Income dependent direct and indirect rebound effects from 'green' consumption choices in Australia

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Abstract

Changing household behaviour is often encouraged as a means of reducing energy demand and subsequently greenhouse gas (GHG) emissions. The direct and indirect rebound effects from cost-saving 'green' household consumption choices were estimated using Australian data. Rebound effects from cost-saving 'green' consumption choices are modelled as income effects, allowing for variation with households income level.

Cases examined are: reduced vehicle use, reduced electricity use, the adoption of energy efficient vehicles, and the adoption of energy efficient electrical lighting.

Four econometric estimation models are utilised to estimate income effects, and the before and after expenditure patterns are matched with life-cycle assessment (LCA) estimates of the embodied GHG of each expenditure category. Direct and indirect rebound effects alone are estimated at around 10% for household electricity conservation, and for reduced vehicle fuel consumption around 20%, at the median household income level.

Direct rebound effects are larger for low-income households; however, indirect effects are larger for higher income households. The scale of the effect estimated, and the variation with household incomes, is attributed to LCA methodologies. These results should be interpreted as the minimum rebound effect, with greater rebound effects, and decreased effectiveness of household 'green' consumption, expected in reality.

Keywords: Rebound effect; conservation; household consumption

JEL Classifications: D11, D12, D33, Q20, Q48, Q50

1. Introduction

More sustainable consumption patterns are promoted by the United Nations as a measure to combat environmental degradation; a stance reiterated by the Organization for Economic Co-operation and Development (OECD) members early this decade (UN 1992; OECD 2002). Efforts to reduce resource consumption, including energy consumption and the associated negative externality of greenhouse gas (GHG) emissions, through household consumption choices are attractive due to the ability for win-win outcomes, where economically justifiable 'green' behaviour simultaneously leads to environmental benefits.

As Adam Smith famously remarked, consumption is the sole end and purpose of all production. While the production process often results in environmental degradation, such processes are fulfilling a necessary role to enable final consumption. This conceptual shift to consumers as the ultimate bearer of responsibility forms the basis of much of the 'green' consumption promoted by governments and environmental organisations and could appropriately be termed a *consumption side approach*. Stern (2007) reiterated this ethical position with regard to climate change saying that "[i]f this interpretation of rights were applied to climate change, it would place at least a moral, if not a legal, responsibility on those groups or nations whose past consumption has led to climate change".

It is commonly assumed that high rates of adoption of win-win 'green' consumption choices will reduce GHG emissions. However, this assumption is typically made using incomplete engineering-type analysis and ignores unintended, yet inevitable, economic rebound effects.

Rebound effects describe the flow-on effects from technology and consumption pattern changes that offset intended environmental benefits. The rebound effect occurs due to price changes and adaptive behaviour of both producers and consumers, and is generally expressed as a ratio of the forgone environmental benefit to the expected engineering environmental benefit (Berkhout et al. 2000).

In the context of cost-effective new technology, rebound effects are generally classified as direct, indirect, or economy wide (Sorrell and Dimitropoulos 2008). Direct effects occur when new technology decreases the effective price of a good or service, and consumers compensate by consuming more of that good or service. Indirect effects occur when reduced costs of a good or service lead to increased consumption of other goods and services, which themselves have embodied energy and GHG emissions. Finally the economy-wide effect considers these two effects, plus changes to the scale and composition of production economy-wide, including the emergence of new products and services.

The rebound effect literature is heavily focused on improvements in energy-efficient technology and centres on the possibility of an economy wide backfire, where rebound effects are larger than engineering estimates of environmental benefits (Saunders 2000; Inhaber 1997; Alcott 2005; Hanley et al. 2008). This means there are net environmental costs from cost-effective energy efficient technology. This situation is known as *Jevons' paradox* and its widespread existence would undermine attempts to reduce GHG emissions with cost-effective energy efficient technologies.

Yet even in the absence of new technology, household 'green' consumption choices are subject to rebound effects. A household that conserves electricity will find their purchasing power redirected to other consumption – an indirect rebound effect. A household that chooses a more fuel-efficient car will be tempted to drive further (a direct effect) and will use spend the cost savings elsewhere in the household budget (an indirect effect).

One widely held view is that the indirect effect with respect to energy and GHG emissions is small due to energy inputs comprising a small component of household expenditure (Lovins et al. 1988; Schipper and Grubb 2000). This view is gradually being eroded. Recent studies utilising life-cycle assessment (LCA) of embodied GHG emissions show that the amount of energy consumed indirectly by households is often higher than energy consumed directly through electricity, gas, and motor fuel, and is a growing proportion (Vringer and Blok

1995, 2000; Vringer et al. 2007; Lenzen 1998; Lenzen et al. 2004; Weber and Perrels 2000; Reinders et al. 2003).

Existing studies of household energy use suggest that rebound effects may be much higher in households, and in countries, with low incomes, due to energy (electricity, coal, wood and liquid fuels) comprising a larger share of the household budget (Baker et al., 1989, Milne, 2000 #130; Roy, 2000; Hong et al., 2006). This evidence points to indirect effects becoming more significant than direct effects over time and with increasing incomes.

The objective of this paper is to expand on the handful of studies which estimate the direct or indirect rebound effects in terms of GHG emissions at a household level for win-win 'green' consumption choices (Alfredsson 2004; Lenzen and Dey 2002; Brannlund et al. 2007; Druckman et al. 2011; Carlsson-Kanyama et al. 2005). In particular, the impact of household income level on the scale of each effect, and the relationship between the two effects, is examined.

The cases considered in this paper are: reduced vehicle use, reduced electricity use, and the adoption of energy efficient vehicles and the adoption of energy efficient electrical appliances.

2. Background

Jevons (1865) first described the economic processes now commonly known the rebound effect. The modern debate, however, was ignited by Brookes (1972; 1990) who argued that on a conceptual and factual level GDP per capita is a measure of energy intensiveness, and that "reductions in energy intensity of output that are not damaging to the economy are associated with increases, not decreases, in energy demand." In the context of regulatory restrictions on energy efficiency, Khazzoom (1980) recognised that there are not one-to-one reductions in energy use due to the price content of energy in the ultimate service delivered to the consumer. Given the wide application of own-price elasticity elsewhere in economics, it is surprising that such an observation needed to be made at all.

Evaluation and econometric methods are the two approaches generally employed in estimating the size of direct and indirect rebound effects. Evaluation methods rely on quasi-experimental studies and measure the 'before and after' changes to energy consumption from the implementation of energy efficient technology. Econometric methods utilise elasticities to estimate the likely effects from changes in the effective price of energy services.

Few studies explicitly or implicitly estimate the magnitude of the indirect rebound effect (Chalkley et al. 2001; Lenzen and Dey 2002; Alfredsson 2004; Brannlund et al. 2007; Mizobuchi 2008; Druckman et al. 2011). Since the rebound effect is expressed in terms of a particular resource or externality, estimates of the indirect effect require an estimate of the embodied resources in household consumption. The scarcity of such embodied resource data is one reason for the dearth of research, which is emphasized by the work of Kok, Benders, and Moll (Kok et al. 2006) who reviewed 19 studies of embodied energy and greenhouse emissions from consumption patterns and found only three provided sufficient detail to allow econometric estimation of the indirect effect at a micro level.

The econometric model of Alfredsson (2004) finds direct and indirect effects of 14% for transport abatement, and 20% for 'green' housing, and a back-fire (approx 200%) for a 'green' diet and a total direct and indirect rebound effect for a combination of these actions of 20% in terms of GHG emissions. Alfredsson (2004) also considers the impact of increasing incomes offsetting any benefits made by consumption pattern changes. She finds that exogenous income growth of 1% per year offsets all but 7% of the decrease in GHG emissions from the combination of changes by 2020, while income growth of 2% will more than compensate for consumption pattern changes, and lead to a 13% increase in GHG emissions by 2020.

Lenzen and Dey (2002) account for the indirect rebound effect from a change to a 'low carbon diet', with estimates between 45 and 54%. Druckman et al. (2011) estimate the direct and indirect rebound effect for three abatement actions – household energy reduction, more efficient food consumption (less throw-away food), and reduced vehicle travel – with results showing a 7%, 59% and 22% rebound effects respectively in terms of GHG emissions.

One feature these econometric studies have in common is that their model of the indirect rebound effect allows for 're-spending' on the goods from which the saving where made. For example, Alfredsson (2004), Lenzen and Dey (2002) and Druckman et al. (2011) use models where households who adopt a 'green' diet then proceed to spend a portion of the cost savings on the previous diet. Whether this has a material impact on the estimates is uncertain, but it is one area where improvements can be made in the study of indirect rebound effects.

One recent evaluation study (Ornetzeder et al. 2008) used a case-control study of a car-free housing project in Vienna to examine differences in household activities and lifestyle characteristics. They found that while households in the car-free settlement had much lower emissions from ground transportation and energy use, they has substantially higher emissions from air travel, nutrition, and 'other' consumption, leading to only slight reductions in emissions by households in the car-free settlement compared to the control group.

Of particular interest is the potential for variation in the magnitude of the indirect effect for consumption-pattern changes due to income-level variation of households. One might expect that since the theory predicts a trade-off between direct and indirect effects, and direct effects have been observed to diminish with rising incomes (Baker et al. 1989; Milne and Boardman 2000; Roy

2000) that indirect effects may increase with rising income levels. Yet LCA data suggests that the opposite might be true due to the decrease in greenhouse gas and resource intensity of luxury goods, and the growing relative size of indirect energy consumption and emissions by households (Lenzen et al. 2004; Lenzen et al. 2006; Hertwich 2005).

It appears that the current state of knowledge of the scale of indirect rebound effects is slim, and while there is suggestive evidence that the size of the rebound effect varies greatly with household income level, that evidence is far from complete. The present paper contributes to the literature by

1. estimating rebound effects as a function of household income;
2. modelling 'green' household choices that are both pure reductions in electricity and motor fuel use, alongside choices where electricity and fuel are used more efficiently with cost-effective existing technologies. These are referred to as conservation cases, and efficiency cases respectively;
3. eliminating 're-spending' on the goods from which savings are made in conservation cases; and
4. separating direct and indirect rebound effects in efficiency cases.

3. Methodology

Following from Berkhout et al. (2000) the rebound effect is generally expressed as a percentage of potential savings of a particular resource in the following manner:

$$\text{Rebound effect} = \frac{\text{potential resource savings} - \text{actual resource savings}}{\text{potential resource savings}}$$

The determination of the baseline potential savings will greatly determine the scale of the rebound effect. For example, an engineering estimate that converts per unit of service reductions in electricity consumption of a more efficient appliance to kWh, then converts that into GHG emissions based on transmission loss, electricity generation efficiency and the emissions per unit of coal combusted, as suggest by some (Lovins et al. 1988; Weizacker et al. 1998), is flawed. The total embodied energy in the more efficient appliance should be subtracted from the potential energy use reductions to determine the baseline, as this embodied resource consumption is necessary and inseparable from the technology itself. This contradicts the position of Sorrell and Dimitropoulos (2008) who proposed that this embodied resource requirements of the more efficient technology comprises part of the indirect rebound effect. In this paper, the baseline potential resource savings (in terms of GHG emissions) is calculated as the cost savings multiplied by the GHG intensity of that expenditure. Actual resource savings are the difference between the total embodied GHG emissions in the before and after consumption pattern.

3.1 Data

The 2003-4 Australian Bureau of Statistics (ABS) Household Expenditure Survey (HES), aggregated into 36 commodity groups, is used in this paper (ABS 2004). The corresponding embodied GHG emissions for each commodity group, calculated using a published input-output based hybrid method, was made available from the Centre for Integrated Sustainability Analysis, Sydney, and is shown in Appendix A (Dey 2008; Lenzen et al. 2004).

Combining the two data sets to examine embodied GHG emissions against household income reveals decreasing emissions intensity, but increasing quantity of emissions, with increasing household expenditure[1] (Figure 1). This corresponds well with the macroeconomic relationship between energy and greenhouse emissions and gross domestic product (GDP) commonly observed, and other household emissions studies (Holtz-Eakin and Selden 1995; Schipper and Grubb 2000; Greening 2001; Lenzen et al. 2004). It also suggests that an Environmental Kuznets Curve for embodied GHG emissions is not observed in panel data.

[1] Household expenditure is presented per week in Figure 1, and all subsequent analysis.

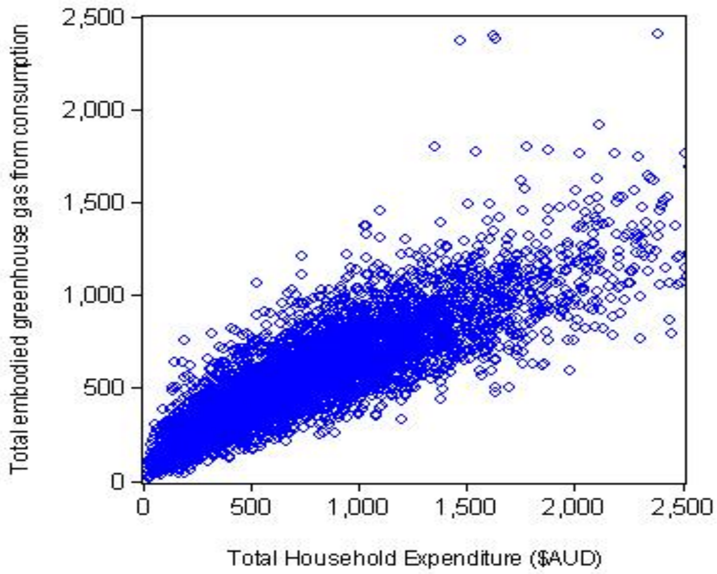

Figure 1. Total household greenhouse gas emissions embodied in consumption

3.2 Model

The rebound effect model is based on a system of household demand equations where expenditure on each commodity group[2] is dependent on total expenditure as a proxy for the household income level (the independent variable)[3], as is common in household demand studies (Deaton and Muellbauer 1980; Haque 2005; Brannlund et al. 2007).

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[2] This demand system represents the final budgeting stage of a household after savings decisions and decisions in housing expenditure in a similar vein to Brannlund, Ghalwash, and Nordstrom (2007). As such, housing demand is excluded from the model, and the model assumes no changes to the household savings rate. Some non-housing commodity groups have also been excluded. Tobacco expenditure in particular has been excluded due to its low correlation with income and very low occurrence of its consumption amongst survey respondents. A non-smoker does not increase his/her consumption of tobacco simply because disposable income increases. Furthermore, only 27% of households from the HES reported consuming tobacco at all. Other commodity groups excluded for these reasons are edible oils, eggs, and other medical expenses.

[3] Total expenditure is used as a proxy for income, which is common in household demand studies (Deaton and Muellbauer 1980; Haque 2005; Brannlund, Ghalwash, and Nordstrom 2007).

Selection of a functional form of the household demand system requires the ability to assess the potential variation in the rebound effect at different income levels, and as such, the system should comply with the following criteria;

- the possibility of threshold or saturation levels,[4]
- the adding up criterion,[5] and
- the best representation of the data.

Two variations of the double semi-log (DSL) functional form[6] are used in this study. One of these regressions contains the following non-income explanatory variables - age of household reference person, A, number of persons in the household, N, state, S, degree of urbanity, U, and dwelling type, D, each of which have been previously shown to have an impact on household emissions (Lenzen et al. 2004; Vringer et al. 2007). For completeness a linear and Working-Leser (WL) functional form are also used to enable some examination of the sensitivity of the final rebound effect estimation to the choice of functional form.

The first version of the DSL form retains only total expenditure, Y, and the log of total expenditure as the independent variables, so that the functional form for expenditure Q on each i commodity is:

$$Q_i = \alpha_i + \beta_i Y + \gamma_i \log Y \qquad (1)$$

The second DSL model (DSL2) has the functional form

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[4] These are turning points in the Engel curve, characteristic of goods becoming inferior above a particular income level.

[5] The adding-up criterion specifies that at all levels of total expenditure, the sum of expenditure on each commodity adds up to total expenditure.

[6] This functional form was determined by Haque (2005) to provide the best fit to the 1976-77 HES data.

$$Q_i = \alpha_i + \beta_i Y + \gamma_i \, log\, Y + C1_i N + C2_i U + C3_i S + C4_i A + C5_i D$$

The linear form is the simplest, but does not allow for threshold or saturation levels. The functional form is:

$$Q_i = \alpha_i + \beta_i Y \qquad (2)$$

At all levels of total expenditure the linear and both DSL models satisfies the adding-up criterion when

$$\sum \alpha_i = 0, \sum \beta_i = 1$$

Finally, the Working-Leser (WL) model relates budget shares, rather than expenditure, linearly with the logarithm of total expenditure. The budget share, w, of each i commodity is calculated by

$$w_i = \frac{Q_i}{Y} \qquad (3)$$

Then the relationship

$$w_i = \alpha_i + \beta_i \, log\, Y \qquad (4)$$

is estimated. This model also satisfies the adding up criterion automatically using ordinary least squares estimation equation by equation, and is true when

$$\sum \alpha_i = 1, \sum \beta_i = 0$$

The functional from of the Engel curve from the WL model is then determined by substituting equation (3) into (4) as follows.

$$w_i = \frac{Q_i}{Y} = \alpha_i + \beta_i Y$$

$$Q_i = \alpha_i Y + \beta_i \, Y. log\, Y \qquad (5)$$

Appendices B through E show the results of the regressions for each demand equation of the four demand models used in this study. In both DSL models, Whites heteroskedasticity consistent method of calculating standard errors and covariance is used. For the linear and WL model, ordinary least squares are used with no further statistical adjustment. The standard errors and significance levels for some of the independent variables in each DSL model are often quite high. It is not expected that expenditure on every commodity group is significantly determined by each of the variables, but it is important to note that total expenditure is a significant variable for every commodity group. This validates to some degree the income determinism assumption underpinning these models. The significance levels observed for the non-income explanatory variables in the DSL2 model also provide evidence that these houeshold characteristics are important determinants of the household expenditure pattern. In the domestic fuel and power and vehicle fuel commodity groups, the most GHG intensive expenditure groups, all of these variables are significant in explaining the expenditure levels (apart from degree of urbanity for domestic fuel and power).

Most other results follow intuitive logic. For meals out, intuition would suggest that urbanity would be a significant factor, as rural household have less option for take away foods. Dwelling type is also significant, and may also partly reflect urbanity, with apartment dwellers more likely to dine out, due to both location factors, and factors such as kitchen size and facilities.

As noted previously, the pattern for spending these cost savings will be determined by the income elasticity of each commodity. For mathematical simplicity, the marginal budget share (MBS) of each commodity, $\frac{\Delta Q_i}{\Delta Y}$ is used to determine the change in expenditure on each commodity over the income range. If the system of demand equations satisfies the adding-up criterion, then for all i commodity groups,

$$\sum MBS_i = 1$$

The interpretation of the MBS is that it is the amount of extra expenditure on commodity i for an increase in total expenditure of one dollar. For each of the functional forms used in this study, the MBS for each commodity is as follows:

DSL/2 - $MBS_i = \beta_i + \frac{\gamma_i}{Y}$ (6)

Linear - $MBS_i = \beta_i$ (7)

WL - $MBS_i = \alpha_i + \beta_i \, log \, Y + \beta_i$ (8)

Two alternative models have been derived for estimating the rebound effect. The first is referred to as the conservation model, which does not allow increases in expenditure on the goods or services from which cost savings were made. Existing studies typically do not control for this in their models, meaning that unlikely behaviour, such as cost savings from reduced electricity use being spent on more electricity, is common in their models (Alfredsson 2004; Brannlund, Ghalwash, and Nordstrom 2007; Druckman et al. 2011).

The second is referred to as the efficiency model, where although technology is fixed, there are cost effective efficient alternatives currently available for providing some household services. For example a household may choose to replace their car with a smaller model. While there has been a sacrifice in the quality of 'passenger kilometres', there is price change for each kilometre of driving. In such cases, the direct effect, caused by the income effect but excluding the substitution effect, will be considered[7]. Also, some technology changes may be limited to the household sector, in which case the direct and indirect rebound effects approximate the economy wide effect. For example, most production sectors already use fluorescent lighting, meaning the impact from compact fluorescent light bulbs is limited to the household sector of the economy.

In the conservation model, if the cost savings are denoted X, then for the commodity S from which the savings are made, the new expenditure level is

$$Q_{s_{new}} = Q_{s_{old}} - X \quad (9)$$

but for all other i commodities the new expenditure level must account for the fact that no re-spending takes place on commodity s, and therefore is calculated by[8],

$$Q_{i_{new}} = Q_{i_{old}} + X.MBS_i + \sum_{n=1}^{\infty} X.MBS_s^n.MBS_i \quad (10)$$

[7] While the absence of the substitution effect is a theoretical shortcoming, one might expect that households who adopt efficient alternatives will be less inclined to substitute expenditure towards that commodity. For this reason, the efficiency case is considered a conservative or minimum estimate of the rebound effect for that type of consumption pattern change.

[8] Model estimate computes n=1 to 5

In the efficiency model, calculating the direct effect is estimated by multiplying the savings, Y, by the MBS of the commodity from which the savings are made

$$Q_{s_{new}} = Q_{s_{old}} + X.MBS_s \tag{11}$$

which leaves the indirect component of the re-spending for all other commodities

$$Q_{i_{new}} = Q_{i_{old}} + X.MBS_i \tag{12}$$

To estimate the change in GHG emissions from the change in consumption patterns, the expenditure in each commodity group is multiplied by the GHG intensity of that commodity. Since there are no technology changes applicable to production stages of the economy, the same embodied emissions data can be used in both the before and after scenario without concerns regarding changing production patterns in the economy.

In the resource generic form of Lenzen and Dey (2002), if the overall embodiment of resource f (in this case GHG emission), for category i, is $R_{f,\,i}$, then the total embodiment of f for all consumption is

$$f = \sum Q_i \, R_{f,i} \tag{13}$$

The potential savings are calculated as X multiplied by the embodied factor R_f for commodity S. The rebound effect for resource f can then be expressed as a percentage of the potential resource savings, as

$$RE = \frac{(Y.R_{f,s}) - (\sum Q_{i_{old}} R_{f,i} - \sum Q_{i_{new}} R_{f,i})}{Y.R_{f,s}} \tag{14}$$

which can be simplified to

$$RE = 1 - \frac{\sum Q_{i_{old}} R_{f,i} - \sum Q_{i_{new}} R_{f,i}}{Y.R_{f,s}} \qquad (15)$$

To differentiate between conservation cases and efficiency cases, Q_{new} is calculated using the two alternative methods in equations 9 to 12 to create two distinct models. Further, each model is estimated using the four functional form of the household demand system. Importantly, in this model the rebound effect is a function of the total expenditure level and it is expected that a degree of variation will be observed across the income range.

3.3 'Green' household consumption choices

3.3.1 Vehicle fuel

Driving less or choosing a more fuel efficient vehicle are widely promoted as effective actions for households to reduce their GHG emissions (AGO 2007; The Green Home Guide 2007; Be climate clever. 2007). Both vehicle fuel cases (conservation and efficiency) have been developed to represent the same engineering baseline reductions in fuel use and GHG emissions.

To ensure realism, and to ensure feasibility at all income levels, it is assumed that in the efficiency case the change of vehicle results in no change to the capital cost of the car. For the efficiency case, evidence suggests that it is possible to replace the average Australian passenger vehicle with one that uses 4L/100Kms less fuel, without a change in capital costs, by sacrificing size and/or quality (Drive: Now your motoring 2008; Research and reviews 2008;

Fuelwatch 2008). The average number of kilometres driven by Australian household per year was approximately 13,900kms in 2003-04, and the price of fuel was $0.90 per litre (ABS 2006; Fuelwatch 2008).

Further to the savings on motor fuel itself, there are cost savings on complementary goods such as vehicle registration, tyres and servicing. The registration cost difference between a four and six cylinder car (the most likely vehicle substitute) in Queensland is currently $111.95 (Registration fees 2008). A saving of $50 has been assumed for the reduction in associated servicing and running costs per year. Combining these figures to construct the cost savings for the efficiency case is shown in Table 1.

Case study changes	**Old**	**Efficient replacement**
Fuel economy	11L/100km	7L/100km
Annual kilometres travelled	13,900	13,900
Registration costs	$362.95	$251.00
Servicing costs	$250	$200

Consumption category changes	**Annual Saving**	**Per Week Saving**
Motor vehicle fuel	$500	$9.62
Vehicle registration and insurance	$111	$2.20
Parts and accessories	$50	$0.96
Total	$661	$12.78

Table 1. Case study weekly expenditure changes for fuel-efficient vehicle replacement.

The conservation case has the same reduction in fuel use as the efficiency case. This could occur with a switch to a more efficient vehicle, without compensation by increased driving, or simply a situation where a household reduces driving from the Australian average of 267kms per week to 167kms per week.

Given that the associated reduction in vehicle running costs improves the economic 'win' for this household choice, it is of interest to estimate the rebound effect with and without these added cost savings. Intuition would suggest that any complementary cost savings would increase the rebound effect, and it would be interesting to quantify the economic 'win' and environmental 'win' trade-off. A conservation rebound model, which assumes these cost savings but no direct rebound effect from increased driving, will be considered alongside a conservation rebound model for reduced driving with no associated cost reductions.

This reduction of expenditure on motor fuel gives a baseline potential GHG emissions reduction in both the efficiency and conservation cases of 25.01kg CO_2-e per week.

3.3.2 Household electricity

In line with the suggestion by the International Energy Agency (IEA), the Australian government has proposed to phase in a ban on incandescent light bulbs as a measure to reduce GHG emissions by an estimated 4million tonnes per annum (Turnbull, 2007). The proposed substitutes for incandescent light bulbs are compact fluorescent light bulbs (CFL). In the past decade, the capital cost of these bulbs has reduced to the point where they are now a cheaper lighting alternative and a classic example of 'win-win' environmental policy.

A number of inputs are required to determine potential cost savings and GHG emissions reduction for the conservation and efficiency cases for household electricity. The inputs include the capital cost of blubs, lighting equivalence, durability, electricity price, and usage.

First, CFLs can produce the equivalent lighting of an incandescent bulb that requires five times more power, such that a 15W compact fluorescent bulb is equivalent to a 75W incandescent bulb (2008e). Second, incandescent bulbs cost between $0.39 and $0.59 for a 75W globe while CFLs cost between $4.49 and $6.29 for a 15W bulbs in Australian supermarkets. For simplicity, a cost of $0.50 and $5.00 is assumed in this case for incandescent and CFLs respectively. Third, the increased lifespan of CFLs must be considered. It is widely claimed by manufacturers that CFLs can last between 8,000 and 15,000 hours compared to 1,000 hours for incandescent bulbs (2008e; 2008j). A 10,000 hour life is assumed for compact fluorescents, and 1,000 for incandescent bulbs in this case study. Fourth, the residential electricity price adopted is 17.10c per kilowatthour for tariff 11, which was the rate for general power and lighting in Queensland (Lucas, 2003). Finally, it is assumed that ten 75W bulbs are replaced by the household and that each bulb is used for 2 hours per day. Taken together these assumptions generate a scenario where that capital cost of lighting per period is equal, as shown in Table 2, and the cost savings arise from $1.43 less electricity consumption per week with potential greenhouse gas reductions of 10.49kg CO2-e per week.

	Old scenario	**New scenario**	**Per week cost savings**
Capital cost per week	$0.07	$0.07	$0
Electricity cost per week	$1.79	$0.36	$1.43

Table 2. Case study weekly expenditure changes for reduced electricity use

The conservation case for electricity conservation case is constructed with a simple assumption of the size of electricity cost savings from behavioural changes such as shorter showers, turning off lights when leaving a room, and turning off stand-by appliances. The ACF Greenhome Guide (2007e) states that stand-by power alone costs the average Australia household $100 per year, or $1.92 per week. For simplicity, the same electricity cost saving as the efficiency case of $1.43 per week is used, which appears a reasonable reflection of real behaviour by environmentally concerned households, and reflects the same baseline potential GHG emission reductions of 10.49kg CO2-e per week.

3.3.3 Combined case

The scenario where a household adopts both of the above cases concurrently, in either their efficiency or conservation form, was also simulated, as a raised level of environmental concern by a household is likely to result in some combination of these actions.

4. Results

Rebound effect estimates are presented graphically across the range of household weekly expenditure of $250 to $1500. Mean household expenditure is $717 per week, and the median is $593 per week. All DSL2 model results are with mean values for other non-income household explanatory variables

4.1 Vehicle fuel

Figure 2 shows the rebound effect estimate for the vehicle fuel conservation case, where no associated non-fuel cost savings are made. The indirect rebound effect is in the range of 7 to 27%, with all forms of the conservation model showing estimates close to 18% at the median expenditure level. Of note is the declining indirect rebound effect with increasing household total expenditure, although for the DSL2 model, where non-income factors where controlled for in the estimation of marginal budget shares, the variation is considerably lower.

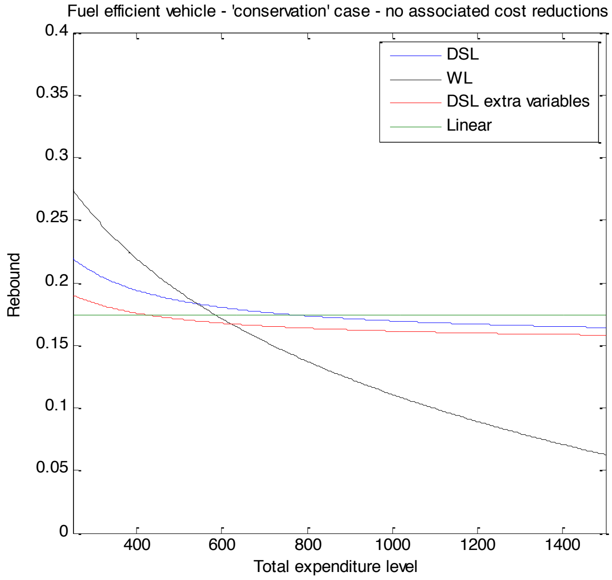

Figure 2. Indirect rebound effect from vehicle fuel conservation case

Figure 3 shows the indirect rebound effect estimate for the conservation case where a household substitutes for a more fuel efficient vehicle and has associated non-fuel costs savings, but does not compensate by increased driving. All conservation rebound models show a higher rebound effect at all income levels, will estimates clustered around 21% at the median expenditure level. This result makes intuitive sense, as the non-fuel cost savings can be directed to other GHG emissions intensive consumption.

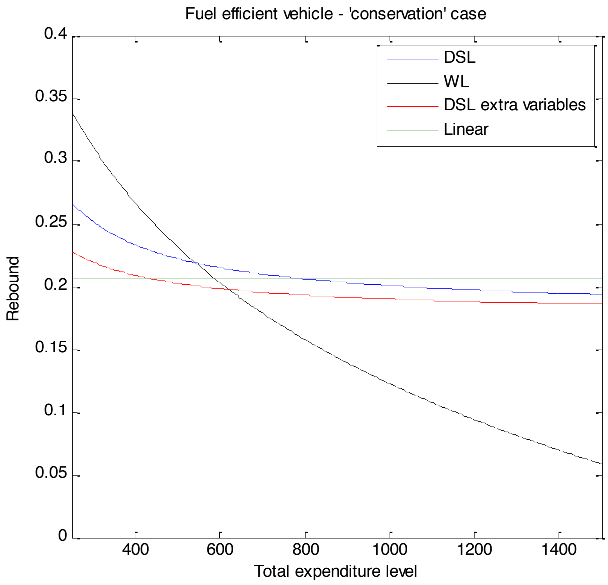

Figure 3. Indirect rebound effect from vehicle fuel conservation case with reductions in maintenance costs

For the efficiency case, the total direct and indirect rebound effect is estimated in the range of 11 to 48%, with all forms of the model showing a rebound effect close to 25% at the median household expenditure level (Figure 4).

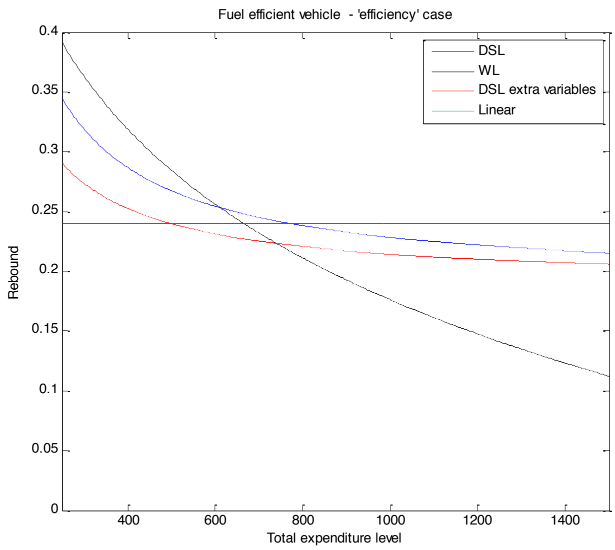

Figure 4. Total rebound effect from vehicle fuel efficiency case

The direct and indirect rebound effects from the efficiency model were separated (Figure 5). The main feature of this result is that the indirect rebound effect is much greater than the direct effect around at all household expenditure levels.

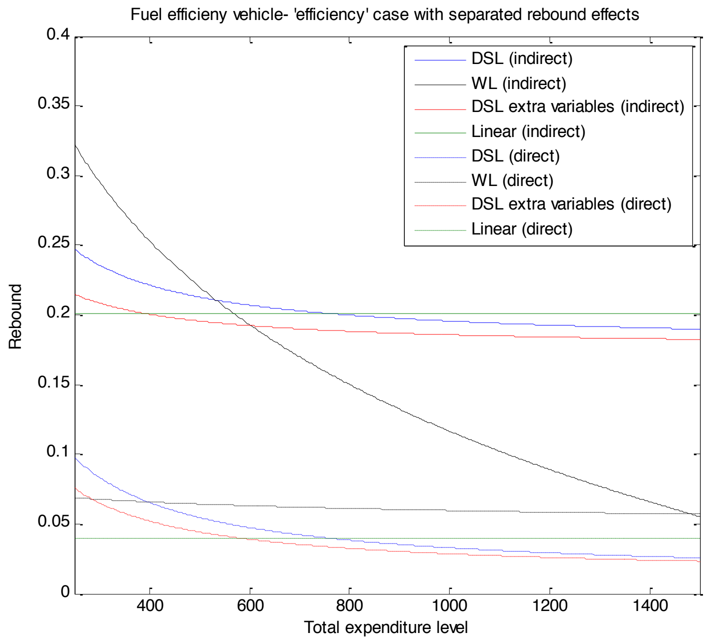

Figure 5. Direct and indirect rebound effect from vehicle fuel efficiency case

To more clearly understand the trade-off of between the direct and indirect rebound effect across the income range, the ratio of direct to indirect effects is plotted in Figure 6. The two DSL models show the direct effect is reducing as a proportion of the indirect effect with increasing expenditure level. While not conclusive, it shows that the indirect effect is a greater concern at higher income levels.

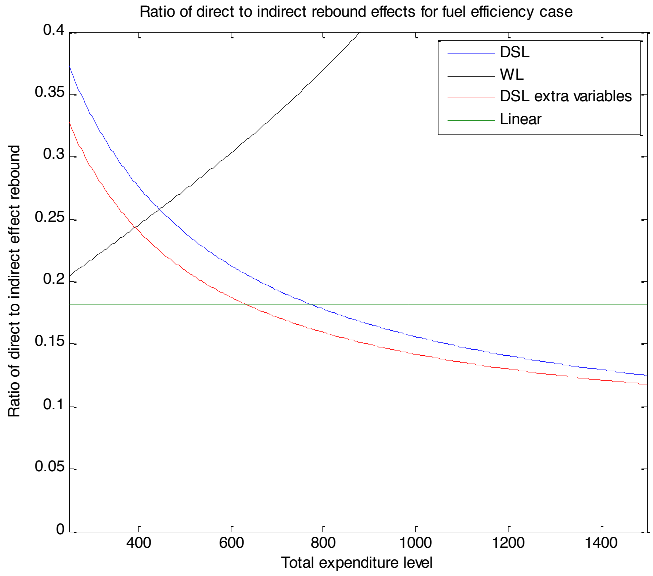

Figure 6. Ratio of direct to indirect rebound effect from vehicle fuel efficiency case

The direct effect is less than 10% at all income levels, and falls as income rises. The direct effect is also shown to be a smaller share of the total rebound effect at high income levels.

4.2 Household electricity

Figure 7 shows the results for the conservation case, with all non-linear household demand models revealing an inverse relationship between the indirect rebound effect and household expenditure level, within a range of 5 to 8%.

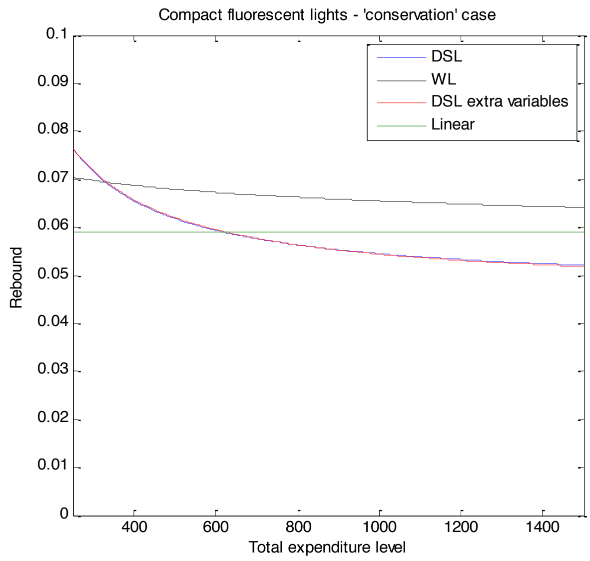

Figure 7. Indirect rebound effect from electricity conservation case

The efficiency rebound model estimates a total rebound effect between 3 and 10% (Figure 8). Consistent with the results from the vehicle fuel case, all non-linear household demand functions result in a decreasing rebound effect with increasing income. Also consistent is the narrow range of results around 7% at the median income level.

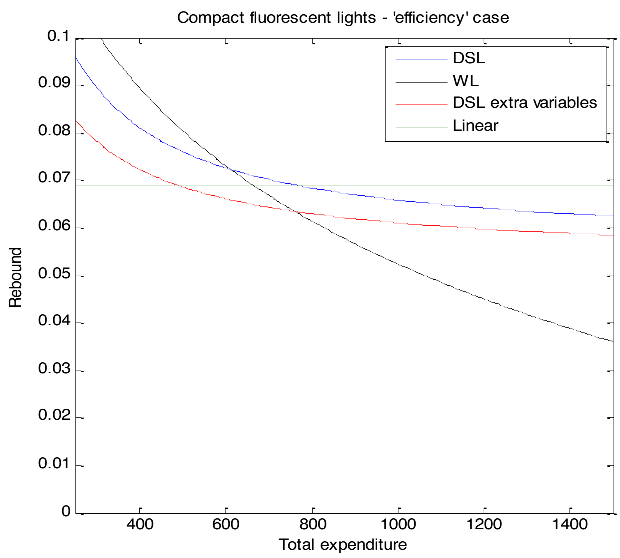

Figure 8. Total rebound effect from electrical efficiency case

Figure 9 shows the direct and indirect effects separately, and again the direct effect is the much smaller component of the total rebound effect. Interestingly, the WL model in this case provides a negative direct rebound effect at household expenditure levels over $800 per week. This is due to household electricity becoming an inferior good above the level in this model.

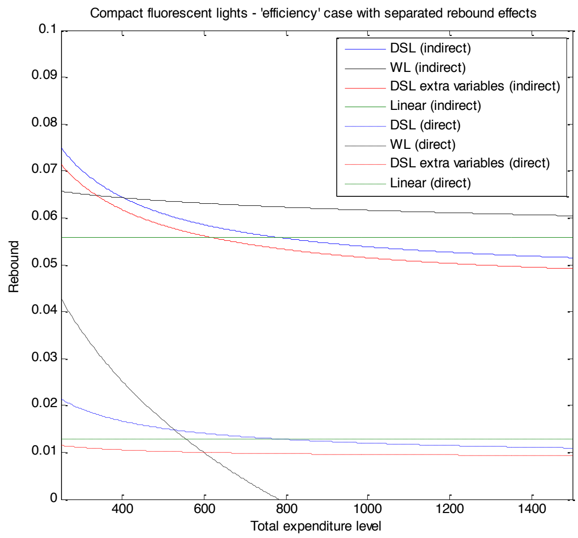

Figure 9. Direct and indirect rebound effect from electrical efficiency case

Again, it is worth appreciating whether the theoretical trade-off between the direct and indirect effect is observable in this case. The direct effect is plotted as a proportion of the indirect effect in Figure 10. The results are inconclusive, with only the DSL and WL models showing the type of trade-off expected, and the best fit DSL2 model showing the unexpected outcome of higher direct effects as a proportion of total rebound effect at higher household income levels.

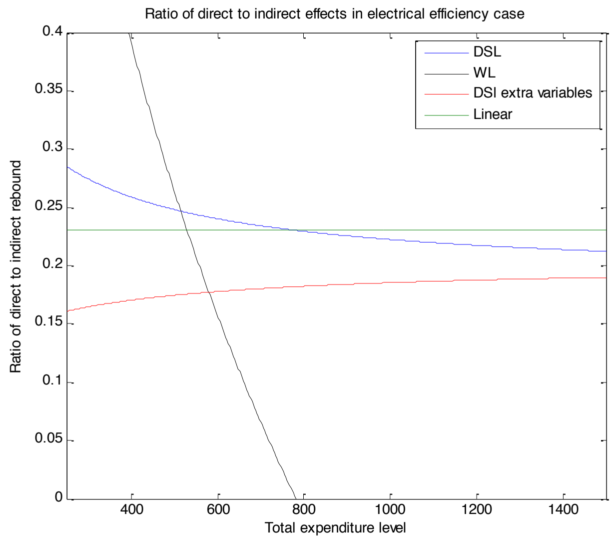

Figure10. Direct and indirect rebound effect from electrical efficiency case

4.3 Combined case

For households undertaking both the electricity and fuel use conservation choices, the indirect rebound effect is estimated between 12 and 15%, with minimal variation shown across household income levels (Figure 11).

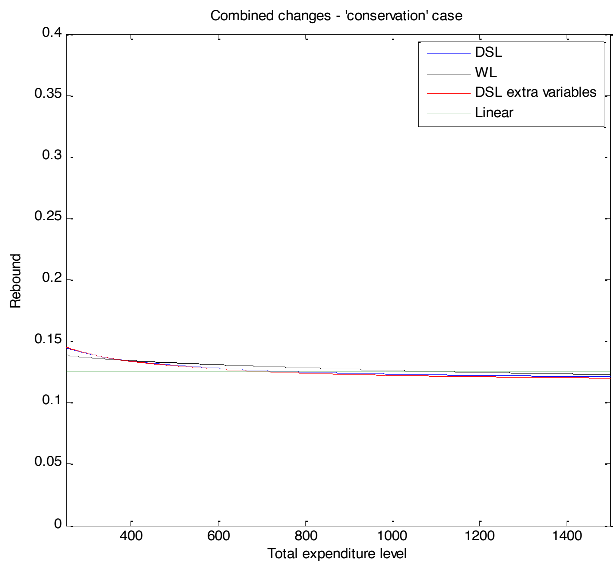

Figure 11. Indirect rebound effect from combined conservation case

The combined conservation case provides some further interesting insights. First, the variation of the rebound effect over the income range is greatly reduced compared to either case in isolation. This is due to the elimination of the two commodities with the highest embodied GHG emissions from the income effect.

Upon closer inspection, the rebound effect in the combined conservation case is less than one would expect from a simple addition of the individual case results. For example, in the vehicle fuel conservation case, net emissions reductions using the DSL2 model at median expenditure is 20.03kg CO2-e. In the electricity conservation case, comparable net GHG emissions reductions were 9.86kg CO2-e. The expected net GHG emissions reductions in the combined conservation case, using the DSL2 model at the median expenditure level, is therefore 29.89kg CO2-e. The modelled outcome however, gives a net reduction of 30.00kg CO2-e, which reflects an indirect rebound effect of 15.8%. It appears the rebound effect is diminished when conservation actions are combined, which is intuitively due to the isolation of expenditure on each of these energy commodities (fuel and electricity) from the income effect.

For households undertaking combined efficiency measures, the rebound effect is estimated between 10 and 30% across the income range, with all forms of the model showing a total rebound around 20% at the median total expenditure level (Figure 12). When direct and indirect effects are separated (Figure 13), it is clear that direct effects are a larger proportion of the total rebound effect compared to each case individually. It is also clear that a direct effect as a proportion of the total rebound effect is inversely related to household incomes (Figure 14).

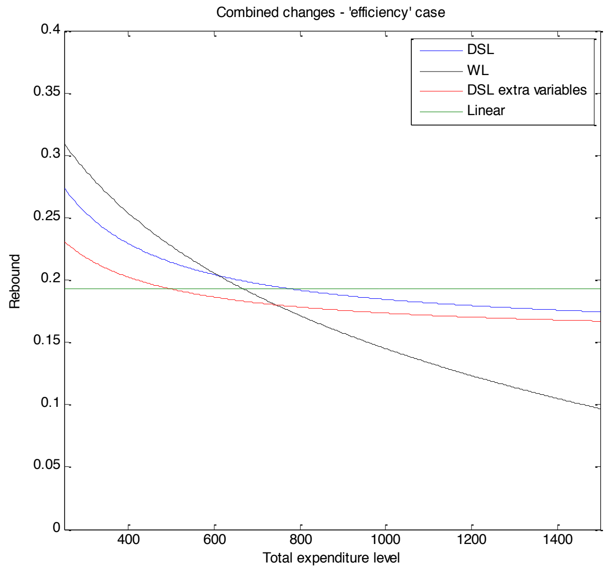

Figure 12. Total rebound effect from combined efficiency case

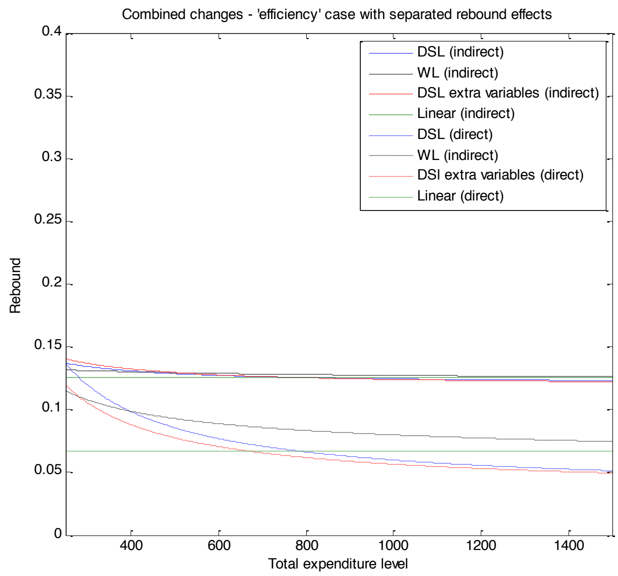

Figure 13. Direct and indirect rebound effect from combined efficiency case

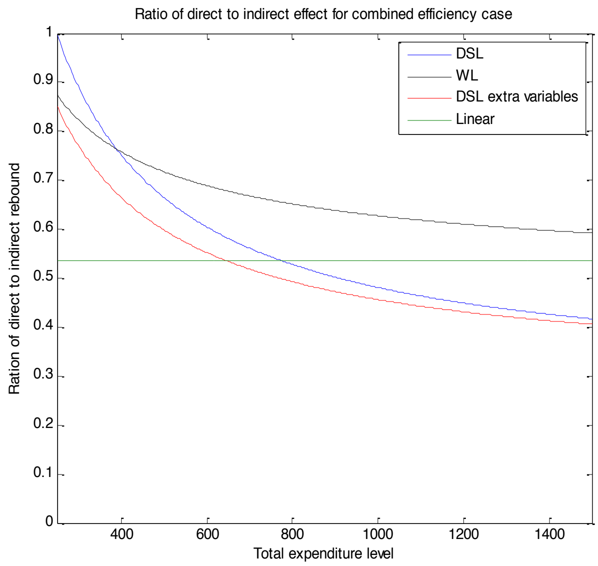

Figure 14. Ratio of direct to indirect rebound effect from combined efficiency case

The efficiency case offers a contrary observation regarding the additive effects of 'green' choices on the rebound effect. In this case, the sum of the net reductions in GHG emissions for each case using the DSL2 model at the median expenditure level is 29.01kg CO2-e, which equates to an expected 18.3% total rebound effect (direct and indirect). In the combined case, the net effect is a 28.86kg CO2-e emissions reduction, and a rebound effect of 18.7%. This represents a loss of environmental benefit when efficiency measures are combined, and is confirmed by all household demand models.

When the direct and indirect effects are isolated in the combined efficiency case, it is shown that the direct effects are a larger proportion of the total effect than in each individual case..

5. Discussion and conclusion

The focus of this paper was an examination of the scale of rebound effects, and the relationship between direct and indirect effects with household income for 'green' consumption choices aimed at reducing GHG emissions.

Applying consumption side rebound analysis to a series of case studies has demonstrated that while consumption pattern changes can be an effective way for households to decrease their GHG emissions, the results are lower than anticipated by engineering estimates. The highest rebound effect estimate was 40% in the case of adopting a more efficient vehicle, although estimates were as low as 5% in the electricity conservation case. At the median household income level, the estimated rebound effect for vehicle fuel conservation was approximately 18 to 21% (depending on the associated non-fuel cost savings), which is slightly higher than the 14% result of Alfredsson (2004), but consistent with the 22% result of Druckman et al. (2011). For the electricity conservation cases, the 5-8% result was far less than Alfredsson's (2004) estimate, but consistent with the 7% result of Druckman et al. (2011). In the combined case,

The empirical results confirm that household income level is an important determinant of the scale of the rebound effect. In both the conservation and efficiency models the total rebound effect, and both the direct and indirect effects individually, was inversely related to household income level. This is consistent with the findings in the literature of higher direct rebound effects for low income households (Baker, Blundell, and Micklewright 1989; Milne and

Boardman 2000; Hong, Oreszczyn, and Ridley 2006) and the implied reduction in direct effects at high incomes due to a saturation of demand for household energy services, as noted by many authors including Khazzoom (Khazzoom 1980) and Wirl (Wirl 1997).

A second key finding regarding the impact of income level is that the indirect effect becomes a larger proportion of the total rebound effect at higher income levels. This supports contentions made by others (Sorrell and Dimitropoulos 2008; Madlener and Alcott 2009) that a low direct rebound effect should not be interpreted as indication of the scale of the total rebound effect, especially in high income countries.

Regarding the use of the two rebound-effect models, efficiency and conservation, some general observations can be made. First, the conservation model, if indeed it is representative of household behaviour, produces a much lower rebound effect than in cases where household choices contain an implied price reduction. Additionally, when conservation measures are combined the environmental benefits are amplified, and the rebound effect reduced, than each case in isolation.

On the other hand, the efficiency model, where consumption changes have a price-reducing element, results in a higher rebound effect, and when efficient alternatives are combined, the rebound effect greater than the sum of each case in isolation. This signals that the focus of promoting 'green' household choices in the context of climate change should be on conservation measures, rather than efficient technologies.

The choice of household demand model for use in the rebound estimation was most important at the high and low extremes of household income level. However, near the average income, all models produced similar rebound effect estimates. Therefore, for estimation of average or aggregate rebound effects, the choice of household demand model unlikely to be a key factor.

These findings also suggest that the greater the economic benefit of household 'green' consumption choices, the larger the rebound effect. This is demonstrated in the vehicle fuel case where two conservation options where estimated - one with cost savings on fuel only, and one with associated reductions in vehicle maintenance costs. The added economic win for the household, in terms of reduced vehicle running costs, greatly increased the rebound effect, indicating an inherent trade-off between economic and environmental benefits. This supports the finding of Carlsson-Kanyama, Engstrom, and Kok (Carlsson-Kanyama, Engstr√∂m, and Kok 2005)who find a negative rebound effect for households adopting a 'green' diet, due to the increased cost of the diet.

A key observation is the way combining household actions changes the expected reductions in GHG emissions. When efficiency cases are combined the environmental effectiveness of the actions is reduced. In contrast, the effectiveness of conservation measures increases when combined. This finding may provide insights into how potential environmental benefits from energy efficient technology can be completely offset as they become more widely adopted throughout the economy.

The observed variation in the GHG intensity of the marginal consumption between low and high income households has wider implications. It suggests that government redistribution between high and low income households will have an associated environmental cost. It also suggests that there will be an environmental cost associated with government re-spending of environmental taxes, either directly, or through other tax reductions. If a revenue neutral position is maintained after the introduction of such taxes, the net effect is to encourage household consumption pattern changes, since real incomes should remain constant.

While many authors have postulated that recycling environmental tax revenues to reduce distortionary taxes, such as income taxes, enables the realisation of a 'double dividend' due to improved efficiency from environmental taxes (Bovenberg and de Mooij 1994; Ekins 2000; Manresa and Sancho 2005; Bento and Jacobsen 2007; Lawn 2007), this analysis supports the hypothesis that an intrinsic trade-off between the benefits of the first dividend, that of pollution reduction, and the second dividend exist (Ekins, 2000; Bento and Jacobsen, 2007). The investigation of rebound effects from government actions appears to be fertile ground for further research.

The major issue that remains for consumption side estimation of rebound effects, even at fixed technology levels, is the use of LCA data. The reason for variation in the size of the rebound effect with income levels is that variation in the estimated GHG intensity of consumption groups. This variation can be attributed to the trade-off between labour and energy intensity, which have been observed as substitutes in production processes (Maddala 1965; Karunaratne 1981; Lenzen and Dey 2002).

Yet the supply of labour into the production process requires the consumption of other commodities. Thus, it is proposed that all labour costs should be treated wholly as an exchange within the LCA input-output model. The rationale for this is simple. While some household consumption could be deemed unnecessary to support the individual to a standard for supplying labour, none of the wages would be deemed unnecessary to supply that particular quality of labour. Since wages equal consumption[9], then all consumption is necessary for keeping labour employed. This approach would greatly diminish the variation in emissions intensity between commodity groups, and as such, greatly reduce the environmental benefit of any consumption pattern change.

Indeed, to overcome these truncation errors, Costanza (1980), on the assumption that labour input itself requires the outputs of the economy,

[9] Savings are simply deferred consumption and also contribute to banking reserves, promoting further lending ie. you can't destroy or defer the purchasing power of wages through non-consumption.

estimated the embodied energy of a number of economic outputs with alternative system boundaries, where the output of the system was defined by gross capital formation, inventory increases, and exports. This method greatly reduced variation in energy intensity across outputs, leading to the observation that "there is a strong relationship between embodied energy and dollar value for a 92-sector U.S. economy if the energy required to produce labour and government services is included".

Within the model of Costanza (1980), consumption pattern changes would provide no net changes to energy consumption or GHG emissions. Indeed, the only way for household to reduce their GHG emissions would be to reduce their income at the same time as reducing expenditure through conservation behaviour, as suggested by Madlener and Alcott (2009).

The fact remains that the determination of the LCA system boundary is an important determinant of the embodied energy and greenhouse gas emissions. With this in mind, the current study should be considered an incremental step in our understanding of the nature of rebound effects for GHG abatement actions. While the relationships between the direct and indirect effects, and household income, are valid upon the accepted LCA methods, the size of the estimated rebound effects should be considered bare minimum estimates.

For governments, the key message is that policies promoting 'green' household consumption choice are a less effective measure for reducing greenhouse gas emissions than they appear when rebound effects are ignored. Certainly, the measureable direct and indirect rebound effects should be normal practice when evaluating the effectiveness of environmental policy.

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Appendix A: Life cycle embodied GHG emissions data at detailed commodity group level, using IO hybrid method

Broad commodity group	Detailed commodity group	Life cycle Greenhouse gas intensity (kg CO2-e/$)
Domestic fuel and power	Domestic fuel and power	7.333
Food and non-alcoholic beverages	Bakery products	0.403
	Condiments	0.444
	Dairy products	1.162
	Fish	0.507
	Fruit and nuts	0.391
	Meals out	0.394
	Meat	1.709
	Non-alcoholic beverages	0.281
	Vegetables	0.398
Alcoholic beverages	Alcohol	0.301
Clothing and footwear	Clothing	0.308
	Clothing services	0.138
	Footwear	0.299
Household furnishings and equipment	Appliances	0.738
	Blankets, linen and furniture	0.349
	Furniture and flooring	0.304
	Glass and tableware	0.614

	Tools	0.239
Household services and operation	Household services	0.205
Medical care and health expenses	Health fees	0.261
	Health insurance	0.017
Transport	Freight	0.753
	Vehicle fuel	2.600
	Motor vehicle purchase	0.289
	Motor vehicle parts and accessories	0.289
	Public transport	0.540
	Vehicle charges	0.152
	Vehicle registration and insurance	0.016
Recreation	Holidays	0.850
	Pets	0.356
	Recreational goods	0.406
	Recreational services	0.127
Personal care	Personal care	0.221
Miscellaneous	Miscellaneous goods	0.312
	Miscellaneous services	0.157

Source: Dey (2008)

Appendix B: Regression results for double-semi log model ***1% significance, **5% significance, *10% significance, with standard errors in parenthesis

	α	β	γ	Adj. r^2
Alcohol	-17.53 (11.91)	0.025*** (0.00048)	3.73 (2.41)	0.15
Appliances	-12.53 (9.21)	0.016*** (0.0040)	2.18 (1.88)	0.052
Bakery	-23.61*** (1.98)	0.0027*** (0.00075)	6.03*** (0.39)	0.23
Blankets/linen	6.98 (8.44)	0.015*** (0.0037)	-1.68 (1.73)	0.059
Clothing	47.57** (23.54)	0.068*** (0.0095)	-10.62** (4.76)	0.24
Clothing services	1.77 (1.21)	0.0020*** (0.00050)	-0.38 (0.25)	0.036
Condiments	-28.11*** (3.57)	0.0061*** (0.0014)	6.73*** (0.72)	0.25
Dairy	-16.38*** (1.40)	0.0012** (0.00052)	4.31*** (0.28)	0.18
Domestic fuel and power	-0.98 (4.72)	0.0088*** (0.0018)	3.13*** (0.94)	0.18
Fish	-2.92* (1.58)	0.0023*** (0.00068)	0.81** (0.32)	0.054
Footwear	3.13	0.012***	-0.88	0.079

	(5.01)	(0.0021)	(1.02)	
Freight	8.12** (3.28)	0.0065*** (0.0015)	-1.66** (0.68)	0.041
Fruit and nuts	-12.73*** (1.65)	0.0030*** (0.00065)	3.24*** (0.33)	0.14
Vehicle fuel	-72.15*** (6.29)	0.0080*** (0.0025)	15.79*** (1.27)	0.21
Furniture/ flooring	5.88 (17.65)	0.042*** (0.0076)	-2.49 (3.59)	0.086
Glass/tableware	0.18 (5.24)	0.0067*** (0.0021)	-0.15 (1.06)	0.067
Health fees	-14.64** (6.91)	0.015*** (0.0030)	2.85* (1.41)	0.090
Health Insurance	-34.70*** (3.23)	0.0080*** (0.0013)	7.52*** (0.65)	0.19
Holidays	-15.50 (17.91)	0.068*** (0.0078)	1.58 3.66)	0.21
Household services	-57.20*** (9.79)	0.031*** (0.0041)	14.51*** (1.98)	0.25
Meals out	-50.20*** (10.21)	0.044*** (0.0042)	9.68*** (2.07)	0.36
Meat	-30.96*** (2.92)	0.0040*** (0.0011)	7.70*** (0.58)	0.17
Miscellaneous	21.96	0.031***	-4.71	0.13

goods	(23.31)	(0.0090)	(4.68)	
Miscellaneous services	133.18*** (46.14)	0.17*** (0.019)	-29.81*** (9.34)	0.31
Motor vehicle purchase	206.36*** (52.30)	0.20*** (0.022)	-47.45*** (10.61)	0.24
Non-alcoholic beverages	-21.15*** (1.74)	0.0039*** (0.0007)	4.91*** (0.35)	0.25
Motor vehicle parts/ accessories	-12.21 (7.33)	0.021*** (0.0029)	2.45** (0.98)	0.04
Personal care	-6.10 (7.33)	0.021*** (.0029)	1.39 (1.48)	0.20
Pets	1.03 (10.14)	0.012*** (0.0045)	-0.15 (20.8)	0.03
Public transport	-6.99*** (1.43)	0.00058 (0.00054)	1.57*** (0.28)	0.020
Recreational goods	60.79* (34.35)	0.083*** (0.014)	-13.13* (6.92)	0.22
Recreational services	-13.29 (10.67)	0.025*** (0.0045)	2.40 (2.16)	0.12
Tools	-8.83** (4.18)	0.0083*** (0.0019)	1.60** (0.085)	0.050
Vegetables	-15.52*** (1.31)	0.0019*** (0.00049)	3.97*** (0.026)	0.18
Vehicle charges	18.55	0.036***	-4.42	0.088

	(17.98)	(0.0073)	(3.63)	
Vehicle registration	-40.62*** (3.29)	0.0066*** (0.0013)	9.44*** (0.656)	0.31

Appendix C: Regression results for DSL2 model ***1% significance, **5% significance, *10% significance, with standard errors in parenthesis

	α	β	γ	Persons/house (C1)	Urbanity (C2)	State (C3)	Age (C4)	Dwelling (C5)	Adj. r^2
Alcohol	-16.88 (12.92)	0.026*** (0.005)	5.11** (2.46)	-3.65*** (0.45)	2.33*** (0.85)	1.19*** (0.27)	-0.47*** (0.07)	0.35 (0.39)	0.17
Appliances	-18.47* (10.17)	0.016*** (0.004)	3.91** (1.89)	-2.45*** (0.55)	0.52 (1.00)	0.55* (0.30)	-0.018 (0.075)	-0.67* (0.35)	0.56
Bakery	-23.35*** (2.17)	0.0020*** (0.0007)	3.49*** (0.39)	4.45*** (0.13)	-0.035 (0.22)	-0.098 (0.089)	0.31*** (0.018)	-0.097 (0.089)	0.39
Blankets/linen	1.24 (9.14)	0.015*** (0.0038)	-0.69 (1.71)	-1.01*** (0.38)	0.088 (0.64)	0.40* (0.22)	0.059 (0.051)	-0.22 (0.26)	0.061
Clothing	56.77**	0.068***	-13.01	2.90*** (0.70)	-0.32 (1.08)	-0.36 (0.3	-0.092	1.09** (0.54)	0.24

	(24.09)	(0.0095)	*** (4.76)			5)	(0.097)		
Clothing services	0.72 (1.30)	0.0019*** (0.00050)	-0.19 (0.25)	-0.086* (0.051)	-0.29*** (0.092)	0.004 (0.029)	0.022*** (0.0081)	0.085* (0.047)	0.039
Condiments	-18.26*** (3.88)	0.0060*** (0.0014)	2.96*** (0.72)	4.69*** (0.18)	0.51* (0.30)	0.19** (0.090)	0.053** (0.024)	-0.042 (0.13)	0.36
Domestic fuel and power	5.28 (4.96)	0.0089*** (0.0017)	0.65 (0.95)	2.70*** (0.17)	-0.041 (0.34)	0.91*** (0.094)	0.084*** (0.028)	-1.25*** (0.16)	0.24
Fish	-5.02*** (1.72)	0.0020*** (0.00069)	1.13*** (0.32)	0.11 (0.093)	-0.69*** (0.18)	-0.28*** (0.051)	0.11*** (0.014)	-0.035 (0.067)	0.065
Footwear	3.11 (4.96)	0.012*** (0.0021)	-1.27 (0.99)	0.71*** (0.24)	0.023 (0.42)	-0.026 (0.1	0.033 (0.035)	0.18 (0.18)	0.080

						3)			
Freight	7.80** (3.50)	0.0065*** (0.0015)	-1.17* (0.65)	-0.66*** (0.18)	-0.60*** (0.20)	-0.011 (0.079)	-0.061** (0.025)	0.48*** (0.15)	0.049
Vehicle fuel	-51.7*** (7.01)	0.0093*** (0.0026)	11.32*** (1.31)	3.19*** (0.41)	3.54*** (0.75)	0.61*** (0.22)	-0.22*** (0.057)	-2.36*** (0.24)	0.24
Furniture/ flooring	-3.32 (18.97)	0.043*** (0.0076)	1.071 (3.64)	-5.46*** (0.81)	2.75* (1.45)	0.47 (0.45)	-0.26** (0.13)	-0.19 (0.67)	0.093
Glass/table ware	-2.93 (5.86)	0.0065*** (0.0021)	0.26 (1.11)	-0.17 (0.13)	0.0075 (0.25)	0.0032 (0.087)	0.057** (0.026)	0.070 (0.14)	0.068
Health fees	-18.83*** (7.97)	0.014*** (0.0030)	3.85** (1.52)	0.075 (0.39)	-3.63*** (0.63)	-0.66*** (0.23)	0.29*** (0.057)	-0.15 (0.28)	0.095

Health Insurance	-54.43*** (3.83)	0.0066*** (0.0013)	9.31*** (0.68)	0.34 (0.23)	-0.79* (0.45)	0.12 (0.13)	0.59*** (0.036)	-0.74*** (0.17)	0.22
Holidays	-56.53*** (19.05)	0.066*** (0.0077)	10.23*** (3.66)	-7.08*** (0.87)	-5.31** (1.74)	0.17 (0.52)	0.62*** (0.15)	0.70 (0.68)	0.22
Household services	-20.72* (10.74)	0.031*** (0.0041)	9.23*** (2.03)	3.97*** (0.55)	-4.12*** (0.98)	-0.67** (0.31)	-0.27*** (0.078)	-1.81*** (0.36)	0.27
Meals out	-28.14*** (10.74)	0.044*** (0.0042)	9.26*** (2.14)	-0.56 (0.51)	-7.19*** (0.83)	-1.79*** (0.28)	-0.41*** (0.079)	2.23*** (0.45)	0.37
Miscellaneous goods	21.20 (24.73)	0.031*** (0.0091)	-5.07 (4.81)	0.98** (0.42)	-1.26* (0.68)	0.088 (0.20)	0.065 (0.062)	0.60* (0.34)	0.13
Miscellaneous	150.05***	0.17***	-31.36	0.61 (1.44)	-0.14 (2.48)	-1.13 (0.7	-0.70*	4.48***	0.31

services	(48.59)	(0.019)	*** (9.33)			3)	** (0.19)	(1.21)	
Motor vehicle purchase	159.39*** (55.25)	0.20*** (0.022)	-38.09*** (10.69)	-12.80*** (1.64)	16.90*** (3.10)	2.04** (0.94)	-0.43* (0.24)	-0.34 (1.21)	0.25
Non-alcoholic beverages	-12.39*** (1.89)	0.0040*** (0.00066)	2.85*** (0.35)	2.24*** (0.12)	-0.49** (0.22)	-0.10 (0.067)	-0.043** (0.017)	0.072 (0.096)	0.30
Motor vehicle parts/accessories	-8.11 (5.26)	0.0057*** (0.0020)	1.68* (0.99)	0.19 (0.30)	1.44*** (0.54)	0.27* (0.15)	-0.12*** (0.041)	-0.34* (0.20)	0.043
Personal care	-11.10 (7.72)	0.020*** (0.0029)	1.87 (1.52)	0.33 (0.29)	-0.94* (0.54)	-0.19 (0.17)	0.14*** (0.045)	0.48** (0.23)	0.20
Pets	1.59 (10.63)	0.013*** (0.004	0.46 (2.046)	-1.53*** (0.37)	1.21 (0.74)	0.18 (0.20)	-0.052 (0.07	-1.29***	0.040

		5)					2)	(0.30)	
Public transport	-0.97 (1.65)	0.00035 (0.00052)	1.27*** (0.30)	0.49*** (0.13)	-2.20*** (0.19)	-0.95*** (0.071)	-0.052*** (0.018)	0.89*** (0.14)	0.068
Recreational goods	80.93** (36.35)	0.085*** (0.014)	-15.08** (6.98)	-0.097 (0.82)	0.55 (1.43)	-0.054 (0.48)	-0.66*** (0.11)	1.54** (0.71)	0.22
Recreational services	-20.06* (11.91)	0.024*** (0.0045)	2.50 (2.22)	0.89 (0.55)	0.51 (1.06)	0.0063 (0.29)	0.20*** (0.075)	0.11 (0.37)	0.12
Tools	-9.52** (4.67)	0.0084*** (0.0019)	1.69* (0.89)	-0.36 (0.35)	0.72 (0.54)	0.32** (0.14)	-0.016 (0.040)	-0.42** (0.17)	0.051
Vegetables	-21.16*** (1.56)	0.0012** (0.00049)	3.82*** (0.27)	1.35*** (0.098)	-0.55*** (0.19)	-0.022 (0.058)	0.26*** (0.016)	-1.47*** (0.16)	0.23
Vehicle	12.82	0.036*	-1.68	-3.64***	0.91	-	-	-0.75*	0.0

charges	(19.56)	** (0.0074)	(3.70)	(0.64)	(1.20)	0.62* (0.36)	0.023 (0.10)	(0.43)	93
Vehicle registration	-26.33*** (3.65)	0.0067*** (0.0013)	7.88*** (0.68)	1.12*** (0.19)	-2.63*** (0.35)	-0.63*** (0.11)	0.0045 (0.029)	-1.47*** (0.16)	0.33
Dairy	-13.74*** (1.57)	0.00098** (0.00051)	2.31*** (0.28)	2.81*** (0.10)	0.49*** (0.18)	0.22*** (0.054)	0.11*** (0.014)	-0.19*** (0.074)	0.30
Fruit and nuts	-22.60*** (1.87)	0.0019*** (0.00063)	3.75*** (0.33)	1.25*** (0.11)	-1.19*** (0.21)	-0.36*** (0.065)	0.39*** (0.019)	0.078 (0.094)	0.20
Meat	-36.37*** (3.31)	0.0030*** (0.0011)	5.78*** (0.59)	4.17*** (0.20)	-0.089 (0.39)	0.20* (0.12)	0.50*** (0.031)	-0.98*** (0.13)	0.25

Appendix D: Regression results for Working-Leser model ***1% significance, **5% significance, *10% significance, with standard errors in parenthesis

	α	β	Adj. r^2
Alcohol	0.026*** (0.0055)	0.0013* (0.00087)	0.00020
Appliances	-0.0089** (0.0048)	0.0039*** (0.00076)	0.0039
Bakery	0.11*** (0.0022)	-0.013*** (0.00034)	0.18
Blankets/linen	- 0.0075*** (0.0028)	0.0026*** (0.00044)	0.0051
Clothing	-0.034*** (0.00540	0.011*** (0.00084)	0.025
Clothing services	-0.00070 (0.00052)	0.00027*** (0.000082)	0.0015
Condiments	0.091*** (0.0025)	-0.0094*** (0.00040)	0.077
Dairy	0.087*** (0.0017)	-0.010*** (0.00027)	0.18
Domestic fuel and power	0.29*** (0.0039)	-0.038*** (0.00061)	0.36
Fish	0.019*** (0.0012)	-0.0020*** (0.00019)	0.017

Footwear	-0.0078*** (0.0023)	0.0024*** (0.00037)	0.0062
Freight	0.0066*** (0.0013)	-0.00054** (0.00021)	0.00082
Fruit and nuts	0.059*** (0.0019)	-0.0066*** (0.00030)	0.071
Vehicle fuel	0.084*** (0.0052)	-0.0052*** (0.00081)	0.0061
Furniture/ flooring	-0.044*** (0.0065)	0.011*** (0.0010)	0.016
Glass/tableware	-0.00046 (0.0014)	0.00089*** (0.00022)	0.0023
Health fees	0.010** (0.0040)	0.0014** (0.00063)	0.00064
Health Insurance	0.045*** (0.0068)	-0.0028*** (0.00059)	0.0031
Holidays	-0.049*** (0.0079)	0.016*** (0.0012)	0.025
Household services	0.28*** (0.0065)	-0.030*** (0.0010)	0.11
Meals out	0.0045 (0.0054)	0.0082*** (0.00085)	0.014
Meat	0.12***	-0.014***	0.090

	(0.0034)	(0.00054)	
Miscellaneous goods	-0.0041 (0.0036)	0.0036*** (0.00057)	0.0059
Miscellaneous services	-0.091*** (0.0096)	0.027*** (0.0015)	0.045
Motor vehicle purchase	-0.24*** (0.011)	0.046*** (0.0018)	0.089
Non-alcoholic beverages	0.056*** (0.0018)	-0.0056*** (0.00028)	0.057
Motor vehicle parts/ accessories	0.0034 (0.0027)	0.00099** (0.00042)	0.00069
Personal care	0.029*** (0.0033)	-0.00059 (0.00053)	0.00004
Pets	0.015*** (0.0034)	-0.00035 (0.00053)	-0.000087
Public transport	0.019*** (0.0018)	-0.0021*** (0.00029)	0.0076
Recreational goods	-0.010 (0.0069)	0.0091*** (0.0011)	0.010
Recreational services	0.00076 (0.0045)	0.0040*** (0.00072)	0.0045
Tools	-0.0013 (0.0026)	0.0017*** (0.00041)	0.0024

Vegetables	0.074*** (0.0017)	-0.0086*** (0.00027)	0.13
Vehicle charges	-0.029*** (0.0053)	0.0077*** (0.00084)	0.012
Vehicle registration	0.10*** (0.0031)	-0.0099*** (0.00049)	0.059

Appendix E: Regression results for Linear model ***1% significance, **5% significance, *10% significance, with standard errors in parenthesis

	α	β	Adj. r^2
Alcohol	2.54*** (0.78)	0.030*** (0.00087)	0.15
Appliances	-0.83 (0.88)	0.019*** (0.00098)	0.052
Bakery	8.82*** (0.23)	0.011*** (0.00026)	0.20
Blankets/linen	-2.061*** (0.58)	0.013*** (0.00065)	0.059
Clothing	-9.57*** (1.07)	0.054*** (0.0012)	0.24
Clothing services	-0.28*** (0.087)	0.0015*** (0.000097)	0.035
Condiments	8.12*** (0.30)	0.015*** (0.00033)	0.23
Dairy	6.78*** (0.18)	0.0067*** (0.00019)	0.15
Domestic fuel and power	15.85*** (0.31)	0.013*** (0.00034)	0.17
Fish	1.46*** (0.15)	0.0033*** (0.00017)	0.053
Footwear	-1.59***	0.011***	0.079

	(0.39)	(0.00044)	
Freight	-0.80*** (0.24)	0.0044*** (0.00027)	0.038
Fruit and nuts	4.68*** (0.20)	0.0072*** (0.00023)	0.13
Vehicle fuel	12.82*** (0.65)	0.028*** (0.00073)	0.19
Furniture/ flooring	-7.51*** (1.38)	0.038*** (0.0015)	0.086
Glass/tableware	-0.60** (0.26)	0.0065*** (0.00030)	0.068
Health fees	0.68 (0.66)	0.019*** (0.00073)	0.089
Health Insurance	5.76*** (0.42)	0.018*** (0.00047)	0.18
Holidays	-6.99*** (1.52)	0.070*** (0.0017)	0.21
Household services	20.16*** (0.95)	0.049*** (0.0011)	0.24
Meals out	1.86** (0.84)	0.056*** (0.00094)	0.35
Meat	10.49*** (0.36)	0.014*** (0.00041)	0.15
Miscellaneous	-3.37***	0.025***	0.13

goods	(0.72)	(0.00081)	
Miscellaneous services	-27.20*** (2.19)	0.13*** (0.0025)	0.30
Motor vehicle purchase	-48.89*** (2.83)	0.14*** (0.0032)	0.23
Non-alcoholic beverages	5.25*** (0.21)	0.010*** (0.00023)	0.23
Motor vehicle parts/ accessories	0.97*** (0.46)	0.0084*** (0.00051)	0.039
Personal care	1.38*** (0.51)	0.023*** (0.00057)	0.20
Pets	0.25 (0.67)	0.012*** (0.00075)	0.036
Public transport	1.45*** (0.22)	0.0026*** (0.00024)	0.017
Recreational goods	-9.84*** (1.39)	0.066*** (0.0016)	0.22
Recreational services	-0.38 (0.85)	0.028*** (0.00095)	0.12
Tools	-0.20 (0.49)	0.010*** (0.00055)	0.050
Vegetables	5.86*** (0.18)	0.0070*** (0.00020)	0.16

Vehicle charges	-5.22*** (1.07)	0.030*** (0.0012)	0.087
Vehicle registration	10.17*** (0.34)	0.019*** (0.00038)	0.27