# Rebound effects from consumption pattern changes: Evidence from Australia

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# Abstract

The objective of this paper is to examine the rebound effect from household behaviour and consumption pattern changes that aim to reducing greenhouse gas emissions, at a fixed level of technology and energy efficiency. Following a theoretical discussion in which component rebound effects are defined, an econometric estimation method is applied to a series of case studies involving household consumption pattern change. These cases include reduced vehicle use, reduced electricity use, and the adoption of energy efficient vehicles and electrical appliances. This estimation method allows variation in the scale of each component rebound effect with household income. The results indicate that rebound effects can substantially affect the environmental benefit of some household behaviours, with an estimated greenhouse gas rebound for reduced household electricity consumption around 10%, and for reduced vehicle fuel consumption around 20%. In all cases rebound effects where higher for low-income households, however indirect effects are more significant for higher income households.

# Keywords

Rebound effect, demand side management, direct rebound effect, indirect rebound effect, greenhouse gas emissions, CO2, household consumption patterns, efficiency, energy, conservation, natural resources.

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

# Introduction

The rebound effect debate has diverse policy implications but currently faces theoretical and empirical constraints. While the debate is generally focused on technology change and energy efficiency improvements, the focus of this paper is the direct and indirect rebound effects from consumption pattern changes at existing technology levels.

Changing to more sustainable consumption patterns was prominently embraced by the United Nations as an measure to combat environmental degradation; a stance that was reiterated by OECD[[1]](#footnote-1) members early this decade (1992; 2002). One of the attractive features of this measure is the ability for win-win outcomes, where both the economy and environment may simultaneously benefit. More broadly, efforts to reduce resource consumption through demand augmentation are referred to as demand side management (DSM) and have been widely adopted in Australian energy policy, and abroad (Lee and Denlay, 2002; 2007a; 2008a; 2008c; 2008d).

Rebound effects are typically said to occur to due technology changes that increase the productivity of a resource (ref here). However, a potentially broader definition exists. This broader definition states that rebound effects are simply unintended flow-on effects from interactions of agents in the economy. For example, producers using more efficient production techniques as a method for reducing environmental impacts are likely to see income and output effects, while consumers are likely to experience income and substitution effects.

Even without technology change, a change in the pattern of consumption is subject to rebound effects. A reduction in use of electricity will reduce costs for households, enabling the household budget to be redistributed towards other consumption goods.

The objective of this paper is to determine the extent of the rebound effect present in win-win demand side approaches, at fixed technology levels, for reducing greenhouse gas emissions. Embodied greenhouse gas emissions of final household consumption goods are used to determine the impact from changed consumption patterns; an approach that is not only ethically justified, but has been highlighted as an effective method for estimating indirect rebound effects (Sorrell, 2007; Stern, 2007). An econometric model of the rebound effect is applied to a series of cases that are advocated by governments and environmental organisations.

The existing rebound effect literature suggests that rebound effects may be much higher in households, and in countries, with low incomes (Baker et al., 1989, Milne, 2000 #130; Roy, 2000; Hong et al., 2006). Therefore the impact of household income level on the magnitude of the rebound effect is explored. Existing rebound effect estimation methods are improved by ensuring that the cost savings are not re-spent on the commodity from which the savings were made. For example, a household who reduces their driving for environmental reasons is unlikely to spend the cost savings on more driving. Furthermore, life-cycle analysis (LCA) data is used in a theoretically consistent manner. Previous estimations of the rebound effect from technology changes have applied LCA data to econometric consumption models (Brannlund et al., 2007; Mizobuchi, 2008). However, since technology, and energy efficiency in particular, determines the embodied resource composition of a commodity, using the same LCA to estimate the energy consumption or greenhouse gas emissions after the technology change is flawed. Therefore, in the case of technology change, alternative methods for rebound estimation should be explored.

The remainder of the paper is structured as follows. Section 2 first outlines the theoretical framework adopted for analysing the direct and indirect rebound effect from consumption pattern changes. Section 3 provides an overview of the data used in the analysis, and develops a model for estimating the rebound effect that builds on previous methods. In Section 4, the case study scenarios and the rebound model results are presented, before a discussion of the results and concluding remarks in Section 5.

# Theoretical overview

Jevons (1865) first described the economic processes that are now commonly known as the rebound effect. The modern debate, however, was ignited by Khazzoom (1980) who, in the context regulatory restrictions on energy efficiency, recognised that there are not one-to-one reductions in energy use due to the price content of energy in the service delivered to the consumer.

In the contemporary literature, the rebound effect is expressed for a particular resource or externality produced, in this case greenhouse gas emissions, and as a percentage of the potential resource reductions that are not realised due to flow-on economic interactions (Berkhout et al., 2000; Sorrell, 2007).

The total rebound effect from technology change is generally considered to comprise of three distinct effects; the direct, indirect and economy-wide effect (Berkhout et al., 2000; Greening et al., 2000). Although the three tier model is widely accepted, the definition, relative magnitude and importance of each component effect remain uncertain (Hertwich, 2005) (Sorrell, 2007).

The direct effect occurs due to a price reduction of a commodity from improved resource efficiency, and can be estimated by the own-price elasticity of the good or service in question. The resulting increase in embodied resource use or externalities from the increases consumption of the good in question constitutes this effect. Consistent with traditional micro-economic theory, evidence suggests that for energy services, such as domestic motor vehicle use and lighting, the direct effect at the household level decreases with increasing household income {Baker, (1989)215;Milne,(2000)Hong(2006)}.

The indirect effect can be described as the increase in resource use or externality embodied in the increased consumption of other goods due to an income effect (as cost saving are utilised elsewhere in the household budget).

Finally, the economy wide (or total) rebound effect incorporates both the direct and indirect effect, as well as all the flow-on effects to other production sectors due to price changes of intermediate goods that lead to multi-factor productivity gains[[2]](#footnote-2) (Brookes). In addition to changing the composition of the economy, the flow-on reduction in prices will enable an expansion of economic activity and consumption of goods by marginal consumers (Wirl, 1997). For cost saving technology changes all production sectors will adopt alternative resource combinations that will ultimately change the resource embodiment of final goods, leading to difficulties in estimating the scale of this effect.

However, the focus of this paper is the rebound effect from household consumption pattern changes where the technical combinations of resources in the ‘up-stream’ production sectors are fixed, and economy wide adjustments will not occur. This means that the embodied resource composition of final goods will not change and the life cycle analysis (LCA) data, which captures these ‘up-stream’ resource combinations, can be reliably used to model the rebound effect.

Two types of behaviour change are examined in this paper. The first is termed conservation, and it is where households choose to simply consume less of a particular good due to moral suasion efforts of governments or environmental groups. The conservation cases examined are using less electricity and gas (by switching off appliances, using less hot water, and turning light on less frequently for example), and using less vehicle fuel (by choosing to walk of cycle as a substitute to driving).

Figure 1 shows how conservation behaviour can be represented as a shift of indifference curves U1 and U2 to U1` and U2`. The new utility maximising position of this new household has less consumption of the target good, in this case kilometres of vehicle travel, but more consumption of other goods their associated embodied resources.

*Efficiency case Conservation case*

Other consumption

Utility2`

Passenger kilometres

Utility2

Utility1`

Utility1

Other consumption

Utility2

Utility1

Passenger kilometres

Figure 1. Theoretical contrast between ‘efficient’ and ‘conservation’ consumption patterns.

In this case, if the cost savings from reduced consumption of the target good are treated as an increase in income, the scale of the indirect rebound effect is determined by the income elasticity of other goods consumed and their greenhouse gas intensity.

The second type of behaviour is termed efficiency, yet it involves no technology change. Instead it is simply the adoption by households of cost effective energy efficient alternatives currently available, such as downsizing the size of a car, and using compact fluorescent light bulbs.

Figure 1 shows how in the efficiency case, due to cost savings, the household budget constraint expands to enable greater consumption of the target good and other goods, subject to income and substitution effects.

One important issue remains in this theoretical discussion. To determine the resource embodied in a good or service, LCA methods take natural resources and labour as raw inputs, when in reality, these inputs are outputs of other processes. For example, the production of coal is not possible without the use of the mining machinery, and labour. Nor is labour itself an absolute input. The commitment of labour time to production itself requires physical support in the form of food, clothing, housing and other necessities. Thus, the need to define a system boundary in LCA methods necessarily leads to embodied resource data suffering from truncation errors.

To overcome these truncation errors, Costanza (1980), on the assumption that labour input itself requires the outputs of the economy, estimated the embodied energy of a number of economic outputs with alternative system boundaries. This method greatly reduced variation in energy intensity across different goods, a finding which lead him to propose an energy theory of value. Within this framework, consumption pattern changes would provide no net changes to energy consumption or greenhouse gas emissions.

While it is not the place here to examine Costanza’s (1980) methods in detail, the important fact remains that the determination of the LCA system boundary is an important determinant of the embodied energy and greenhouse gas emissions. Thus, improvements in LCA methods should be sought alongside improvements in rebound effect estimation methods, and any rebound estimates that using LCA data should be considered a conservative minimum estimate.

# Methods

The rebound effect model is based on a system of household demand equations where expenditure on each commodity is dependent on household income level (the independent variable)[[3]](#footnote-3). The 2003-4 Australian Bureau of Statistics (ABS) Household Expenditure Survey (HES), aggregated into 36 commodity groups[[4]](#footnote-4), is used in this paper (ABS, 2004). The corresponding embodied greenhouse gas emissions for each commodity group, calculated using an input-output based hybrid method, was made available from the Centre for Integrated Sustainability Analysis, Sydney, and is shown in Appendix B (Dey, 2008). This approach was suggested by Sorrell (2007), and enables analysis of the impact of household income level on the scale of the rebound effect.

Combining the two data sets to examine embodied greenhouse gas emissions against household income reveals a decreasing emissions intensity, but increasing quantity of emissions, with increasing household expenditure (Figure 2). 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). This data provides no evidence to suggest an environmental Kuznets curve (EKC) for household greenhouse gas emissions within Australia using a consumption side approach.

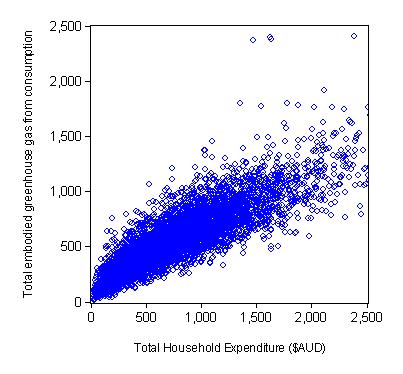


Figure 2. Total household greenhouse gas emissions embodied in consumption.

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,[[5]](#footnote-5)
* the adding up criterion,[[6]](#footnote-6) and
* the best representation of the data.

Two variations of the double semi-log (DSL) functional form[[7]](#footnote-7) are used in this study. One of these regressions contains further variables of 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 functional form are also used to examine 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 on each *i* commodity is:

(2)

The second DSL model (DSL2) has the functional form

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

(3)

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

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

(4)

Then the relationship

(5)

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

The functional from of the Engel curve from the WL model is then determined by substituting equation (4) into (5) as follows.

(6)

Appendices C through F 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 extra explanatory variables in the DSL2 model also provide evidence that these factors are important determinants of the household expenditure pattern. In the domestic fuel and power and vehicle fuel commodity 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, 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,

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 - (7)

Linear - (8)

WL - (9)

Two alternative models have been derived for estimating the rebound effect. The first is the conservation model where there is no increase in expenditure on the commodity from which the saving was made (a model not yet seen in the literature). The second is the efficiency model, where although technology is fixed, there are more 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[[8]](#footnote-8). 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.

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

(10)

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,

(11)

For the efficiency case, calculating the direct effect[[9]](#footnote-9) is estimated by multiplying the savings, *Y*, by the MBS of the commodity from which the savings are made

(12)

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

(13)

To estimate the change in greenhouse gas emissions from the change in consumption patterns, the expenditure in each commodity group is multiplied by the greenhouse gas intensity of that commodity. Since there are no technology changed applicable to production stages of the economy, the same embodied emissions data may be used in both the before and after scenario.

In the resource generic form of Lenzen and Dey (2002), if the overall embodiment of resource *f,* for category *i*, is *Rf, i*, then the total embodiment of *f* for all consumption is

(14)

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

(15)

which can be simplified to

(16)

To differentiate between conservation cases and efficiency cases, *Qnew* is calculated using the two alternative methods previously discussed to create two distinct models. Importantly, in this model the rebound effect is simply a function of the total expenditure level.

# Cases

#### 4.1 Vehicle fuel

Driving less, or choosing a more fuel efficient vehicle is widely promoted as an effective action for households to reduce their greenhouse gas emissions (2007b; 2007a; AGO, 2007). To construct an efficiency case, evidence suggests that it is possible to replace the average Australian passenger vehicle with one that uses 4L/100Km less fuel, without a change in capital costs by sacrificing size and/or quality (2008b; 2008i; 2008g). Also, the average number of kilometres per year was approximately 13,900kms, and the price of fuel in 2003-4 was $0.90 per litre (ABS, 2006; 2008g). Further to the direct savings of fuel, there are cost savings on complementary goods such as registration, tyres and servicing. The registration cost difference between a four and six cylinder car in Queensland is currently $111.95 (2008h). A token saving of $50 has been assumed for the reduction in associated servicing and running costs per year. Combining these figures to construct the efficiency case is shown in Table 1.

|  |  |  |
| --- | --- | --- |
| Case study changes | Old | Efficient replacement |
| Fuel economy | 11L/100kms | 7L/100kms |
| 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 details for fuel-efficient passenger vehicle replacement.

A conservation case could be identical to the efficiency case, except that the household does not respond to the effective price change by increasing driving. Alternatively, the conservation case could be a situation where a household reduces its fuel consumption simply through reducing driving distance. For the same fuel cost saving this reduction is from the average of 267 down to 167kms per week. The potential resource reductions in both the efficiency and conservation cases are 25.01kg CO2-e per week.

The rebound simulation results for this case are presented in Appendix E for household total expenditure levels between $250 and $1500 per week.[[10]](#footnote-10) In the efficiency case, the total (direct and indirect) rebound effect is in the range of 11 to 39%. Around the median total expenditure level of $593 per week, all four household demand models provide results between 23 and 27%, indicating that aggregate estimates of greenhouse gas reductions from this type of activity should be revised down by that order.

By separating the direct and indirect effect in the efficiency case it can be shown that the indirect effect is much higher than the direct effect. The direct effect is less than 10% at all income levels, and falls as income rises. This is consistent with previous studies of the direct effect and income level (Baker et al., 1989; Milne and Boardman, 2000; Hong et al., 2006). The direct effect is also shown to be decreasing in proportion to the indirect effect with increasing household income, meaning that at high income levels the indirect effect forms the majority of the total rebound effect.

In the conservation case, the results from all non-linear household demand models show a decreasing indirect rebound effect with increasing household income level within a range of 5-35%. At the median total household expenditure level of $593/week, all four demand models produce a rebound effect in the narrow range of 20-23%. When the associated cost reductions are removed, to simulate simple a reduction in driving, the rebound effect increases in all versions of the model.

#### 4.2 Household electricity

In line with the suggestion by the International Energy Agency (IEA) publication, Light’s Labour’s Lost, the Australian government has proposed to phase in a ban on incandescent light bulbs as a measure to reduce greenhouse gas emissions (Turnbull, 2007). The proposed substitute for incandescent light bulbs is compact fluorescent light bulbs (CFL). It is suggested that the regulation will reduce Australia’s greenhouse emissions can by 4 million tonnes per year (Turnbull, 2007). In the past decade however, 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 construct this case, including the capital cost, 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[[11]](#footnote-11). 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 kilowatt-hour 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, 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.

The rebound simulation results of the household electricity case are presented in Appendix F. The efficiency rebound model estimates a rebound effect between 3 and 10%. 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 the median income level. For the separation of the direct and indirect effects, again the direct effect is much lower and decreasing as a proportion of the total effect with increasing income. Interestingly, the WL model in this case provides a negative direct rebound effect at incomes above $800 per week. This is due to household electricity becoming an inferior good above the level in this model. Finally, the direct effect is decreasing in proportion to the indirect effect in the efficiency case for the WL and DSL model, but shows the reverse pattern for the DSL model.

In the conservation case, the results from all household demand models results in a decreasing total rebound effect with increasing household income level within a range of 5-8%. As expected, the rebound effect in the conservation case is lower than in the efficiency case.

#### 4.3 Combined case

The scenario where a household adopts both of the above cases concurrently was also simulated. The results are presented in Appendix G. The conservation rebound model produces a rebound effect between 12 and 15%, while the efficiency rebound model produces a rebound effect between 10 and 30%. Both the models follow the downward trend with increasing household income, and the efficiency model strongly supports a decreasing direct effect as a proportion of the total rebound effect as household incomes increase.

The combined conservation case provides some further interesting insights. First, the variation of the rebound effect over the income range has been greatly reduced. This is due to the elimination of the two commodities with the highest embodied greenhouse gases from the pattern of new spending. Upon closer inspection, the rebound effect in this case is less than one would expect from a simple addition of the individual case results. For example, in the vehicle fuel case, the potential greenhouse emissions reductions were 25.01kg CO2-e per week with a DSL2 rebound effect of 20% at the median income level, with a net emissions reduction of 20.03kg CO2-e. In the electricity case, the potential greenhouse emissions reductions were 10.49kg CO2-e per week with the median DSL2 net reduction of 9.86kg CO2-e. The combined expected net effect for the DSL2 model at median expenditure level is 29.89kg CO2-e, which reflects an indirect rebound effect of only 15.8%. This result of a diminished rebound effect appears due to the elimination of expenditure on each of the energy commodities from new consumption pattern.

The efficiency case offers a contrary observation. In this case, the expected combined net effect for the DSL2 model at median expenditure is 29.01kg CO2-e, which equates to an 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, from visual inspection it is clear that the direct effects are a larger proportion of the total effect than in each individual case. An obvious explanation is that the direct effect now incorporates expenditure on both energy commodities.

# Discussion and conclusion

The focus of this paper was an examination of the rebound effects from consumption pattern changes. Behaviour changes advocated by governments and environmental groups have been modelled, with rebound effect estimates determined by treating cost savings as income, with the allocation of spending amongst commodity groups determined by the econometric model of household demand.

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 contribution to greenhouse gas emissions, the results are often much lower than anticipated. 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. All estimates are a conservative minimum, given the assumptions that underpin LCA methods, and the omission of substitution effects. For policy makers, the key message is that policies promoting household consumption patterns changes can be much less effective measure for reducing greenhouse gas emissions than they appear when rebound effects are ignored.

On a more detailed level, the empirical results validate 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 decreased with increasing household income level. This is consistent with existing studies that have found much higher direct rebound effects for low income households {Baker, (1989)215;Milne, (2000)Hong(2006). The 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 suggests that a low direct rebound effect should not be interpreted as indication of the scale of the total rebound effect.

Regarding the use of the two rebound effect models, for 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. Additionally, when conservation measures are combined the environmental benefits are greater, and the rebound effect lower, 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, results in a rebound effect greater than the sum of each case in isolation. This signals that the focus of DSM in the context of climate change should be at 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 aggregate rebound effects, the choice of household demand model unlikely to be a key factor.

These findings point to the limitations of proposed win-win policies. For example, the economic benefits for the household due to reduced vehicle maintenance costs increased the rebound effect from that case, therefore reducing the environmental benefits. In the combined efficiency case, the reduction in environmental benefit further questions the benefits of cost saving energy efficient technologies.

The major issue that remains for consumption side estimation of rebound effects, even at fixed technology levels, is the use of LCA data. Given the Background discussion of the shortcomings of the methods used to generate this data, and the possibility of equal energy greenhouse gas emissions intensity for all commodities, is must be emphasised that the true rebound effect from these cases may lie somewhere between these estimates and 100%. A more robust theoretical discussion of the method employed is necessary to move this area of research forward.

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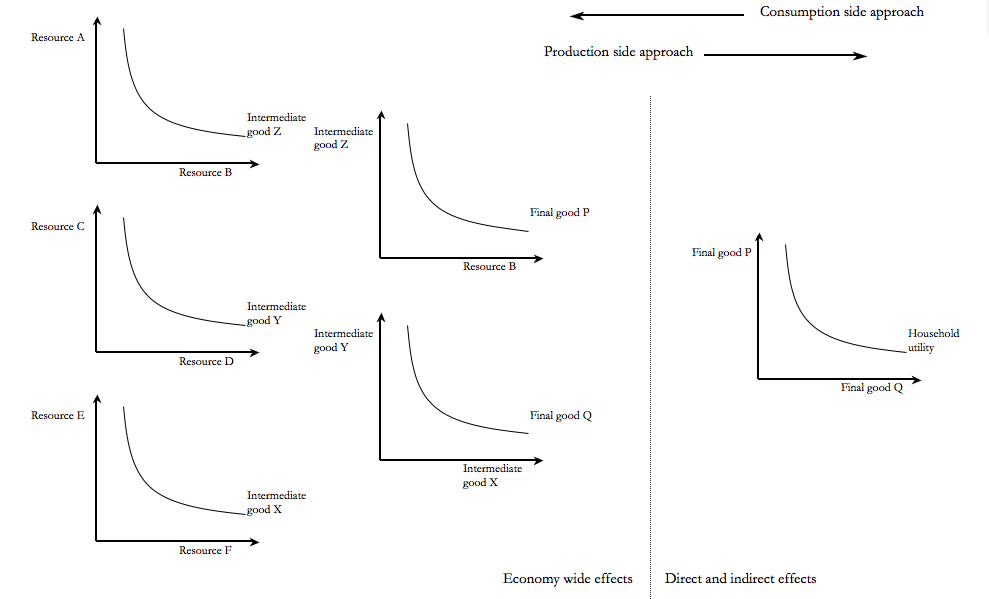
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Appendix A: Stylised economy with classical production frontiers and intermediate production stages.*[[12]](#footnote-12)*



Appendix B: Life cycle greenhouse 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 C: Regression results for double-semi log model. \*\*\*1% significance, \*\*5% significance, \*10% significance, with standard errors in parenthesis.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *α* | *β* | *γ* | *Adj. r2* |
| *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  (5.01) | 0.012\*\*\*  (0.0021) | -0.88  (1.02) | 0.079 |
| *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*  *goods* | 21.96  (23.31) | 0.031\*\*\*  (0.0090) | -4.71  (4.68) | 0.13 |
| *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  (17.98) | 0.036\*\*\*  (0.0073) | -4.42  (3.63) | 0.088 |
| *Vehicle*  *registration* | -40.62\*\*\*  (3.29) | 0.0066\*\*\*  (0.0013) | 9.44\*\*\*  (0.656) | 0.31 |

Appendix D: Regression results for double-semi log model with extra explanatory variables. \*\*\*1% significance, \*\*5% significance, \*10% significance, with standard errors in parenthesis.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *α* | *β* | *γ* | *Persons/house* | *Urbanity* | *State* | *Age* | *Dwelling* | *Adj. r2* |
| *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\*\*  (24.09) | 0.068\*\*\*  (0.0095) | -13.01\*\*\*  (4.76) | 2.90\*\*\*  (0.70) | -0.32  (1.08) | -0.36  (0.35) | -0.092  (0.097) | 1.09\*\*  (0.54) | 0.24 |
| *Clothing services* | 0.72  (1.30) | 0.0019\*\*\*  (0.00050) | -0.19  (0.25) | -0.086\*  (0.051) | -0.29\*\*\*  (0.092) | 0.0004  (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  (0.13) | 0.033  (0.035) | 0.18  (0.18) | 0.080 |
| *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/tableware* | -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*  *services* | 150.05\*\*\*  (48.59) | 0.17\*\*\*  (0.019) | -31.36\*\*\*  (9.33) | 0.61  (1.44) | -0.14  (2.48) | -1.13  (0.73) | -0.70\*\*\*  (0.19) | 4.48\*\*\*  (1.21) | 0.31 |
| *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/accesories* | -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\*\*\*  (0.0045) | 0.46  (2.046) | -1.53\*\*\*  (0.37) | 1.21  (0.74) | 0.18  (0.20) | -0.052  (0.072) | -1.29\*\*\*  (0.30) | 0.040 |
| *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 charges* | 12.82  (19.56) | 0.036\*\*\*  (0.0074) | -1.68  (3.70) | -3.64\*\*\*  (0.64) | 0.91  (1.20) | -0.62\*  (0.36) | -0.023  (0.10) | -0.75\*  (0.43) | 0.093 |
| *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 E: Results of vehicle fuel rebound simulations.

*FuelconservationcaseFuelconservationcasenoass*

Fuelefficiencycase2Fuelefficiencycaseserparated1

Fuel efficiency ratio

Appendix F: Results of household electricity rebound simulations.

LightsconservationcaseLightsefficiencycaseLightsefficiencycaseseparatedElec efficiency ratio

Appendix G: Results of combined case rebound simulations.

ComcasesconservationComcasesefficiencyComcaseefficiencyseparatedCombined efficiency ratio

1. Organisation for Economic Co-operation and Development [↑](#footnote-ref-1)
2. Brookes (2000) expressed the interdependence of resource productivity grandly as “the principle of the indivisibility of economic productivity”. [↑](#footnote-ref-2)
3. Total expenditure is used as a proxy for income, which is common in household demand studies (Deaton and Muellbauer, 1980; Haque, 2005; Brannlund et al., 2007). [↑](#footnote-ref-3)
4. This demand system represents the final budgeting stage of a household after savings decisions and decisions in housing expenditure. As such, housing demand is excluded from the model, and the model assumes not changes to the household savings rate (which is supported by recent Australian data which show negative household savings rates (2008f)). Also, saving itself is simply deferred consumption, so the long run effect offsets any short run effects.

   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 [↑](#footnote-ref-4)
5. These are turning points in the Engel curve, characteristic of goods becoming inferior above a particular income level. [↑](#footnote-ref-5)
6. The adding-up criterion specifies that at all levels of total expenditure, the sum of expenditure on each commodity adds up to total expenditure. [↑](#footnote-ref-6)
7. This functional form was determined by Haque (2005) to provide the best fit to the 1976-77 HES data. [↑](#footnote-ref-7)
8. 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. [↑](#footnote-ref-8)
9. From the income effect only. [↑](#footnote-ref-9)
10. All DSL2 model results are with mean values for other variables. [↑](#footnote-ref-10)
11. After an quick survey of Brisbane CBD supermarket shelves [↑](#footnote-ref-11)
12. Isoquants on the left of the delineation are output levels at given technology level (a given production function), and on the right, are indifference curves. The output of each graph becomes an input to the one on the right. [↑](#footnote-ref-12)