What if consumers decided to all 'go green'? Environmental rebound effects from consumption decisions

Murray, Cameron K.

University of Queensland

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Cameron K. Murray[1,*]

University of Queensland,St Lucia, Queensland, Australia, 4067

Abstract

Shifting consumer preferences towards 'green' consumption is promoted by many governments and environmental groups. Rebound effects, which reduce the effectiveness of such actions, are estimated for cost-saving 'green' consumption choices using Australian data.

Cases examined are: reduced vehicle use, reduced electricity use, changing to smaller passenger vehicles, and utilising fluorescent lighting. It is found that if rebound effects are ignored when evaluating 'green' consumption, environmental benefits will be overstated by around 20% for reduced vehicle use, and 7% for reduced electricity use. Rebound effects are higher, and environmental benefits lower, when more efficient vehicles or lighting are utilised rather than simple conservation actions of forgoing use. In addition, lower income households have higher rebound effects, suggesting that environmental policy directed at changing consumer behaviour is most effective when targeted at high income households. Additionally, an inherent trade-off between economic and environmental benefits of 'green' consumption choices is demonstrated.

The size of the rebound effect, and the observed variation with household income, is attributed to life-cycle analysis (LCA) methodologies associated with the calculation of embodied GHG emissions of consumption goods. These results should be therefore be interpreted as the minimum rebound effect to include in policy evaluation.

Keywords: Rebound effect; conservation; household consumption; greenhouse emissions

*Corresponding author
Email address: ckmurray@gmail.com (Cameron K. Murray)
[1]ph. +617 3255 2936, m. +61422 144 674

1. Background

More sustainable consumption patterns are promoted by governments, environmental groups and international agencies as a measure to combat environmental degradation (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 cost saving 'green' behaviour simultaneously leads to environmental benefits. If consumer preferences can be nudged towards less every and resource intensive consumption, through information and marketing campaigns, then environmental externalities can be party corrected by being brought into consumer utility functions.

Before promoting an agenda to nudge consumer preferences towards 'green' consumption, the scale of potential environmental benefits should be understood. It is commonly assumed that high rates of adoption of win-win 'green' consumption choices will significantly reduce GHG emissions. However, this assumption is typically made using incomplete engineering-type analysis, where many little actions are expected to add up to significant economy wide changes. This type of calculation ignores economic rebound effects.

Rebound effects describe the flow-on effects from technology and consumption pattern changes that offset intended environmental benefits. 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 (or price effects) occur when new technology decreases the effective price of a good or service, and consumers adapt by consuming more of that good or service. Indirect effects (or incomes effects) occur when reduced costs of a good or service lead to increased consumption of other goods and services, which themselves have embodied 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.

One widely held view is that the indirect effect with respect to 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)

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 embodied resource data is one reason for slim body of research, a point emphasised in Kok et al. (2006) reviewed 19 studies of embodied energy and GHG emissions from consumption patterns, finding only three that provided sufficient detail to allow econometric estimation of the indirect effect. Given the variation in the embodied energy and GHG emissions due to different composition of national energy sources, one would expect the some cross-country variation of indirect rebound effects.

The rebound effect literature is also 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).

The most promising area for demand-side environmental policies to have short-run pay-offs is not new technology, but the adoption of 'green' consumption choices in the absence of any changes to technology. In this context, better targeted nudging of consumer preferences may improve the environmental pay-off of such policies. But a better understanding of nature of rebound effects, and therefore the potential size of environmental benefits, is required to achieve this aim.

2. Rebound effects from pure consumption choices

This paper considers the scenario where technology and product choice are fixed, and only consumer preferences change. In the absence of technology changes, cost-saving 'green' consumption choices are subject to rebound effects when liberated purchasing power is utilised for additional consumption. A household with new 'green' preferences choosing a smaller but more fuel-efficient car may be tempted to drive further, and will spend the resulting cost savings elsewhere in the household budget.

Specific definitions of direct and indirect rebound effects are required in the context of pure consumption choices with fixed technology. The direct effect is the offsetting environmental impact that occurs when cost savings are spent on the commodity from which they are saved. For example, changing to a fuel efficient small car will generate savings for the household from fuel expenses, but driving further will incur some offsetting fuel costs. The indirect effect is the offsetting environmental impact from the increased spending in other areas of the household budget.

In this paper, consumption choices that involve new household capital, such as new appliances or vehicles, are referred to as because the household service, of lighting or transport, is produced more cheaply (ignoring any reductions in quality). In these scenarios one would expect both direct and indirect effects.

A household that goes 'green' without changing its capital stock, but instead chooses a conservation approach, such as replacing driving with cycling or utilising electrical appliances more sparingly, the indirect rebound effect will be the total rebound effect. These scenarios are pure *conservation choices*. Distinguishing between the two types of behaviour provides a clearer picture of net effect of household choices, at least in the short run, and the types of consumption choices that have better associated environmental benefits.

Existing estimates of rebound effects from consumption choices alone are limited. Alfredsson (2004) estimates rebound effects from 'green' consumption choices of 14% for transport abatement, and 20% for 'green housing, and a back-fire (approximately 200%) for a 'green diet and a rebound effect for these combined actions of 20% in terms of GHG emissions. Additionally, the impact of increasing incomes was shown to offset any benefits made by consumption pattern changes. Specifically, 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 rebound effect from a change to a cheaper low carbon diet, with estimates around 50%. 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 common feature of these studies is that the rebound effect model allows for re-spending on the goods from which the saving where made, meaning in all scenarios have a direct rebound effect. 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 this paper improves the estimation of rebound effects, and enables differentiation between pure *conservation choices* and *efficient consumption choices*.

Of particular interest is the potential for variation in the magnitude of the rebound effect for consumption choices across the different household incomes. One might expect that since there is a trade-off between direct and indirect effects, and direct effects have been observed to diminish with rising incomes that indirect rebound effects may increase with rising income levels (Baker et al., 1989; Milne and Boardman, 2000; Roy, 2000). Yet LCA data of embodied GHG emissions suggests that the opposite might be true due to the decrease in GHG intensity of luxury goods (Lenzen et al., 2004, 2006; Hertwich, 2005).

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 fuels comprising a larger share of the household budget (Baker et al., 1989; Milne and Boardman, 2000; Roy, 2000; Hong et al., 2006). This evidence points to indirect effects becoming more significant than direct effects over time and with increasing incomes.

Girod and De Haan (2010) suggest that evaluation of GHG emissions from consumption may overstate emissions at high income levels due to increasing quality. The basic argument is that twice the expenditure on a product does does purchase twice to physical quantity. Yet these elevated prices are either reflective of increased inputs to production, or some form of rent transferred to the producer, meaning that this assertion remains unclear at a macro level Vringer and Blok (1995).

Indeed, as a backdrop to this literature, there remains a major concern about the limitations of LCA data due to necessary boundary specifications of inputs and outputs of the economy. Variation in GHG intensity of consumption goods ultimately determines the size of the rebound effect and the net environmental benefit of consumption choices. Typically LCA data shows a trade-off between labour and energy intensity (Maddala, 1965; Karunaratne, 1981; Lenzen and Dey, 2002), yet the supply of labour into the production process requires the consumption of other commodities.

To overcome these truncation errors, with the assumption that labour input is merely a transfer, Costanza (1980) estimated the embodied energy of a number of economic outputs with alternative system boundaries. 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". Within Costanza's (1980) framework, 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).

With this in mind, this paper builds on these handful of studies of rebound effects from consumption choices. In particular, pure conservation choices by households are modelled with indirect effects only, and the sensitivity of the scale of the rebound effect to household incomes is examined. The differential benefits of 'green' consumption across the income range may provide clues to better targeted policy, particularly in light of the relative attractiveness of cost-saving 'green' choices for low income households. Indeed, any difference in effectiveness between *efficiency* and *conservation* behaviour, and the additive effects of multiple 'green' choices, are also important policy considerations.

3. Methodology

Rebound effects are generally expressed as the amount of energy, resources or externality, generated by offsetting consumption, as a percentage of potential reductions where not offsetting consumption occurs (Berkhout et al., 2000). Measuring this baseline potential reduction is a critical factor in determining 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, is flawed. (Lovins et al., 1988; Weizacker et al., 1998) The total embodied energy in the more efficient appliance (replacement capital) should be subtracted from the potential energy reductions to determine the baseline, as this embodied resource consumption is necessary and inseparable from the new appliance itself. This contrasts the position of Sorrell and Dimitropoulos (2008) who propose that the embodied resource requirements of replacement capital comprise part of the rebound effect. In this paper, the baseline potential reduction of GHG emissions is calculated as the cost saving multiplied by the GHG intensity of that expenditure. Offsetting GHG emissions are those embodied in the consumption of goods enabled by the cost savings.

3.1. Data

The 2003-4 Australian Bureau of Statistics (ABS) Household Expenditure Survey (HES) of 6,957 households aggregated into 36 commodity groups is used in this paper (ABS, 2004). The corresponding embodied GHG emissions for each commodity group, calculated using an input-output based hybrid method, was made available from the Centre for Integrated Sustainability Analysis, Sydney (Dey, 2008) (Appendix A).

Matching the two data sets shows decreasing emissions intensity with household income level, but increasing quantity of emissions. No evidence of an environmental Kuznets curve for GHG emissions is observed, which corresponds with the macroeconomic relationship between energy, or greenhouse emissions, and gross domestic product typically seen in household emissions studies (Holtz-Eakin and Selden, 1995; Schipper and Grubb, 2000; Greening, 2001; Lenzen et al., 2004).

3.2. Household demand models

The rebound effect model is based on a system of household demand equations where expenditure on each commodity is dependent on total expenditure as a proxy for the household income level, as is common in household demand studies (Deaton and Muellbauer, 1980; Haque, 2005; Brannlund et al., 2007). Housing expenditure is excluded from data, as is expenditure on tobacco and health services, which are not expected to be susceptible to the incorporation of environmental damage into the utility function. Additionally, savings rates are assumed to be constant (saving reduced costs would lead to greater future consumption in any case).

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 allow for the possibility of threshold or saturation levels, where goods become inferior at particular income levels. For completeness, four different household demand models are used to generate parameters that feed into the estimation of the rebound effect;

1. a basic double semi-log (DSL) specification,
2. a DSL specification with non-income explanatory variables (DSL2),
3. the Working-Leser (WL) model of budget shares, and
4. a linear model.

Utilising this array of common functional forms also sheds some light on the sensitivity of estimates to the statistical methods applied, which may be an important practical consideration for policy assessment. The basic DSL is of the form

$$q_i = \alpha_i + \beta_i Y + \gamma_i \ln Y \tag{1}$$

where q_i is the expenditure in on each of the 36 i commodities, and Y is total expenditure. The extended DSL model in Equation 2 includes 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).

$$q_i = \alpha_i + \beta_i Y + \gamma_i \ln Y + \theta_{1_i} N + \theta_{2_i} U + \theta_{3_i} S + \theta_{4_i} A + \theta_{5_i} D \tag{2}$$

The 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

$$w_i = \frac{q_i}{Y} \tag{3}$$

then the relationship

$$w_i = \alpha_i + \beta_i \ln Y \tag{4}$$

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

$$q_i = \alpha_i Y + \beta_i Y \ln Y \tag{5}$$

Appendices B through E provide results of these model regressions. In both DSL models, Whites heteroskedasticity consistent method of calculating standard errors and covariance is used, while for the linear and WL model, ordinary least squares is used with no further statistical adjustment. 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 extended DSL2 model also provide evidence that these household characteristics are important determinants of expenditure choices. In the domestic fuel and power and vehicle fuel commodity groups, the most GHG intensive expenditure groups, almost all of the non-income variables are significant. Most other results follow intuitive logic.

3.3. Rebound effect model

The marginal budget share (MBS), or the amount of extra expenditure on commodity i for an increase in total expenditure of one dollar, is utilised in the rebound estimation model based on estimated coefficients from the household demand model. For each of the functional forms used in this study, the MBS for each i commodity is as follows:

DSL	$MBS_i = \beta_i + \frac{\gamma_i}{Y}$
Linear	$MBS_i = \beta_i$
WL	$MBS_i = \alpha_i + \beta \log Y + \beta_i$

Two alternative models are used for estimating the rebound effect. The first applies to *efficient consumption choices*, an efficiency model, where although technology is fixed there are cheaper energy efficient alternatives currently available for providing similar household services. Given that technology is unchanged, there is a sacrifice in the quality of service, such as passenger kilometres, that accompanies the reduction in price. In such cases, the direct effect, caused by the income effect but excluding the substitution effect, will be considered. New 'green' consumer preferences cause the change in household capital, so estimating prices effects based on the 'ungreen' sample, and ignoring quality changes, would be misleading to some extent.

The second applies to *conservation choices*, a conservation model, which only allows increases in expenditure on the goods or services from which cost savings were not made. For example, an individual who chooses to cycle instead of drive is unlikely to use any cost savings to drive further. And even if they did, it would simply be a reduction in the conservation measure, and not a rebound effect. Existing studies typically do not control for this in their models, meaning that unlikely behaviour such as cost savings from electricity conservation being spent on more electricity is a common outcome (Alfredsson, 2004; Brannlund et al., 2007; Druckman et al., 2011).

Denoting cost savings from 'green' consumption choices X, then for commodity s from which savings are made, the new expenditure in the efficiency model is

$$Q_{s_{new}} = Q_{s_{old}} - X + X.MBS_s \tag{6}$$

while for all other for other i commodities in the household budget the new expenditure, $Q_{i_{new}}$, is

$$Q_{i_{new}} = Q_{i_{old}} + X.MBS_i. \tag{7}$$

In the conservation model the new expenditure on the conserved commodity is

$$Q_{s_{new}} = Q_{s_{old}} - X \tag{8}$$

while for all other i commodities the new expenditure level ensures Walras' Law by reallocating the expected MBS_s across all other commodities.

$$Q_{i_{new}} = Q_{i_{old}} + X.MBS_i + \sum_{n=1}^{\infty} X.MBS_s^n.MBS_i. \tag{9}$$

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 commodity i, is $R_{f,i}$, then the total embodiment of f for all consumption is

$$f = \sum Q_i R_{f,i} \tag{10}$$

The potential resource savings, or the denominator of the rebound effect, 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

$$RE = \frac{(X.R_{f,s}) - (\sum Q_{i_{old}} R_{f,i} - \sum Q_{i_{new}}.R_{f,i})}{X.R_{f,s}} \tag{11}$$

which simplifies to

$$RE = 1 - \frac{\sum Q_{i_{old}} R_{f,i} - \sum Q_{i_{new}}.R_{f,i}}{X.R_{f,s}} \tag{12}$$

Conservation and efficiency model are generated by using the two alternative Q_{new} calculations. Further, each model is estimated using the four functional forms of the household demand system. Importantly, in this model the rebound effect is a function of the total expenditure level (as a proxy for income) and it is expected that a degree of variation will be observed across the income range.

3.4. Cases

3.4.1. Vehicle fuel

Driving less, or choosing a smaller fuel efficient vehicle, are widely promoted choices households can make to reduce GHG emissions (Foundation, 2007; Government, 2007). Both vehicle fuel cases (conservation and efficiency) have been developed to represent the same baseline reductions in fuel use and GHG emissions.

To ensure feasibility at all income levels, the efficiency case allows for the replacement of passenger vehicles (household capital) with no change in capital cost. Evidence suggests that replacing the average Australian passenger vehicle on the second hand market with one that uses 4L/100Kms less fuel is possible without increased capital costs, by sacrificing size and quality (:20, 2008; of Consumer and Protection, 2008). Other input includes include the average number of kilometres driven by Australian household per year, at approximately 13,900kms in 2003-04, and the price of fuel at $0.90 per litre (ABS, 2006; of Consumer and Protection, 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 $111.95 (Transport, 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.

Table 1: Vehicle fuel case details

Case study changes	Old	New	Consumption category	Annual saving
Fuel economy (L/100km)	11	7	Motor vehicle fuel	$500
Annual Kms travelled	13,900	13,900	Vehicle reg. and insurance	$111
Registration costs	$363	$251	Parts and Accessories	$50
Servicing costs	$250	$200	Total	$661

The conservation case has the same fuel use reduction as the efficiency case. This could occur by replacing driving with cycling, car pooling, or any other means with which a household reduces driving from the Australian average of 13,900kms per year to 8,720kms per year. Reducing vehicle mileage will reduce non-fuel running costs and improve the economic pay-off for this household choice. It is therefore of interest to estimate the rebound effect with and without additional cost savings, which are assumed for the sake of the exercise to be equal those from the efficiency case.

In both cases, the reduced motor fuel use gives a baseline potential GHG emissions reduction in both the efficiency and conservation cases of 1,300kg CO_{2-e} per year.

3.4.2. Household electricity

Numerous behavioural changes, including changing the stock of household electrical appliances, can save money and decrease electricity use. In terms of conservation choices, cost savings from behavioural changes such as shorter showers (where there is electric water heating), turning off lights when leaving a room, and turning off stand-by appliances can save a typical household $100 per year (Foundation, 2007).

For an efficiency case that involves replacing household capital, this analysis uses the replacement of incandescent light bulbs with compact fluorescent lightbulbs (CFL), which are a cost effective option. CFLs can produce the equivalent lighting of an incandescent bulb that requires five times more power. In Australian supermarkets 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 . For simplicity, a cost of $0.50 and $5.00 is assumed in this case for incandescent and CFLs respectively. The increased lifespan of CFLs must be considered, which is widely claimed to be around ten times longer than incandescent bulbs (Mirabella, 2008). A 10,000 hour life is assumed for compact fluorescents, and 1,000 for incandescent bulbs in this case study. Residential electricity price adopted is 17.10c per kilowatt-hour for tariff 11, which was the rate for general power and lighting in Queensland in 2003 (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, and the cost savings arise from $75 less electricity use per year with potential GHG emissions reductions of 550kg CO_{2-e}.

A scenario where a household adopts both of the vehicle fuel and electricity cases, in either their efficiency or conservation form, was also estimated.

4. Results

In the following sections, rebound effect estimates are presented graphically across a \$300 to \$1,200 per week household income range. All DSL2 model results are with mean values for other non-income household explanatory variables

4.1. Vehicle fuel

Rebound effect estimates for the vehicle fuel cases are in Figure 1. Depending on the household demand model applied, the rebound effect in the conservation case is somewhere between 12 and 17% at the median household income level (\$37,400 per year, or \$717 per week), reducing the expected environmental benefit of 1,330kg CO_{2-e} per year to the range of 1,090 -1,100kg CO_{2-e}. The size of the rebound effect varies significantly by choice of household demand model. In all non-linear models the rebound effect is lower at higher income levels.

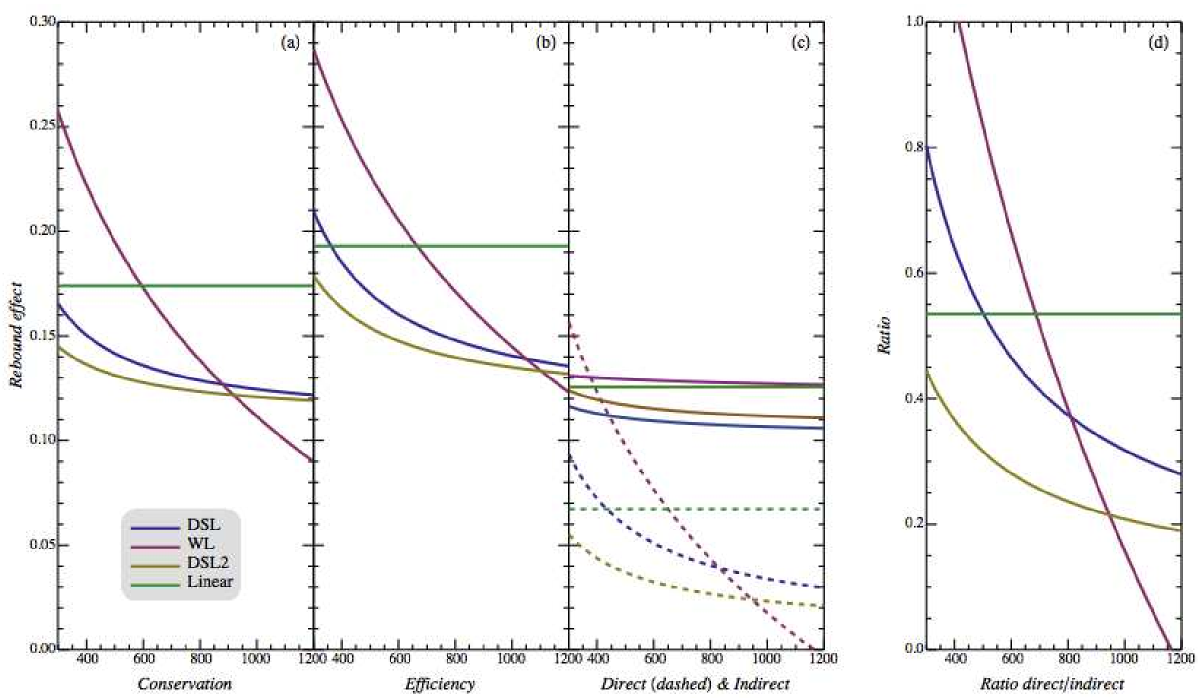

Figure 1: *Rebound effects from vehicle fuel cases*

In the efficiency case, the rebound effect is slightly larger, as expected, between 14 and 20% at the median household income level, reducing the expected environmental benefit to the range of 1,065 - 1,140kg CO_{2-e}.

Between a third and one fifth of the rebound effect is from direct effects due to increased vehicle use in this scenario. The two DSL models show the direct effect falls as a proportion of the indirect effect with increasing expenditure level, suggesting that it is more important to consider the indirect effect at higher income levels, and vice-versa.

In the conservation case, adding additional non-fuel cost savings expected from reduced driving increases the rebound effect significantly. Rather than a range of 12 to 17%, the range increases to 15 to 22%. This supports the contention that a trade-off exists between the economic pay-off of 'green' household consumption, and the environmental benefit.

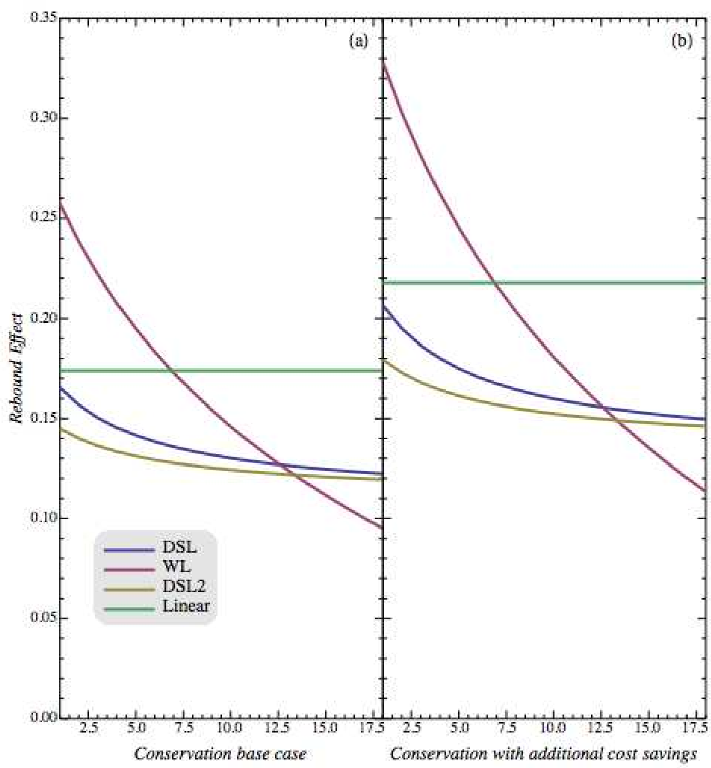

Figure 2: *Rebound effect for vehicle fuel conservation with/without additional cost savings*

4.2. Household electricity

Rebound effect estimates for the 'green' electricity cases are in Figure 3. The rebound effect in the conservation case is between 4.5 and 6.5% at the median household income level, reducing the expected environmental benefit from 550kg CO_{2-e} per year to between 515 and 526kg CO_{2-e}. As with the vehicle fuel case, the size of the rebound effect varies significantly by choice of household demand model, and with lower rebound effects at higher income levels for all non-linear models.

The electricity efficiency case has slightly higher rebound effects than the conservation case, in the order of 5 to 7.5%. Only one quarter to one sixth of the rebound effect is from direct effects due to increased electricity, with direct effects still clearly more important at lower income levels.

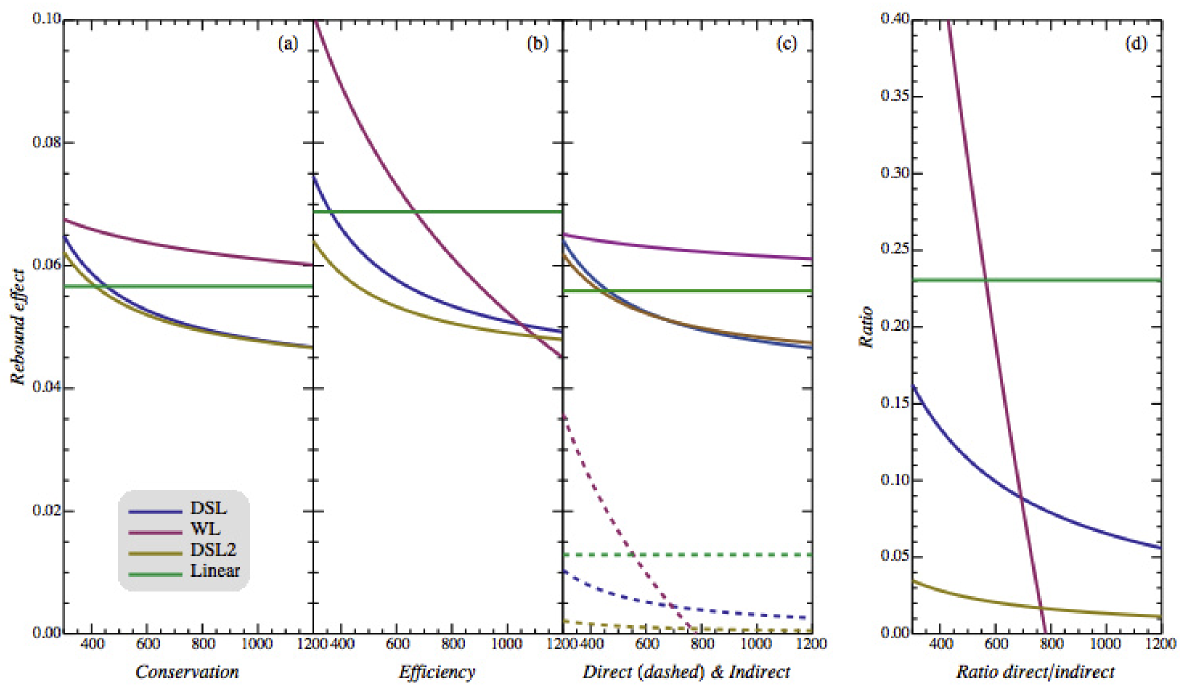

Figure 3: *Rebound effects for electricity cases across household incomes*

4.3. Combined case

For households undertaking combined conservation measures, the rebound effect is estimated at 12 and 14% near the median income (Figure 4). This reduces the expected GHG emissions benefits from 1880kg CO_{2-e} to between 1655 and 1615kg CO_{2-e} per year.

In the efficiency case it is clear that direct effects are a larger proportion of the total rebound effect, at over half the indirect effect, especially compared to each case individually where direct effects were a mere one fifth or sixth of the indirect effect. The direct effect is also more strongly inversely related to household incomes in the combined case.

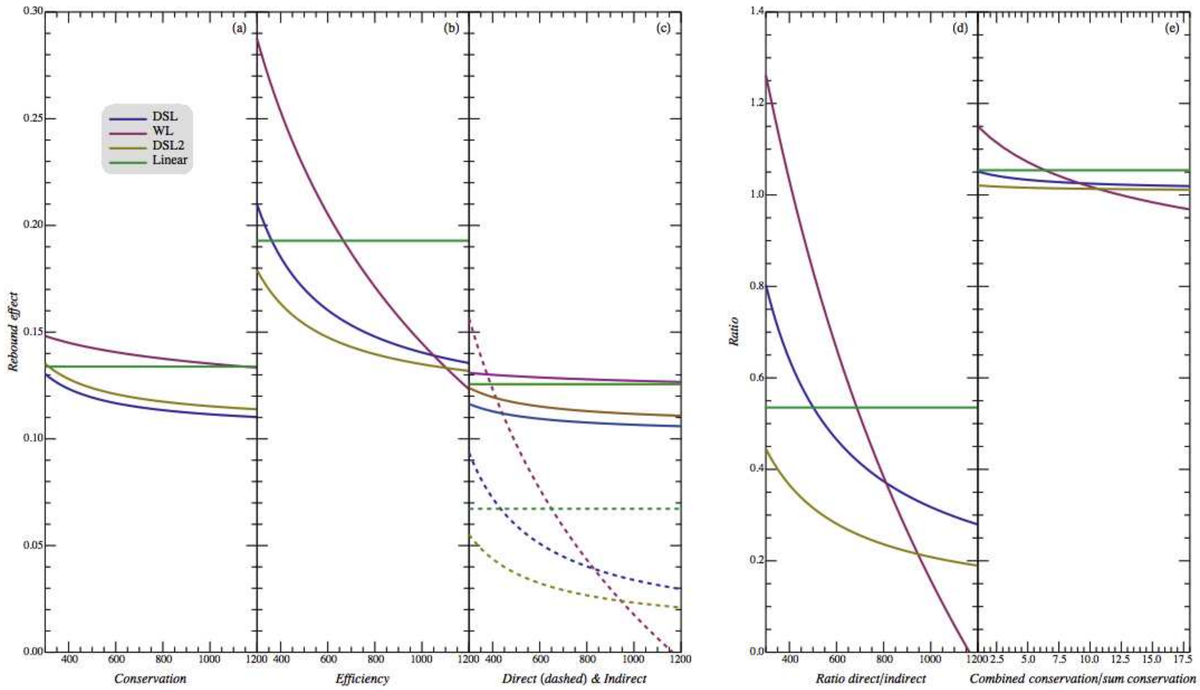

Figure 4: *Rebound effects from combined case*

The combined cases also offer some insight into the additive effects of green choices. The combined conservation case shows greatly reduced variation of the rebound effect over the income range compared to either case in isolation, while the combined efficiency case appears shows no change in income variation. This is primarily due to the elimination of the two commodities with the highest embodied GHG emissions, electricity and vehicle fuel, from the income effect.

Upon closer inspection, the rebound effect in the combined conservation case is slightly less than one would expect from a simple addition of the individual case results, meaning that the environmental benefits of the actions together is greater than in isolation (for example, the same household making both choices, rather than one household doing each). The net effect of the combined case, compared to the sum of each case, is shown in Panel (d) of Figure 4, with the combined conservation case between 2 and 5% more effective for reducing environmental externalities than the sum of each case. For the efficiency case however, the combined case has exactly the same net environmental impact as the sum of the two individual cases.

5. Discussion

This rebound analysis of a series of 'green' household consumption 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. Depending on the household demand models used and household income level, the highest rebound effect estimate was around 20% in the case of adopting a more efficient vehicle, while estimates were as low as 4% in the electricity conservation case.

At the median household income level, the estimated rebound effect for vehicle fuel conservation was approximately 12 to 17% (depending on the associated non-fuel cost savings), which is in line with the 14% result of Alfredsson (2004), but not too far off the 22% result of Druckman et al. (2011). One would expect that the variation in results has much to do with both the different embodied GHG emissions pattern for the consumption goods across countries, and the structure of the model. Australia's electricity generation is almost purely from coal, for example, potentially leading to higher embodied emissions per dollar of electricity consumption than the electricity generation from more mixed sources in much of Europe. For the electricity conservation cases, the 5-8% result was far less than Alfredsson's (2004) estimate, due to the fact that the current conservation model does not allow responding electricity savings on more electricity consumption. The result is more consistent with the 7% estimate of Druckman et al. (2011)..

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, were 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 et al., 1989; Milne and Boardman, 2000; Hong et al., 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 (1980) and Wirl (1997). This suggests that public policy to promote 'green' consumption choices might be more effective if focussed on higher income households.

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 comments 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 when household internalise environmental externalities into their utility function, produces a much lower rebound effect than in cases where household choices contains an implied price reduction due to capital replacement. Additionally, when conservation measures are combined the environmental benefits are amplified, and the rebound effect reduced, compared each case in isolation.

Moreover, when efficient choices are combined, the rebound effect becomes a mere average of the two, with the environmental benefits equal to the sum of each case in isolation. One could easily imagine that if price effects played a role, in addition to income effects, that the additive effects of efficient technology would result in combined rebound effects being higher, and environmental benefits lower, than the sum of each case.

A third key finding is that the greater the economic benefit of household 'green' consumption choices, the larger the rebound effect and less effective the action. 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 et al. (2005) who find a negative rebound effect for households adopting a green diet, due to the increased cost of the diet. As a rule of thumb it seems that in the context of 'green' consumption, the greater the economic benefit, the lower the environmental benefit.

Lastly, the choice of household demand model used in the rebound estimation was most important at the high and low extremes of household income level. Near the average income, the linear model seemed to overestimate the size of the rebound effect, while the WL model greatly overestimated rebound effects at low income, and possibly underestimated at high incomes. The DSL specification appears to offer a more accurate income-dependent specification to utilise in rebound effect analysis at a household level.

The policy implications from these results are clear enough. Conservation, rather than more efficient consumption, is a preferable household action. Indeed, combining conservation actions improves outcomes, and is more effectively achieved by high income households who have lower rebound effects. Also, it is clear that there is a trade-off between the cost benefits to the household, and the environmental benefits. Thus, publicising the economic pay-off from 'green' consumption choices, might lead to households adopting the least environmentally effective consumption choices.

To be clear, avoiding rebound effects from household consumption requires a corresponding reduction in household income (Madlener and Alcott, 2009). Robinson (2007) espoused the idea that if households were to properly internalise the environmental externalities of their consumption, they would actually work less and reduce total consumption. Yet, working less is not a well publicised household conservation choice.

These results are also generally consistent with the idea that supply limitations on environmental externalities such as cap-and-trade quotas, which force reduced consumption of goods whose production involves that externality, are more effective than demand side measures, as they eliminate rebound effect types of outcomes.

A few critical but unanswered questions remain about conservation choices and rebound effects, and it is worth briefly commenting on them.

1. Do household income variations in environmental impacts of consumption choice have implications for redistribution policies?

2. How might one better address the boundary problems of LCA methodologies for determining embodied environmental externatlities?

3. What general equilibrium effects are being overlooked?

Regarding household income variations, if one does believe the data, then clearly yes, there will be significant environmental costs from income redistribution. While a lot of research has uncovered the non-linear relationship between GHG emissions and household income, no one is yet to use the data to examine environmental costs of income redistribution through the tax and welfare system.

This may not be a concern if one actually believes that the boundary specifications required to generate the LCA data of embodied GHG emissions are not theoretically sound. Ignoring inputs into labour supply in LCA analysis leads to a divergence of environmental externalities associated with different goods, that simply does not exist in reality. While authors have suggested that higher quality goods have lower environmental intensity (Girod and De Haan, 2010), the typical finding is that lower energy intensity of goods it mostly due to a labour-energy trade-off that is eliminated when one considers the inputs required for labour supply (Costanza, 1980; Maddala, 1965; Karunaratne, 1981; Lenzen and Dey, 2002). This issue has routinely been overlooked in studies of rebound effects and in analysis of benefits of demand-side environmental policies more generally.

Finally, regarding general equilibrium effects from household conservation behaviour, one must consider the likely producer reactions to any genuine reduction in demand that results from wide adoption of 'green' choices. If conservation of electricity actually reduces electricity use in a connected area, suppliers are likely to decrease prices to encourage higher use from the non-conserving portion of the population to maintain optimal returns.

In terms of fuel use, will the small marginal reductions in fuel demand have a price impact, however minor, that increases demand by non-conservers elsewhere in the economy? The answer to these question is clearly yes, but the degree is uncertain.

'Green' household consumption choices, including conservation, are very indirect ways to promote environmental aims. Regulation of environmental externalities at their source, such as enacting (tradable) quota systems, will not incur rebound effects, and are preferred to consumer-focussed actions. Indeed, facilitation of a transition towards energy sources or technologies with fewer environmental externalities is another way to directly change the environmental burden of consumption at the broadest level.

6. Conclusion

It was found that rebound effects occur from the type of 'green' consumption choices promoted as ways for households to decrease their environmental impact. If rebound effects are ignored when evaluating the environmental benefits from 'green' consumption, then they will overstate the actual likely benefits by at least 15% in the case of vehicle fuel conservation, and 6% in the case electricity conservation.

Indeed, the cost-effective nature of these consumption choices means that they will be more attractive to household with lower incomes, but these households will have the highest rebound effects, and lowest resulting environmental improvement. Environmental policy directed at changing consumer behaviour is therefore best targeted at high income households, with conservation measures rather than efficiency measures being promoted as more effective environmental consumption choices. Indeed, reduced work and increased leisure time should also be promoted as effective environmental consumption choices for households. Rebound effects estimated in this paper should be considered conservative minimum estimates, given the limitations of life cycle analysis.

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Appendix A

Broad commodity group	Detailed commodity group	GHG intensity (kg CO_{2-e}/\$)
Domestic fuel and power	Domestic fuel and power	7.33
Food and beverages	Bakery products	0.40
	Condiments	0.44
	Dairy products	1.16
	Fish	0.51
	Fruit and nuts	0.39
	Meals out	0.39
	Meat	1.71
	Non-alcoholic beverages	0.28
	Vegetables	0.40
Alcoholic beverages	Alcohol	0.30
Clothing and footwear	Clothing	0.31
	Clothing services	0.14
	Footwear	0.30
Household furnishings	Appliances	0.74
	Blankets, linen and furniture	0.35
	Furniture and flooring	0.30
	Glass and tableware	0.61
	Tools	0.24
Household services	Household services	0.21
Medical care & health	Health fees	0.26
	Health insurance	0.02
Transport	Freight	0.75
	Vehicle fuel	2.60
	Motor vehicle purchase	0.29
	Vehicle parts and accessories	0.29
	Public transport	0.54
	Vehicle charges	0.15
	Registration & insurance	0.02
Recreation	Holidays	0.85
	Pets	0.36
	Recreational goods	0.41
	Recreational services	0.13
Personal care	Personal care	0.22
Miscellaneous	Miscellaneous goods	0.31
	Miscellaneous services	0.16

Source: Centre for Integrated Sustainability Analysis, Sydney (Dey, 2008)

Appendix B

***1% significance, **5% significance, *10% significance.

Double Semi Log	α	β	γ	Adj. r^2
Alcohol	-17.53	0.025***	3.73	0.15
	(11.91)	(0.000)	(2.41)	
Appliances	-12.53	0.016***	2.18	0.05
	(9.21)	(0.004)	(1.88)	
Bakery	-23.6***	0.003***	6.03***	0.23
	(1.98)	(0.001)	(0.39)	
Blankets/linen	6.98	0.015***	-1.68	0.06
	(8.44)	(0.004)	(1.73)	
Clothing	47.6**	0.068***	-10.6**	0.24
	(23.54)	(0.01)	(4.76)	
Clothing services	1.77	0.002***	-0.38	0.04
	(1.21)	(0.001)	(0.25)	
Condiments	-28.1***	0.006***	6.73***	0.25
	(3.57)	(0.001)	(0.72)	
Dairy	-16.4***	0.001**	4.31***	0.18
	(1.40)	(0.001)	(0.28)	
Domestic fuel & power	-0.98	0.009***	3.13***	0.18
	(4.72)	(0.002)	(0.94)	
Fish	-2.92*	0.002***	0.81**	0.05
	(1.58)	(0.001)	(0.32)	
Footwear	3.13	0.012***	-0.88	0.08
	(5.01)	(0.002)	(1.02)	
Freight	8.12**	0.007***	-1.66**	0.04
	(3.28)	(0.002)	(0.68)	
Fruit and nuts	-12.73***	0.003***	3.24***	0.14
	(1.65)	(0.001)	(0.33)	
Vehicle fuel	-72.15***	0.008***	15.79***	0.21
	(6.29)	(0.002)	(1.27)	
Furniture/ flooring	5.88	0.042***	-2.49	0.09
	(17.65)	(0.008)	(3.59)	
Glass/tableware	0.18	0.007***	-0.15	0.07
	(5.24)	(0.002)	(1.06)	
Health fees	-14.64**	0.015***	2.85*	0.09
	(6.91)	(0.003)	(1.41)	
Health Insurance	-34.70***	0.008***	7.52***	0.19
	(3.23)	(0.001)	(0.65)	
Holidays	-15.50	0.068***	1.58	0.21
	(17.91)	(0.008)	(3.66)	

	α	β	γ	Adj. r^2
Household services	-57.20***	0.031***	14.51***	0.25
	(9.79)	(0.004)	(1.98)	
Meals out	-50.20***	0.044***	9.68***	0.36
	(10.21)	(0.004)	(2.07)	
Meat	-30.96***	0.004***	7.70***	0.17
	(2.92)	(0.001)	(0.58)	
Miscellaneous goods	21.96	0.031***	-4.71	0.13
	(23.31)	(0.009)	(4.68)	
Miscellaneous services	133.18***	0.17***	-29.81***	0.31
	(46.14)	(0.019)	(9.34)	
Motor vehicle purchase	206.36***	0.20***	-47.45***	0.24
	(52.30)	(0.022)	(10.61)	
Non-alcoholic beverages	-21.15***	0.004***	4.91***	0.25
	(1.74)	(0.001)	(0.35)	
Vehicle parts/ accessories	-12.21	0.021***	2.45**	0.04
	(7.33)	(0.003)	(0.98)	
Personal care	-6.10	0.021***	1.39	0.20
	(7.33)	(0.003)	(1.48)	
Pets	1.03	0.012***	-0.15	0.03
	(10.14)	(0.005)	(20.8)	
Public transport	-6.99***	0.001	1.57***	0.02
	(1.43)	(0.001)	(0.28)	
Recreational goods	60.79*	0.083***	-13.13*	0.22
	(34.35)	(0.014)	(6.92)	
Recreational services	-13.29	0.025***	2.40	0.12
	(10.67)	(0.005)	(2.16)	
Tools	-8.83**	0.008***	1.60**	0.05
	(4.18)	(0.002)	(0.085)	
Vegetables	-15.52***	0.002***	3.97***	0.18
	(1.31)	(0.000)	(0.026)	
Vehicle charges	18.55	0.036***	-4.42	0.09
	(17.98)	(0.007)	(3.63)	
Vehicle registration	-40.62***	0.007***	9.44***	0.31
	(3.29)	(0.001)	(0.656)	

Appendix C

Age - 1-30 for age of head of household with 30 categories from 15 to >80
Occupancy - 1-6 (where 6 is six or more persons per household)
State - 1-New South Wales, 2-Victoria, 3-Queensland, 4-South Australia, 5-Western Australia, 6-Tasmania, 7-A.C.T. and NT
Urbanity - 0-NA, 1-Capital City, 2-Balance of state
Dwelling - 1-Separate house, 2-Semi-detached one storey, 3-Semi-detached two or more storeys, 4-Apartment in 1 or 2 storey block, 5-Apartment in a 3 storey block, 6-Apartment in a 4 or more storey block, 7-Apartment attached to a house, 8-Caravan, houseboat, improvised home

***1% significance, **5% significance, *10% significance.

DSL2	α	β	γ	Occup.	Urbanity	State	Age	Dwelling	Adj. r^2
Alcohol	-16.88	0.026***	5.11**	-3.65***	2.33***	1.19***	-0.47***	0.35	0.17
	(12.92)	(0.005)	(2.46)	(0.45)	(0.85)	(0.27)	(0.07)	(0.39)	
Appliances	-18.47*	0.016***	3.91**	-2.45***	0.52	0.55*	-0.018	-0.67*	0.56
	(10.17)	(0.004)	(1.89)	(0.55)	(1.00)	(0.30)	(0.075)	(0.35)	
Bakery	-23.35***	0.0020***	3.49***	4.45***	-0.035	-0.098	0.31***	-0.097	0.39
	(2.17)	(0.001)	(0.39)	(0.13)	(0.22)	(0.089)	(0.018)	(0.089)	
Linen	1.24	0.015***	-0.69	-1.01***	0.088	0.40*	0.059	-0.22	0.061
	(9.14)	(0.004)	(1.71)	(0.38)	(0.64)	(0.22)	(0.051)	(0.26)	
Clothing	56.77**	0.068***	-13.01***	2.90***	-0.32	-0.36	-0.092	1.09**	0.24
	(24.09)	(0.0095)	(4.76)	(0.70)	(1.08)	(0.35)	(0.097)	(0.54)	
Cloth. serv.	0.72	0.002***	-0.19	-0.086*	-0.29***	0.000	0.022***	0.085*	0.039
	(1.30)	(0.001)	(0.25)	(0.051)	(0.092)	(0.029)	(0.008)	(0.047)	
Condiment	-18.26***	0.006***	2.96***	4.69***	0.51*	0.19**	0.053**	-0.042	0.36
	(3.88)	(0.001)	(0.72)	(0.18)	(0.30)	(0.09)	(0.024)	(0.13)	
Power	5.28	0.009***	0.65	2.70***	-0.041	0.91***	0.084***	-1.25***	0.24
	(4.96)	(0.002)	(0.95)	(0.17)	(0.34)	(0.094)	(0.028)	(0.16)	
Fish	-5.02***	0.002***	1.13***	0.11	-0.69***	-0.28***	0.11***	-0.035	0.065
	(1.72)	(0.001)	(0.32)	(0.093)	(0.18)	(0.051)	(0.014)	(0.067)	
Footwear	3.11	0.012***	-1.27	0.71***	0.023	-0.026	0.033	0.18	0.080
	(4.96)	(0.002)	(0.99)	(0.24)	(0.42)	(0.13)	(0.035)	(0.18)	
Freight	7.80**	0.0065***	-1.17*	-0.66***	-0.60***	-0.011	-0.061**	0.48***	0.049
	(3.50)	(0.002)	(0.65)	(0.18)	(0.20)	(0.079)	(0.025)	(0.15)	
Vehicle fuel	-51.7***	0.0093***	11.32***	3.19***	3.54***	0.61***	-0.22***	-2.36***	0.24
	(7.01)	(0.0026)	(1.31)	(0.41)	(0.75)	(0.22)	(0.057)	(0.24)	
Furniture	-3.32	0.043***	1.071	-5.46***	2.75*	0.47	-0.26**	-0.19	0.093
	(18.97)	(0.008)	(3.64)	(0.81)	(1.45)	(0.45)	(0.13)	(0.67)	
Tableware	-2.93	0.007***	0.26	-0.17	0.008	0.003	0.057**	0.07	0.068
	(5.86)	(0.002)	(1.11)	(0.13)	(0.25)	(0.087)	(0.026)	(0.14)	
Health fees	-18.83**	0.014***	3.85**	0.075	-3.63***	-0.66***	0.29***	-0.15	0.095
	(7.97)	(0.003)	(1.52)	(0.39)	(0.63)	(0.23)	(0.057)	(0.28)	

DSL2	α	β	γ	Occup.	Urbanity	State	Age	Dwelling	Adj.r^2
Health Ins.	-54.43***	0.007***	9.31***	0.34	-0.79*	0.12	0.59***	-0.74***	0.22
	(3.83)	(0.001)	(0.68)	(0.23)	(0.45)	(0.13)	(0.036)	(0.17)	
Holidays	-56.53***	0.066***	10.23***	-7.08***	-5.31**	0.17	0.62***	0.70	0.22
	(19.05)	(0.008)	(3.66)	(0.87)	(1.74)	(0.52)	(0.15)	(0.68)	
House serv	-20.72*	0.031***	9.23***	3.97***	-4.12***	-0.67**	-0.27***	-1.81***	0.27
	(10.74)	(0.004)	(2.03)	(0.55)	(0.98)	(0.31)	(0.078)	(0.36)	
Meals out	-28.14***	0.044***	9.26***	-0.56	-7.19***	-1.79***	-0.41***	2.23***	0.37
	(10.74)	(0.004)	(2.14)	(0.51)	(0.83)	(0.28)	(0.079)	(0.45)	
Misc. goods	21.20	0.031***	-5.07	0.98**	-1.26*	0.088	0.065	0.60*	0.13
	(24.73)	(0.009)	(4.81)	(0.42)	(0.68)	(0.20)	(0.062)	(0.34)	
Misc. services	150.05***	0.17***	-31.36***	0.61	-0.14	-1.13	-0.70***	4.48***	0.31
	(48.59)	(0.019)	(9.33)	(1.44)	(2.48)	(0.73)	(0.19)	(1.21)	
Vehicle purch.	159.39***	0.20***	-38.09***	-12.80***	16.90***	2.04**	-0.43*	-0.34	0.25
	(55.25)	(0.022)	(10.69)	(1.64)	(3.10)	(0.94)	(0.24)	(1.21)	
Beverage	-12.39***	0.004***	2.85***	2.24***	-0.49**	-0.10	-0.043**	0.072	0.30
	(1.89)	(0.001)	(0.35)	(0.12)	(0.22)	(0.067)	(0.017)	(0.096)	
Vehicle part	-8.11	0.006***	1.68*	0.19	1.44***	0.27*	-0.12***	-0.34*	0.043
	(5.26)	(0.002)	(0.99)	(0.30)	(0.54)	(0.15)	(0.041)	(0.20)	
Personal care	-11.10	0.02***	1.87	0.33	-0.94*	-0.19	0.14***	0.48**	0.20
	(7.72)	(0.003)	(1.52)	(0.29)	(0.54)	(0.17)	(0.045)	(0.23)	
Pets	1.59	0.013***	0.46	-1.53***	1.21	0.18	-0.052	-1.29***	0.04
	(10.63)	(0.005)	(2.05)	(0.37)	(0.74)	(0.20)	(0.072)	(0.30)	
Public trans.	-0.97	0.000	1.27***	0.49***	-2.20***	-0.95***	-0.052***	0.89***	0.068
	(1.65)	(0.001)	(0.30)	(0.13)	(0.19)	(0.071)	(0.018)	(0.14)	
Rec. goods	80.93**	0.085***	-15.08**	-0.097	0.55	-0.054	-0.66***	1.54**	0.22
	(36.35)	(0.014)	(6.98)	(0.82)	(1.43)	(0.48)	(0.11)	(0.71)	
Rec. serv.	-20.06*	0.024***	2.50	0.89	0.51	0.006	0.20***	0.11	0.12
	(11.91)	(0.005)	(2.22)	(0.55)	(1.06)	(0.29)	(0.075)	(0.37)	
Tools	-9.52**	0.008***	1.69*	-0.36	0.72	0.32**	-0.016	-0.42**	0.051
	(4.67)	(0.002)	(0.89)	(0.35)	(0.54)	(0.14)	(0.040)	(0.17)	
Vegetables	-21.16***	0.001**	3.82***	1.35***	-0.55***	-0.022	0.26***	-1.47***	0.23
	(1.56)	(0.000)	(0.27)	(0.098)	(0.19)	(0.058)	(0.016)	(0.16)	
Veh. charges	12.82	0.036***	-1.68	-3.64***	0.91	-0.62*	-0.023	-0.75*	0.093
	(19.56)	(0.007)	(3.70)	(0.64)	(1.20)	(0.36)	(0.10)	(0.43)	
Vehicle reg	-26.33***	0.007***	7.88***	1.12***	-2.63***	-0.63***	0.005	-1.47***	0.33
	(3.65)	(0.001)	(0.68)	(0.19)	(0.35)	(0.11)	(0.029)	(0.16)	
Dairy	-13.74***	0.001**	2.31***	2.81***	0.49***	0.22***	0.11***	-0.19***	0.30
	(1.57)	(0.000)	(0.28)	(0.10)	(0.18)	(0.054)	(0.014)	(0.074)	
Fruit / nuts	-22.60***	0.002***	3.75***	1.25***	-1.19***	-0.36***	0.39***	0.078	0.20
	(1.87)	(0.001)	(0.33)	(0.11)	(0.21)	(0.065)	(0.019)	(0.094)	
Meat	-36.37***	0.003***	5.78***	4.17***	-0.089	0.20*	0.50***	-0.98***	0.25
	(3.31)	(0.001)	(0.59)	(0.20)	(0.39)	(0.12)	(0.031)	(0.13)	

Appendix D

***1% significance, **5% significance, *10% significance.

WL model	α	β	r^2
Alcohol	0.026***	0.001*	0.000
	(0.006)	(0.001)	
Appliances	-0.009**	0.004***	0.004
	(0.005)	(0.001)	
Bakery	0.11***	-0.013***	0.18
	(0.002)	(0.000)	
Blankets/linen	-0.008***	0.003***	0.005
	(0.003)	(0.000)	
Clothing	-0.034***	0.011***	0.025
	(0.005)	(0.001)	
Clothing services	-0.001	0.000***	0.002
	(0.001)	(0.000)	
Condiments	0.091***	-0.009***	0.077
	(0.003)	(0.000)	
Dairy	0.087***	-0.010***	0.18
	(0.002)	(0.000)	
Domestic fuel / power	0.29***	-0.038***	0.36
	(0.004)	(0.001)	
Fish	0.019***	-0.002***	0.017
	(0.001)	(0.000)	
Footwear	-0.008***	0.002***	0.006
	(0.002)	(0.000)	
Freight	0.007***	-0.001**	0.001
	(0.001)	(0.000)	
Fruit and nuts	0.059***	-0.007***	0.071
	(0.002)	(0.000)	
Vehicle fuel	0.084***	-0.005***	0.006
	(0.005)	(0.001)	
Furniture/ flooring	-0.044***	0.011***	0.016
	(0.007)	(0.001)	
Glass/tableware	-0.000	0.001***	0.002
	(0.001)	(0.000)	
Health fees	0.010**	0.001**	0.001
	(0.004)	(0.001)	
Health Insurance	0.045***	-0.003***	0.003
	(0.007)	(0.001)	
Holidays	-0.049***	0.016***	0.025
	(0.008)	(0.001)	
Household services	0.28***	-0.03***	0.11
	(0.007)	(0.001)	
Meals out	0.005	0.008***	0.014
	(0.005)	(0.001)	
Meat	0.12***	-0.014***	0.09
	(0.003)	(0.001)	
Miscellaneous goods	-0.004	0.004***	0.006
	(0.004)	(0.001)	

WL model	α	β	r^2
Miscellaneous services	-0.091***	0.027***	0.045
	(0.01)	(0.002)	
Motor vehicle purchase	-0.24***	0.046***	0.089
	(0.011)	(0.002)	
Non-alcoholic beverages	0.056***	-0.006***	0.057
	(0.002)	(0.000)	
Motor vehicle parts/accessories	0.003	0.001**	0.001
	(0.003)	(0.000)	
Personal care	0.029***	-0.001	0.000
	(0.003)	(0.001)	
Pets	0.015***	-0.000	-0.000
	(0.003)	(0.001)	
Public transport	0.019***	-0.002***	0.008
	(0.002)	(0.000)	
Recreational goods	-0.010	0.009***	0.010
	(0.007)	(0.001)	
Recreational services	0.001	0.004***	0.005
	(0.005)	(0.001)	
Tools	-0.001	0.002***	0.002
	(0.003)	(0.000)	
Vegetables	0.074***	-0.009***	0.13
	(0.002)	(0.000)	
Vehicle charges	-0.029***	0.008***	0.012
	(0.005)	(0.001)	
Vehicle registration	0.10***	-0.01***	0.059
	(0.003)	(0.000)	

Appendix E

***1% significance, **5% significance, *10% significance.

Linear model	α	β	r^2
Alcohol	2.54***	0.030***	0.15
	(0.78)	(0.001)	
Appliances	-0.83	0.019***	0.052
	(0.88)	(0.001)	
Bakery	8.82***	0.011***	0.20
	(0.23)	(0.000)	
Blankets/linen	-2.061***	0.013***	0.059
	(0.58)	(0.001)	
Clothing	-9.57***	0.054***	0.24
	(1.07)	(0.001)	
Clothing services	-0.28***	0.002***	0.035
	(0.087)	(0.000)	
Condiments	8.12***	0.015***	0.23
	(0.30)	(0.000)	
Dairy	6.78***	0.007***	0.15
	(0.18)	(0.000)	
Domestic fuel and power	15.85***	0.013***	0.17
	(0.31)	(0.000)	
Fish	1.46***	0.003***	0.053
	(0.15)	(0.000)	
Footwear	-1.59***	0.011***	0.079
	(0.39)	(0.000)	
Freight	-0.80***	0.004***	0.038
	(0.24)	(0.000)	
Fruit and nuts	4.68***	0.007***	0.13
	(0.20)	(0.000)	
Vehicle fuel	12.82***	0.028***	0.19
	(0.65)	(0.001)	
Furniture/ flooring	-7.51***	0.038***	0.086
	(1.38)	(0.002)	
Glass/tableware	-0.60**	0.007***	0.068
	(0.26)	(0.000)	
Health fees	0.68	0.019***	0.089
	(0.66)	(0.001)	
Health Insurance	5.76***	0.018***	0.18
	(0.42)	(0.000)	
Holidays	-6.99***	0.070***	0.21
	(1.52)	(0.002)	
Household services	20.16***	0.049***	0.24
	(0.95)	(0.001)	
Meals out	1.86**	0.056***	0.35
	(0.84)	(0.001)	
Meat	10.49***	0.014***	0.15
	(0.36)	(0.000)	

Linear model	α	β	r^2
Miscellaneous goods	-3.37***	0.025***	0.13
	(0.72)	(0.001)	
Miscellaneous services	-27.20***	0.13***	0.30
	(2.19)	(0.003)	
Motor vehicle purchase	-48.89***	0.14***	0.23
	(2.83)	(0.003)	
Non-alcoholic beverages	5.25***	0.01***	0.23
	(0.21)	(0.000)	
Motor vehicle parts/accessories	0.97***	0.008***	0.039
	(0.46)	(0.001)	
Personal care	1.38***	0.023***	0.20
	(0.51)	(0.001)	
Pets	0.25	0.012***	0.036
	(0.67)	(0.001)	
Public transport	1.45***	0.003***	0.017
	(0.22)	(0.000)	
Recreational goods	-9.84***	0.066***	0.22
	(1.39)	(0.002)	
Recreational services	-0.38	0.028***	0.12
	(0.85)	(0.001)	
Tools	-0.20	0.010***	0.050
	(0.49)	(0.001)	
Vegetables	5.86***	0.007***	0.16
	(0.18)	(0.000)	
Vehicle charges	-5.22***	0.03***	0.087
	(1.07)	(0.001)	
Vehicle registration	10.17***	0.019***	0.27
	(0.34)	(0.000)	