for GHG *reduction* achieved through the household actions, GHG emissions may *increase* – in the worst case, by as much as 515%. But again this estimate depends on the level of commodity disaggregation used. A more disaggregated analysis may enable categories of expenditure to be identified that have higher GHG intensity than gas, such as, perhaps, personal aviation. In this case the worst case rebound effect may be even higher.

Our study also investigated the influence that the relative proportions of disposable income that households choose to spend or save have on the size of the rebound effect. If households were intent on 'green choices' and aware that re-spend of the avoided expenditure gives rise to extra GHG emissions, they may put the money into the bank. However, savings cannot be treated as GHG-neutral, since they either represent deferred consumption or they provide a source of funds for investment. In this study we treat savings as investments and, using the average GHG intensity of UK investments as a proxy for the intensity of household investment, our results suggest that placing all the avoided expenditure in investment would lower the rebound effect to around 26%.

A more enlightened household intent on achieving the best outcome might put the avoided expenditure into 'green' investments. Depending on the GHG intensity of the chosen investment and the time period being compared, the rebound may in this case approach zero. Furthermore, if the money were invested in ultra low carbon technology, it is possible, in theory, to achieve *negative* emissions. This would result in a negative rebound effect. In other words, the overall emissions reductions due to the action would be *greater* than those estimated without taking account of the rebound effect.

Awareness of the likely size of the rebound effect is not enough: policy-makers also need to be given guidance on how to mitigate its effect. A discussion of possible strategies is beyond the scope of this paper, but our study points to two key ways forward. First, the study highlights the importance of shifting patterns of consumption to lower GHG intensive categories (Alfredsson 2004). This might be achieved through, for example, publicity campaigns, or economy-wide carbon pricing (Kerkhof et al. 2008; Weber and Matthews 2008; Feng et al. 2010). A second key strategy is to encourage households to invest in low carbon investments.

In conclusion, our study has shown that the rebound effect is not negligible, and needs to be taken account when estimating the emission reductions achievable through behavioural change. If rebound effects are ignored and no steps are taken to reduce them, achieving our emissions reduction targets will become even more of a Sisyphean task than it already seems. On the other hand, moving to lower GHG intensity consumption patterns, and shifting incomes to 'green' investments are clearly viable strategies for mitigating rebound.

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Endnotes

[1] Abatement actions may be thought of as increasing real income, which allows households to consume more goods and services and thereby increase overall 'utility'. This is termed the 'income effect'. In addition, a reduction in the price of a good or service encourages a household to consume more of that good or service and less of other goods and services, holding utility constant. This is termed the 'substitution effect'. Energy efficiency improvements (such as replacing incandescent lightbulbs with CFLs) reduce the price of energy services and thereby lead to both substitution and income effects. In contrast, behavioural changes (such as turning lights off in unoccupied rooms) do *not* change the price of energy services and therefore only lead to income effects. This study is confined to behavioural changes and therefore to income effects.

[2] For example, the UK Living Costs and Food Survey (LCFS) (2008) classifies household consumption into 247 categories using the 'Classification of Individual Consumption According to Purpose' (COICOP) scheme. But these categories are not compatible with those for which embedded GHG emissions are estimated and the number of categories is impractical for econometric estimation. Therefore, consumption data are aggregated into a relatively small number of categories for empirical work.

[3] Brannlund *et al.*'s use of the term 'heating' is misleading, since this category actually represents total direct energy consumption and therefore includes non-heating end-uses.

[4] The Linear Almost Ideal Demand (LAIDS) model which has become the standard in the field. As with other systems of consumer demand equations, this model imposes a number of restrictions on consumer behaviour in order to gain sufficient degrees of freedom (Deaton, A.and Muelbauer, 1980).

[5] See www.energysavingtrust.org.uk/ ; www.actonco2.direct.gov.uk/ and www.lovefoodhatewaste.com.

[6] ESRC Research Group on Lifestyles, Values and Environment.

[7] SELMA is a general framework that can be applied to, for example, resource use (such as energy use), carbon dioxide emissions or GHGs. In this study we use results from SELMA in terms of a basket of six GHGs: carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride. These are estimated in units of carbon dioxide equivalent (CO_2e) as used in the UK Environmental Accounts (ONS 2008).

[8] Investment includes: Gross fixed capital formation; Valuables; and Changes in inventories.

[9] Classification of Individual Consumption According to Purpose (UN 2005).

[10] UK average temperature is included in the expenditure equations for electricity, gas and other fuels.

[11] See http://actonco2.direct.gov.uk/actonco2/home/what-you-can-do/In-the-home/Reduce-your-CO2-emissions.html. ACT ON CO_2 *"is a key part of the Government's plan to help tackle [climate change]..... The website includes dozens of tips to help people reduce their carbon footprint. ACT ON CO_2 is a cross-Government initiative, currently involving the Department of Energy and Climate*

Change (DECC), the Department for Transport (DfT) and Department for Environment Food and Rural Affairs (DEFRA). This collective approach demonstrates the Government's commitment to taking action on climate change, working with businesses and individuals in order to reduce CO_2 emissions".
http://actonco2.direct.gov.uk/actonco2/home/about-us.html Accessed 16.06.10.

[12] These percentages are calculated based on information in DECC (2009: Table 3.7).

[13] In reality this is not the case for many fuel tariffs in the UK.

[14] The study by WRAP (2008) resulted in a publicity campaign based on this one third finding, and newspapers published articles such as "*More than three million tons of wasted food are being dumped every year by households - about one third of what they buy, Government researchers have found. The watchdog group Wrap said people could cut down on left over food by simply looking in the cupboard or fridge before shopping.*" (Johnstone 2007). More work has subsequently been carried out on this topic since the publication of WRAP (2008) disaggregating the types of food wasted by households (WRAP 2009; WRAP 2010). However, to illustrate the rebound effect for the purposes of this study, the broad 1/3 finding is a good start.

[15] A low savings ratio implies that a small proportion of Δy is saved (see Appendix).

[16] Housing includes household rent, maintenance, repair and water supply.

[17] The household saving ratio published by the Office for National Statistics differs slightly from our definition in this study (ONS 2010). The ONS make an adjustment for the change in net equity of households in pension funds whereas this adjustment is not carried out in our study.

[18] In the 'behaviour as usual' case the savings ratio (r) is 4%.

[19] Observed during 1971 and 1977.

[20] We define a luxury good as a good that carries out the same function as a non-luxury good but has a higher price.

Appendix. Derivation of equations for estimating the rebound effect.

In this appendix we derive an equation for estimating the rebound effect for a household action that has a potential (hoped for) reduction in GHG emissions of ΔH. This action results in avoided annual expenditure Δy.[21] We can think of avoided expenditure as being analogous to an increase in real disposable income (y).

We assume that Δy can either be re-spent on goods and services in categories 1 to 16 of household expenditure, or it can be saved (invested).

$$\Delta y = \sum_{i=1}^{16} \Delta \exp_i + \Delta s \qquad i=1, \ldots, 16 \tag{1}$$

where $\Delta \exp_i$ is the amount of money re-spent in category *i* and Δs is the additional money invested.

The change in GHG emissions ΔG due to the re-spending and change in savings (investments) is given by:

$$\Delta G = \sum_{i=1}^{16} u_i \Delta \exp_i + u_s \Delta s \tag{2}$$

where u_i is the GHG intensity of expenditure in spending category *i* and u_s is the GHG intensity of investment.[22]

We first derive an expression for Δ*s*. ELESA estimates expenditure in each of the 16 expenditure categories with the remainder of disposable income being saved (invested). This can be written as

$$y = \sum_{i=1}^{16} \exp_i + s \tag{3}$$

where *y* is disposable income, exp_i is expenditure in each category and *s* is money saved (invested).

The savings ratio *r* is defined as.

$$r = \frac{s}{y} \tag{4}$$

So the proportion of avoided expenditure that is saved is given by:

$$\Delta s = r \Delta y \tag{5}$$

Substituting for Δ*s* in Equation 1 we obtain a relationship that will be used in the next step:

$$\sum_{i=1}^{16} \Delta \exp_i = (1 - r) \Delta y \tag{6}$$

The next step is to estimate the amount of money households re-spend in each of expenditure categories 1 to 16. As mentioned above, we can think of the avoided expenditure as being analogous to having extra income. Therefore, holding other variables affecting expenditure constant and using the income elasticity of expenditure (β_i) we can express the change in expenditure for each category due to change in income as:

$$\Delta \exp_i = \beta_i \frac{\Delta y}{y} \exp_i \qquad i=1 \ldots, 16 \tag{7}$$

Substituting for $\Delta \exp_i$ in Equation 6 we get:

$$\frac{\Delta y}{y} \sum_{i=1}^{16} \beta_i \exp_i = (1 - r) \Delta y \tag{8}$$

Re-arranging:

$$y = \frac{\sum_{i=1}^{16} \beta_i \exp_i}{(1 - r)} \tag{9}$$

Substituting for *y* in Equation 7 we have:

$$\Delta \exp_i = \beta_i \frac{(1 - r) \Delta y}{\sum_{i=1}^{16} \beta_i \exp_i} \exp_i \tag{10}$$

Substituting Δs from Equation 5 and $\Delta \exp_i$ from Equation 10 into Equation 2 we get:

$$\Delta G = \left(\frac{(1-r)\Delta y}{\sum_{i=1}^{16} \beta_i \exp_i} \right) \sum_{i=1}^{16} \beta_i \exp_i u_i + r u_s \Delta y \qquad (11)$$

This can be used to estimate the rebound effect.

$$\text{Rebound} = \frac{\Delta G}{\Delta H} \qquad (12)$$

Therefore the rebound effect can be expressed as

$$\text{Rebound} = \frac{1}{\Delta H} \left[\left(\frac{(1-r)\Delta y}{\sum_{i=1}^{16} \beta_i \exp_i} \right) \sum_{i=1}^{16} \beta_i \exp_i u_i + r u_s \Delta y \right] \qquad (13)$$

In summary, Equation 13 estimates the rebound effect in terms of:

- Δy which is the expenditure avoided by the energy abatement action. This is determined exogenously as explained in Section 3.2.
- ΔH which is the anticipated GHG reductions. This is also determined exogenously as explained in Section 3.2.
- r which is the savings ratio, defined here as the ratio of disposable income y that is put into savings. It is estimated through ELESA, then adjusted exogenously in order to explore the rebound effect in cases of a higher or lower savings ratio.
- exp_i which is expenditure in category *i.* This is derived from ELESA.
- u_i and u_s which are GHG intensities in expenditure category i and investment respectively. These are estimated using ELESA.
- β_i which is the income elasticity of expenditure. This is estimated using ELESA.

Equation 13 gives the general case for estimating the rebound effect for both direct and indirect rebound. In this paper we focus on the indirect rebound effect since a direct rebound effect is unlikely for the abatement actions we are considering[23]. Accordingly Equation 13 is modified to exclude re-spend in the category in which the action takes place. So for example, in the case of reducing food waste, re-spend is not allowed on food. For reducing the thermostat setting, re-spend is not allowed on fuel for space heating, but we do allow re-spend on fuel for other uses, such as gas for cooking and hot water heating, and electricity for lighting. In the study we first consider each of the three actions separately, and then in combination. When examining the combination, we do not allow any re-spend on food, transport or space heating.

Endnotes – Appendix

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[21] Δ denotes changes in variables within the same year.

[22] GHG intensity of expenditure (investment) is GHGs attributable to each category (investment) divided by expenditure (investment) in the same category.

[23] This is best explained with regard to the food example. Eliminating food waste is assumed to occur by more careful attention to food shopping, budgeting and usage. In these circumstances a simple direct rebound effect is unlikely. In the other two categories, direct rebound on fuels for space heating and personal transport fuels is, in theory, possible but again somewhat counter-intuitive if people are sensitised to demand reduction.