HOUSEHOLD DEMAND, ENERGY EFFICIENCY IMPROVEMENT AND THE REBOUND EFFECTS

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Introduction

- UK Government encourages households environmental behaviour change and use of energy efficiency improvement measures at home (e.g. grants)
- The aim is to lower (direct and indirect) energy consumption and associated GHG emissions by households
- The expected reduction in energy consumption and GHG emissions might not be achieved due to rebound effects.

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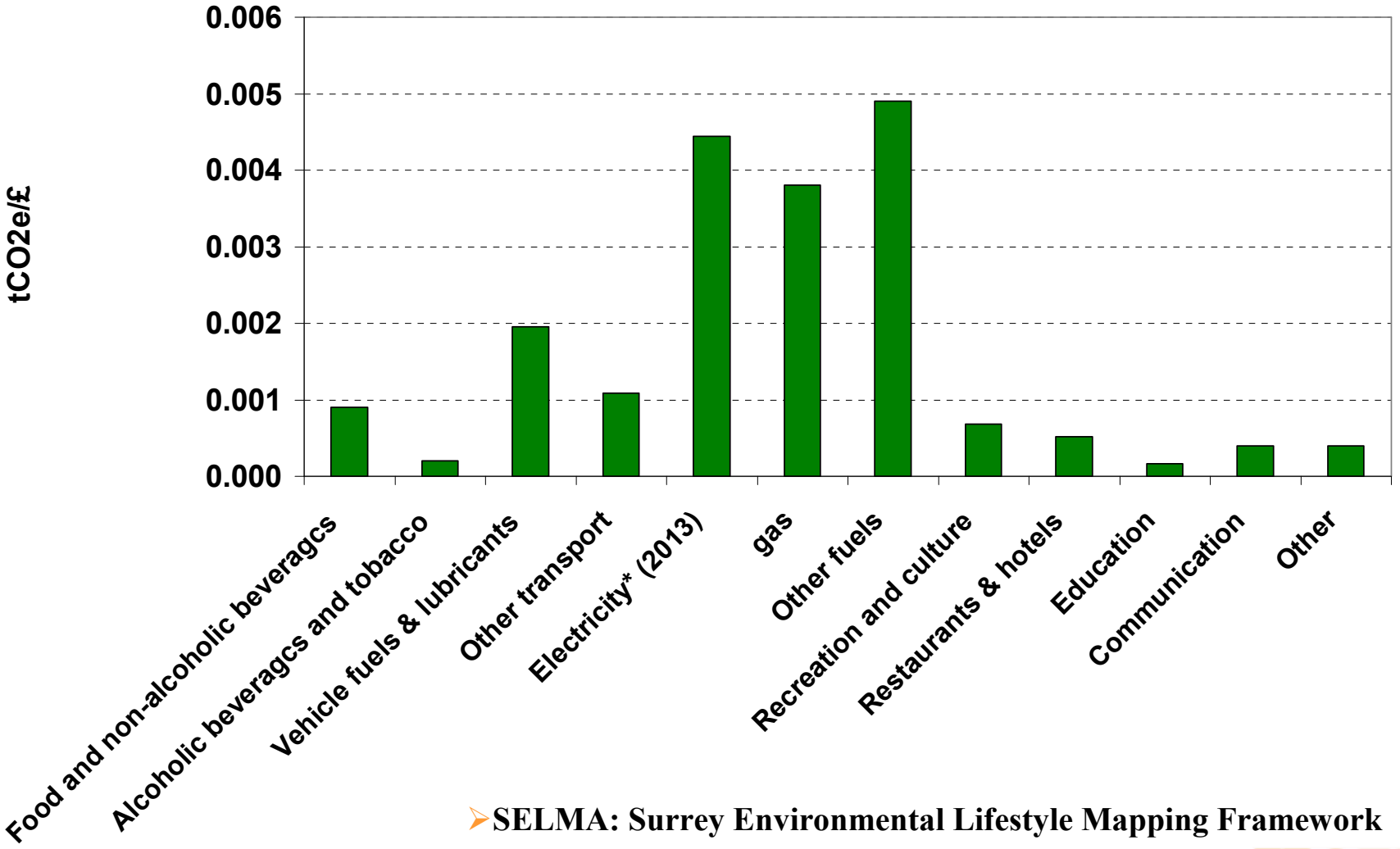
GHG intensity in 2004 (GHGs/£)



- SELMA: Surrey Environmental Lifestyle Mapping Framework

Quasi-Multi-Regional Input-Output model

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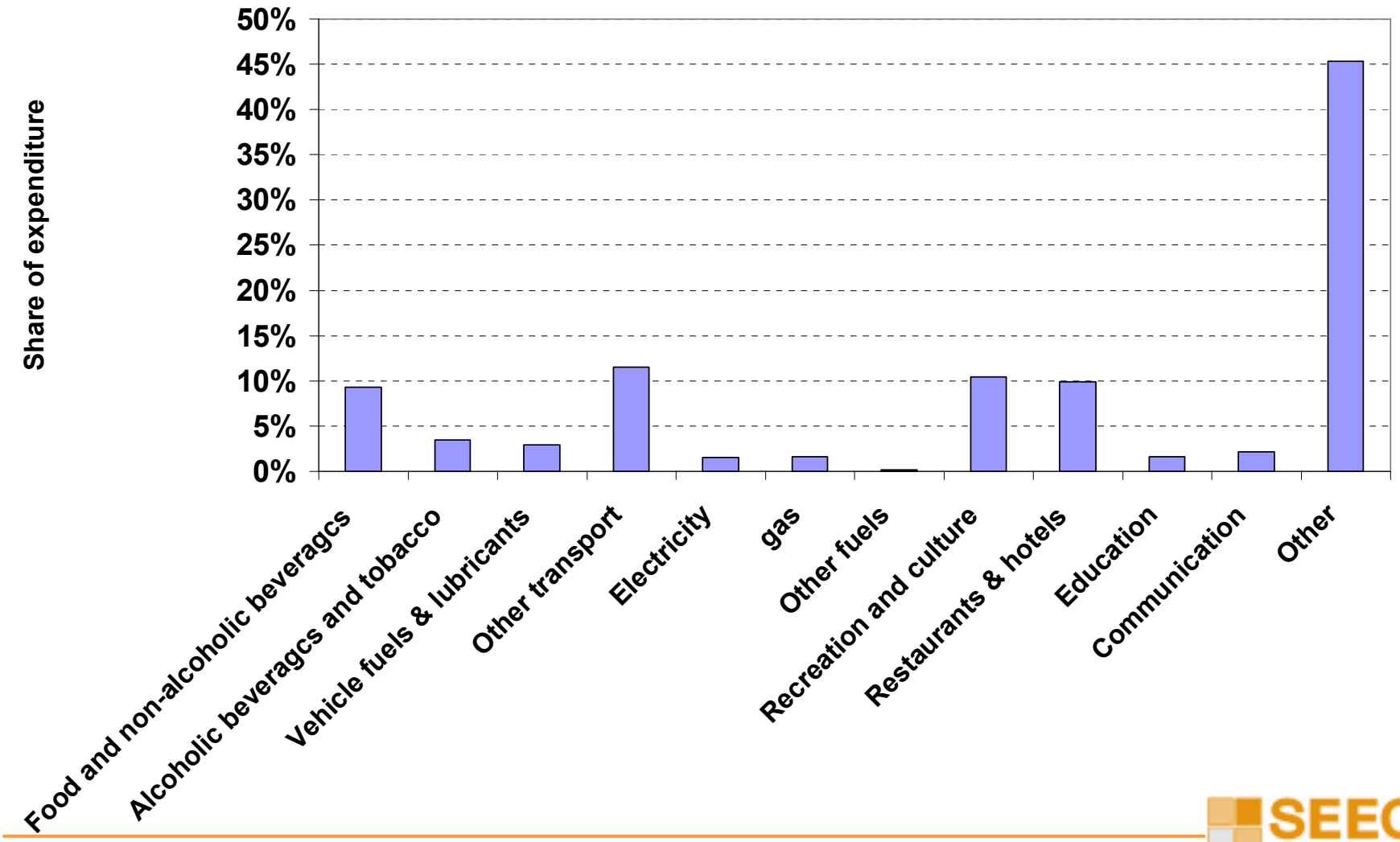
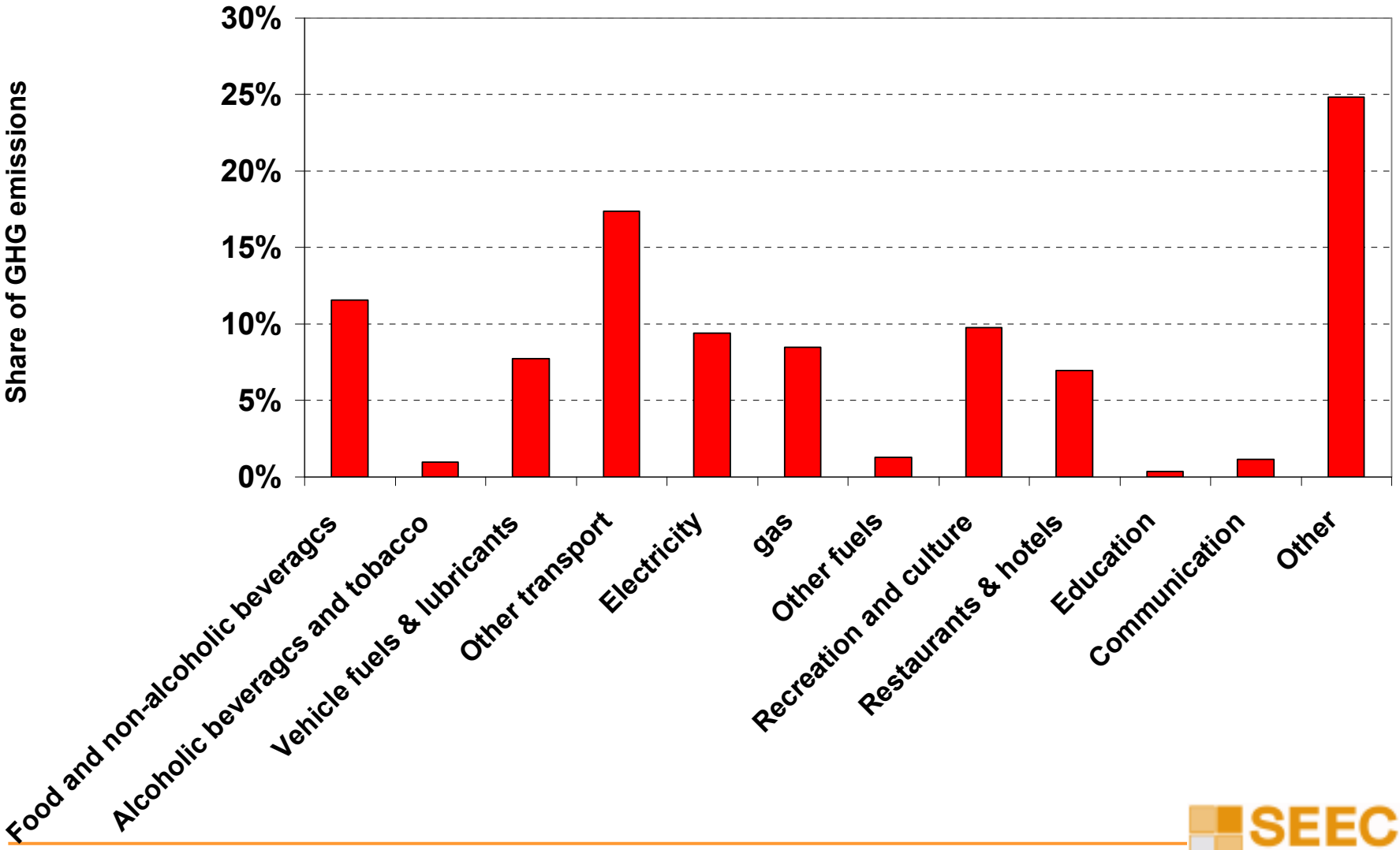
Expenditure share in 2013



GHGs share in 2013



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Background

Author	Region	Measure	Area	Metric	Energy/ emissions	Estimated rebound effect (%)
Lenzen and Day	Australia	Efficiency & sufficiency	Food; heating	GHGs	Direct and embodied	45-123%
Alfreddson	Sweden	Sufficiency	Food; travel; utilities	CO_2	Direct and embodied	7-300%
Druckman et al	UK	Sufficiency	Transport, heating, food	GHGs	Direct and embodied	7-51%
Thomas and Azevedo	US	Efficiency	Transport, electricity	Energy and CO_2	Direct and embodied	7-25%
Murray	Australia	Efficiency & sufficiency	Transport, lighting	GHGs	Direct and embodied	4–24%
Chitnis et al	UK	Efficiency	Heating, lighting	GHGs	Direct and embodied	5–15%
Chitnis et al	UK	Efficiency and sufficiency	Transport, heating, lighting, food	GHGs	Direct and embodied	5-106%
Brannlund et al	Sweden	Efficiency	Transport; utilities	CO_2	Direct and embodied	120-175%
Mizobuchi	Japan	Efficiency	Transport; utilities	CO_2	Direct and embodied	12-38%
Lin et al	China	Efficiency	Transport; utilities	CO_2	Direct and embodied	37%

Rebound effect for energy efficiency measures: GHGs emissions

Energy efficiency measure e.g. efficient car

Embodied GHGs ΔM: *embodied effect*

Cost £

Grant

Price of energy service falls: income and substitution effects

Changes in energy demand for the same goods & services e.g. driving more (Direct rebound)

Changes in other goods & services demand e.g. holiday or Save in bank (Indirect rebound)

Expected GHG reduction ΔH: *engineering effect*

$$\text{Rebound} = -\frac{\Delta G + \Delta M}{\Delta H}$$

GHGs due to re-use ΔG: *re-spending effect*

Rebound model

$$\Delta G = u_s^x \Delta x_s^G + \sum_{i(i \neq s)} u_i^x \Delta x_i$$

$$\Delta G = u_s^x x_s \tau \eta_{q_s, p_s} + \sum_{i(i \neq s)} u_i^x x_i \tau \eta_{q_i, p_s}$$

$$\Delta H = u_s^x x_s \rho \qquad \tau = -\rho$$

$$R_T = \frac{\Delta G}{\Delta H} = (-\eta_{q_s, p_s}) - \sum_{i(i \neq s)} \psi_i \eta_{q_i, p_s}$$

where $$\psi_i = \frac{u_i^x w_i}{u_s^x w_s}$$

u: GHG intensity

x: expenditure

q: quantity of demand

s: relevant energy services

i: other goods and services

w: expenditure share

ρ : % change in efficiency

τ : % change in energy service price

η : price elasticity

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Rebound model

Using *Slutsky* equation, R_T is decomposed to substitution R_{SU} and income effects R_I : $R_T = R_{SU} + R_I$

$$\eta_{q_i,p_s} = \tilde{\eta}_{q_i,p_s} - w_s E_{q_i,x}$$

η_{q_i,p_s} Uncompensated price elasticity

$\tilde{\eta}_{q_i,p_s}$ Compensated price elasticity

$E_{q_i,x}$ Income elasticity

$$R_T = \underbrace{\left[w_s \eta_{q_s,x} + (-\tilde{\eta}_{q_s,p_s})\right]}_{\text{Direct}} + \underbrace{\left[\sum_{i(i \neq s)} \psi_i w_s \eta_{q_i,x} - \psi_i \tilde{\eta}_{q_i,p_s}\right]}_{\text{Indirect}}$$

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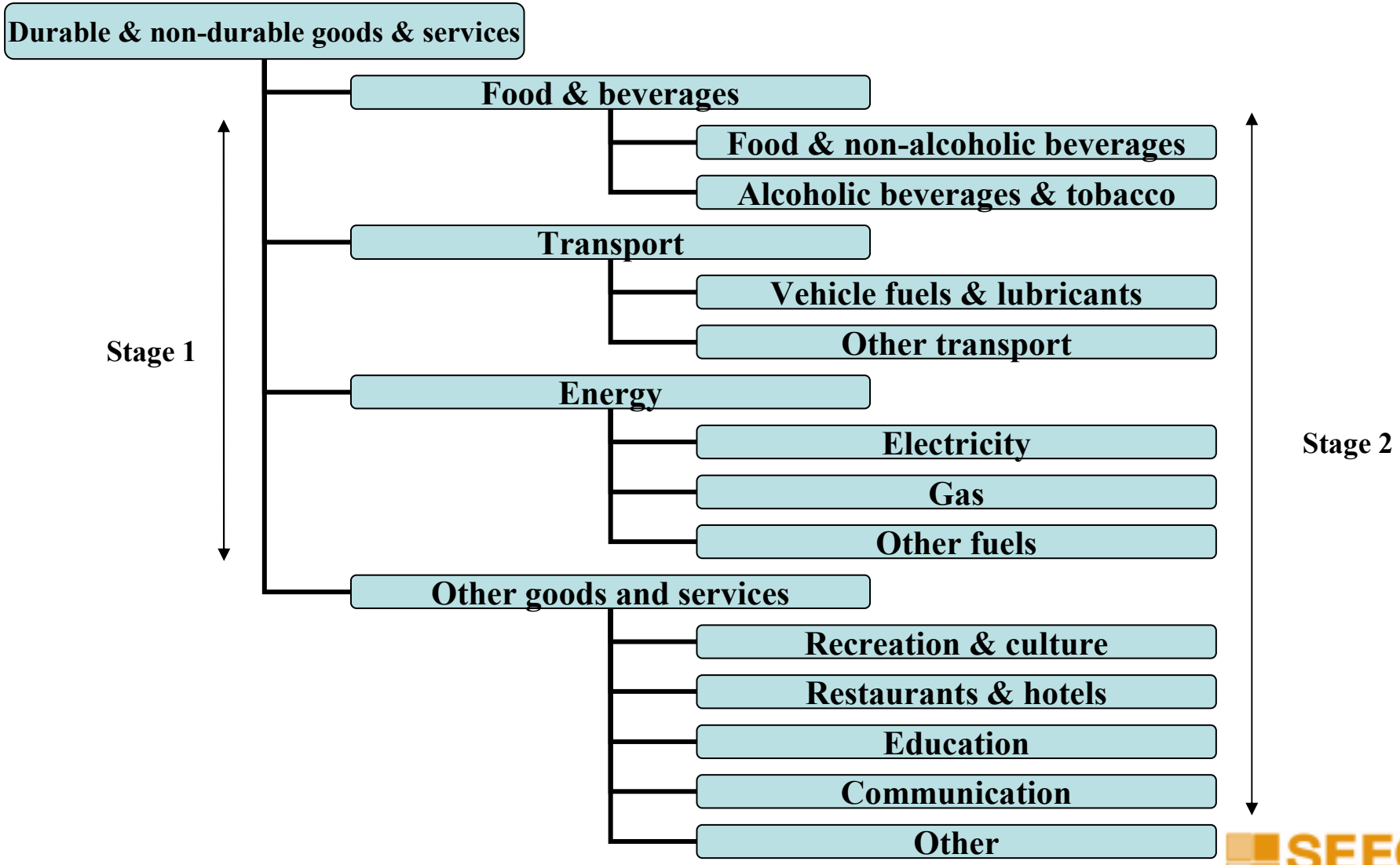
Two stage budgeting model



Almost Ideal Demand System (AIDS)

Stage 1:

$$w_{rt} = \alpha_r + \sum_s \gamma_{ij} \, ln \, p_{st} + \beta_r \, ln(x_t / P_t) + \sum_s \lambda_{rs} w_{s\,t-1} + \varepsilon_t \qquad \text{r, s: 1, … , 4}$$

where:

w_r=budget share of category r

P_s=price of category s

x=expenditure on durable & non-durable goods and services per household

P=Stone price index $\quad \boldsymbol{ln \, P_t = \sum_r w_{rt} \, ln \, p_{rt}}$

- Adding up: $\quad \sum_r \alpha_r = 1, \sum_r \beta_r = 0, \sum_r \gamma_{rs} = 0, \sum_r \lambda_{rs} = 0$
- Symmetry: $\quad \gamma_{rs} = \gamma_{rs}$
- Homogeneity: $\quad \sum_r \gamma_{rs} = 0$

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Almost Ideal Demand System (AIDS)

Stage 2:

$$w_{it}^{r} = \alpha_i + \sum_{j \in r} \gamma_{ij} \ln p_{jt} + \beta_i \ln(x_{rt} / P_{rt}) + \sum_{j \in r} \lambda_{ij} w_{j_{t-1}} + \upsilon_t \qquad \text{i, j: 1, … , n}$$

where:

w_i=budget share of category i

P_j=price of category j

x_r=expenditure on category r per household

P_r=Stone price index $\quad \boldsymbol{\ln P_{rt} = \sum_i w_{it} \ln p_{it}}$

- Adding up: $\sum_i \alpha_i = 1, \sum_i \beta_i = 0, \sum_i \gamma_{ij} = 0, \sum_1 \lambda_{ij} = 0$
- Symmetry: $\gamma_{ij} = \gamma_{ij}$
- Homogeneity: $\sum_i \gamma_{ij} = 0$

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Estimation

- UK household annual time series data 1964-2013 obtained from Office for National Statistics (ONS)
- Iterative Seemingly Unrelated Regressions (ISUR) method for system estimation:
  - suitable for having restrictions on the model
  - ISUR will correct the estimation for any correlation of the residuals between the equations in the system.
- Unrestricted model is estimated and ‘Wald test’ is used for testing the restrictions. If the restriction is not rejected then the relevant restriction is imposed to the model. One equation is dropped in each group to satisfy the adding up restriction.

Wald test for symmetry and homogeneity restrictions

Group	Durable and non-durable goods & services	Food & beverages	Transport	Energy	Other goods & services
Symmetry	33.5*	-	-	5.4*	41.4*
Homogeneity	5.7	1.2	2.7	27.8*	4.7
Symmetry & Homogeneity	45.4*	-	-	27.8*	58.3*
Symmetry based on Homogeneity	39*	-	-	-	53.2*

* represents that the null hypothesis is rejected at 5% probability level.

Elasticities for two-stage budgeting model (Edgerton 1997)

Within group elasticities:

Income elasticity $$E_r = 1 + \frac{\beta_r}{w_r}$$

Uncompensated price elasticity $$e_{rs} = \frac{\gamma_{rs} - \beta_r w_s}{w_r} - \delta_{rs}$$

Compensated price elasticity $$\tilde{e}_{rs} = \frac{\gamma_{rs}}{w_r} + w_s - \delta_{rs}$$

δ_{rs} : Kronecker's delta equal to one when r=s and zero elsewhere.

Total/between group elasticities:

Income elasticity $$E_i = E_{(r)i} E_r$$

Uncompensated price elasticity $$e_{ij} = \delta_{rs} e_{(r)ij} + E_{(r)i} w_{(s)j} [\delta_{rs} + e_{(r)(s)}]$$

Compensated price elasticity $$\tilde{e}_{ij} = \delta_{rs} \tilde{e}_{(r)ij} + E_{(r)i} w_{(s)j} \tilde{e}_{(r)(s)}$$

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Estimated total elasticities

Uncompensated price elasticity

Uncompensated price elasticity	Food & non-alcoholic beverages	Alcoholic beverages	Vehicle fuels	Other transport	Electricity	Gas	Other fuels	Recreation & culture	Restaurants & hotels	Education	Communication	Other
Electricity	0.02	0.03	-0.06	-0.08	-0.39	0.10	-0.08	-0.01	-0.01	-0.01	-0.01	-0.01
Gas	0.02	0.02	-0.05	-0.06	0.07	-0.59	0.36	-0.01	-0.01	-0.01	-0.01	-0.01
Vehicle fuels	-0.01	-0.01	-0.59	-0.001	0.07	0.15	0.16	-0.03	-0.02	-0.03	-0.02	-0.02

Compensated price elasticity

Compensated price elasticity	Food & non-alcoholic beverages	Alcoholic beverages	Vehicle fuels	Other transport	Electricity	Gas	Other fuels	Recreation & culture	Restaurants & hotels	Education	Communication	Other
Electricity	0.04	0.05	-0.04	-0.06	-0.39	0.11	-0.08	0.01	0.01	0.01	0.01	0.01
Gas	0.03	0.03	-0.03	-0.04	0.07	-0.58	0.37	0.01	0.01	0.01	0.01	0.01
Vehicle fuels	0.01	0.01	-0.55	0.04	0.07	0.15	0.16	0.01	0.01	0.01	0.01	0.01

Income elasticity

	Food & non-alcoholic beverages	Alcoholic beverages	Vehicle fuels	Other transport	Electricity	Gas	Other fuels	Recreation & culture	Restaurants & hotels	Education	Communication	Other
Income elasticity	0.71	0.88	1.01	1.33	0.07	0.15	0.16	1.22	1.15	1.23	1.06	1.01

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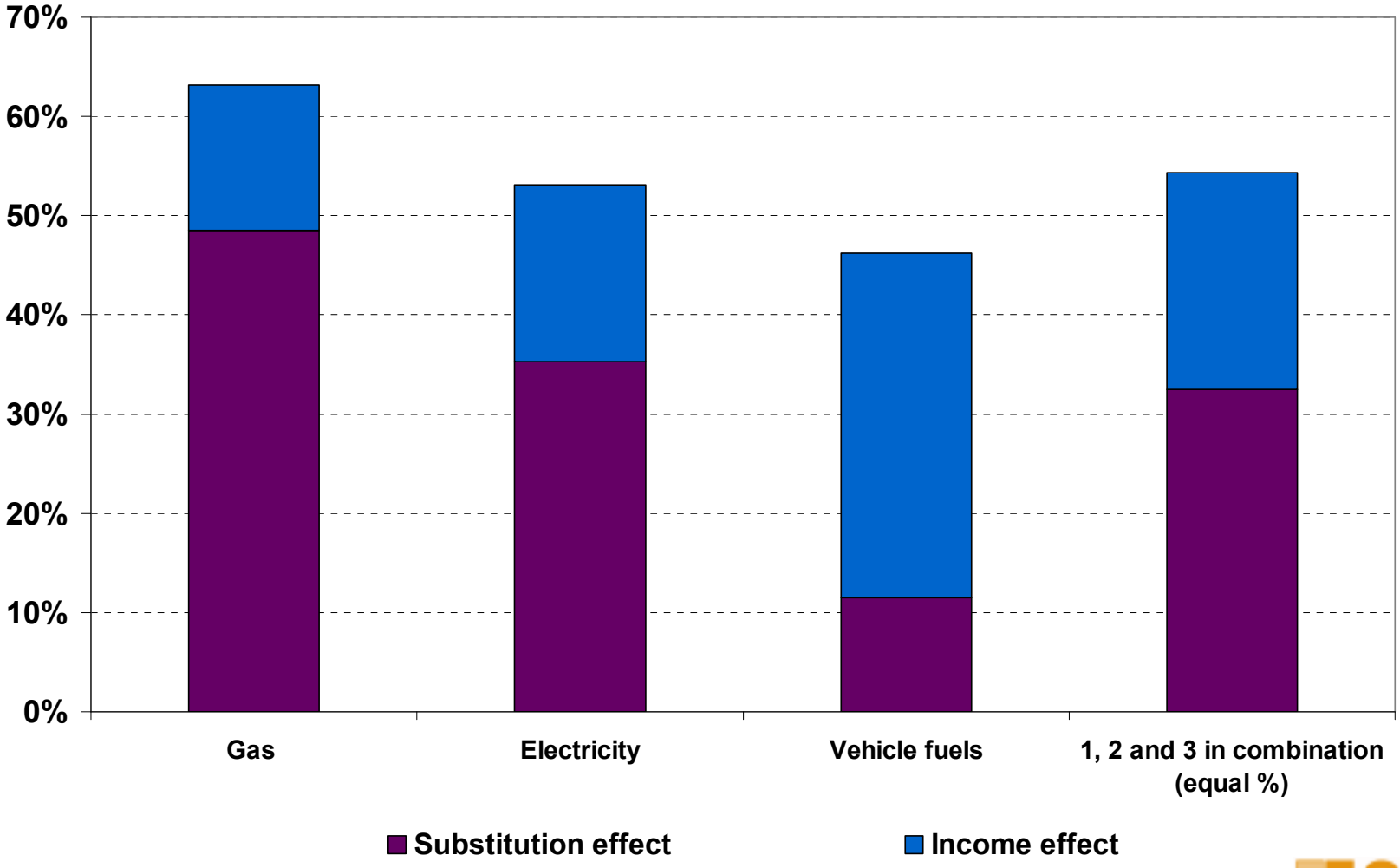
Estimated rebound effects for average UK households (no capital cost, no embodied effect)



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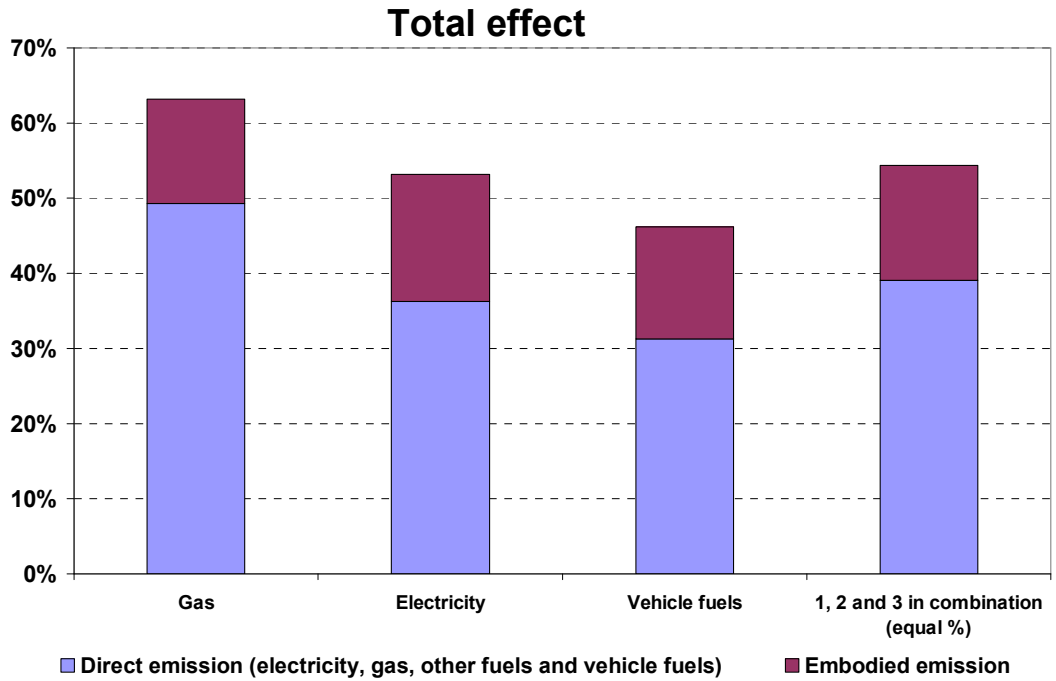
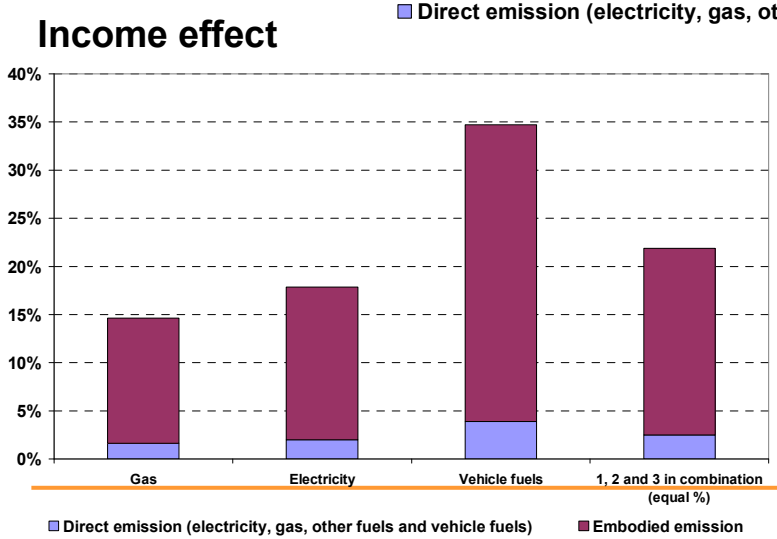
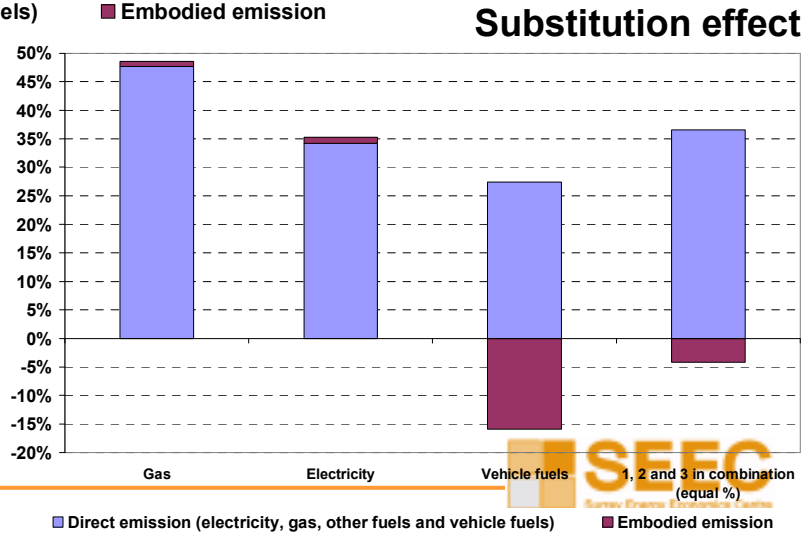
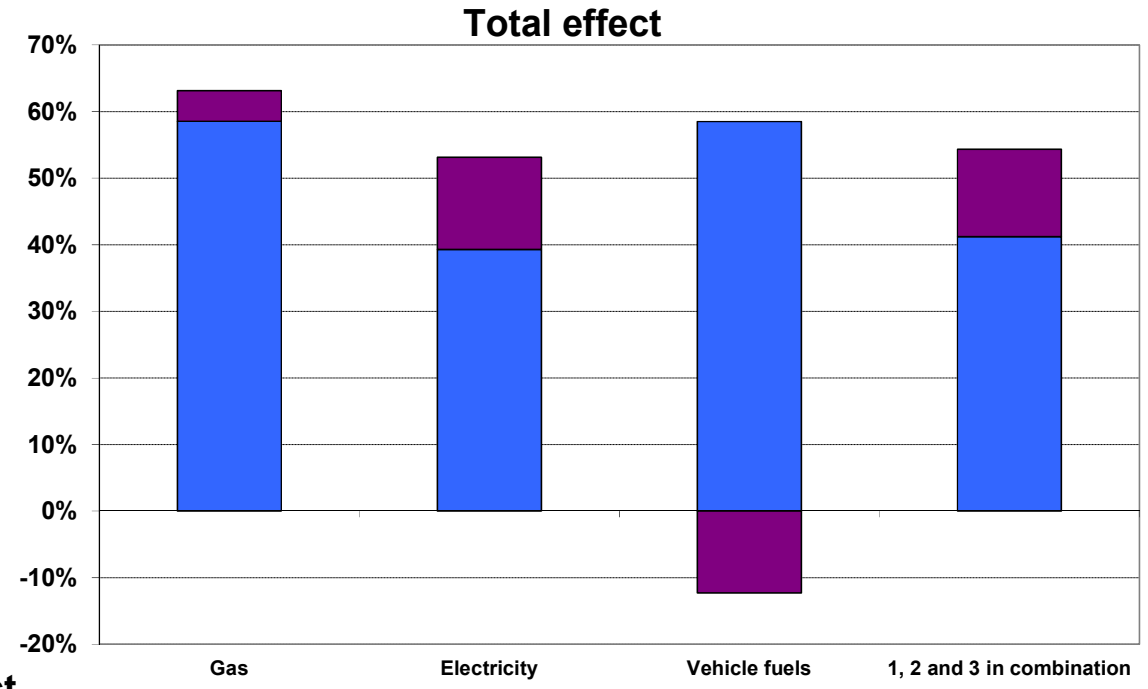
Rebound effect from direct and embodied emission

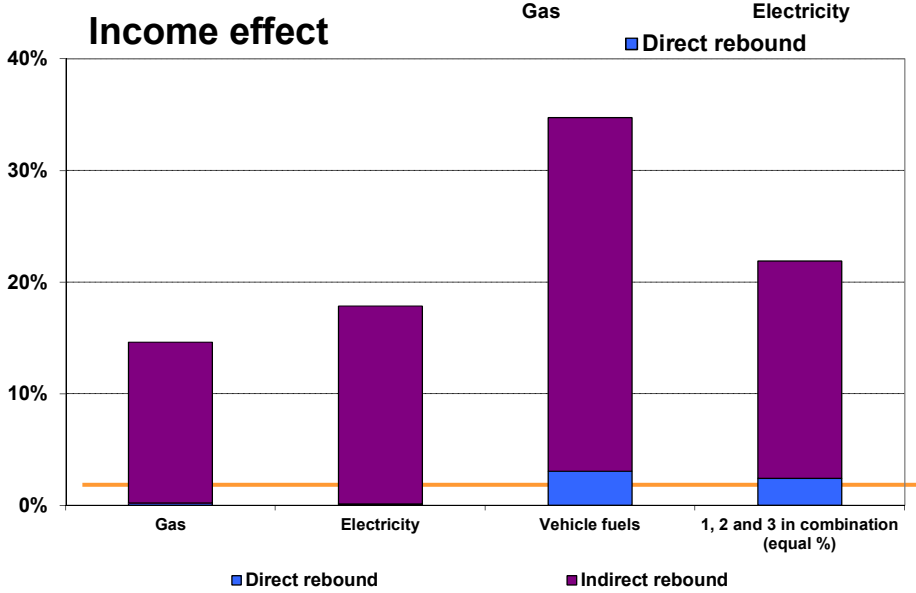


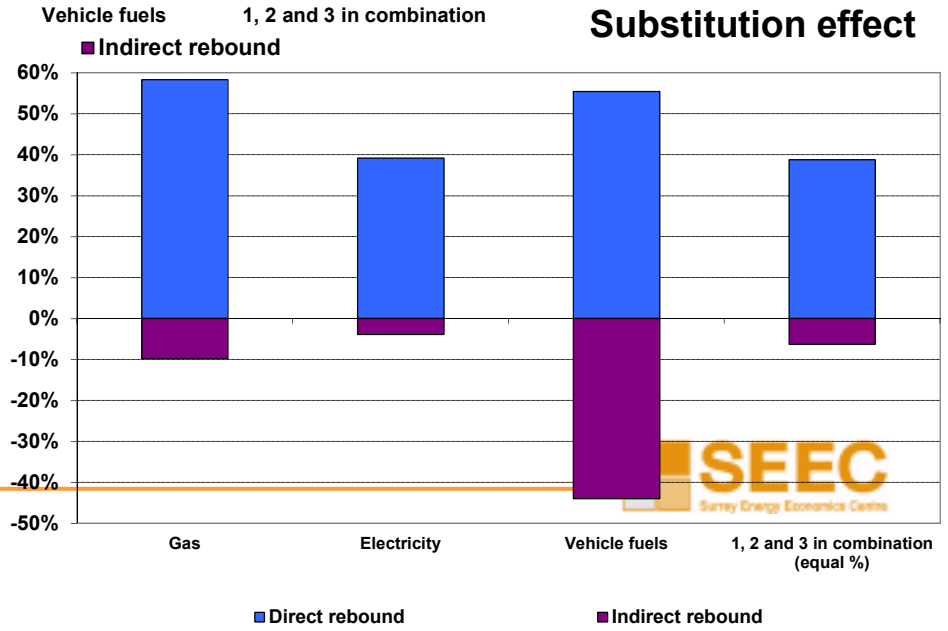




Direct and indirect rebound effects







Discussion

- No backfire
- Rebound effect is relatively high and for domestic energy is larger than for vehicle fuels
- Direct emissions dominate the total rebound effect
- Rebound effects for electricity measures will increase over time as GHG intensity of electricity falls
- Assumptions are for UK average household
- Greater commodity disaggregation could give a different picture

Extreme backfire

- Policy-makers need to take rebound into account when setting targets
- Shift patterns of expenditure to lower GHG intensive goods and services

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Increase in GHGs offsetting the engineering effect