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LIVING UP TO EXPECTATIONS: ESTIMATING DIRECT AND INDIRECT REBOUND EFFECTS FOR UK HOUSEHOLDS

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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.

Background

- Rebound effects are challenging to estimate and widely ignored. Limited evidence base largely confined to ‘direct effects’ for transport and heating.
- Very few studies of combined ‘direct & indirect effects’ for households (Murray, 2011 and Thomas et al., 2012).
- ‘Rebound’ is a generic term for multiple mechanisms, but most analytical techniques only capture a subset.

Rebound effect: GHGs emissions

Energy efficiency measure

Embodied GHGs ΔM: *embodied effect*

Cost £

Grant

£ Expenditure avoided

Re-use £

Re-spend on the same good or service (Direct rebound)

Re-spend on other goods & services 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: *income effect*

Estimation of rebound effect

- ***Engineering effect (ΔH_t)***

$$\Delta H_t = \sum_f s_{ft} \Delta E_{ft}$$

s_{ft}: GHG intensity of energy carrier *f*

ΔE_{ft} : the change in average annual reduction in demand for energy carrier *f* per household

***t:* time period**

- ***Embodied effect (ΔM_t)***

$$\Delta M_t = M_t - M'_t$$

M_t : average household embodied emissions for the energy efficiency measure

M'_t : average household embodied emissions of the alternative inefficient measure

Estimation of rebound effect

- ***Income effect***
  - ***Avoided expenditure (ΔC_t)***

$$\Delta C_t = \sum_f k_{ft} \Delta E_{ft}$$

k_{ft} : price per unit of energy carrier

  - ***Capital cost (ΔK_t)***

$$\Delta K_t = K_t - K'_t$$

K_t : average household capital cost for the energy efficiency measure

K'_t : average household capital cost of the alternative inefficient measure

  - ***Changes in real disposable income (ΔY_t)***

$$\Delta Y_t = \Delta C_t - \Delta K_t$$

Changes in expenditure on different goods & services ( ) ΔX_{it}

Changes in saving (ΔS_t

Estimation of rebound effect

– ***Income effect (ΔG_t)***

$$\Delta G_t = \sum_{i=1}^{I} [u_{it} \Delta X_{it}] + u_{st} \Delta S_t$$

u_{it} : GHG intensities of expenditure for category i and saving

u_{st} : GHG intensities of saving

Using the definition of expenditure elasticity for category i (β_i), saving ratio (r_t) and Engel aggregation:

$$\Delta G_t = \left[\frac{(1 - r_t) \Delta Y_t}{\sum_{i=1}^{I} \beta_i X_{it}} \right] \Sigma_{i=1}^{I} u_{it} \beta_i X_{it} + u_{st} r_t \Delta Y_t$$

Underlying models

➢ CDEM: Community Domestic Energy Model

- Developed by Loughborough University (Firth et. al.) to simulate energy use in the English housing stock and to explore options for reducing CO_2 emissions.
- Used to estimate the expected energy saving by each energy efficiency measure for 'average UK household'

Loughborough University

➢ SELMA: Surrey Environmental Lifestyle Mapping Framework

- Quasi-Multi-Regional Input-Output model
- Estimates the GHG intensities of UK household expenditure and savings (investment) for 1992-2004.

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RESOLVE

Engel curve estimation

- ***'Working- Leser'*** **:**

$$W_i = \alpha_i + \lambda_i x + \gamma_i HRP + \nu_i$$

W_i: equivalised budget share of expenditure category i

x: logarithm of equivalised total expenditure

HRP: age of household reference person

- **UK households cross-section data for 2009**
- **'White heteroskedasticity-consistent standard errors & covariance'**
- **Adding up condition is satisfied automatically.**
- **Expenditure elasticities are estimated for 16 categories of goods & services by household *income quintiles*.**

$$\beta_{X_{ij} X_j} = \frac{\lambda_i}{\overline{W}_{ij}} + 1$$

- **'Double Semi-Log' functional form was also estimated for comparison.**

Estimated expenditure elasticities by quintiles in 2009

Category \ Quintile	Working-Leser					
	1	2	3	4	5	All
Food & non-alcoholic beverages	0.65	0.57	0.48	0.38	0.06	0.39
Alcoholic beverages & tobacco	0.71	0.68	0.65	0.60	0.45	0.59
Clothing & footwear	1.51	1.34	1.32	1.27	1.28	1.30
Electricity	0.57	0.37	0.17	0.00	-0.62	0.05
Gas	0.62	0.49	0.34	0.15	-0.25	0.23
Other fuels	0.85	0.77	0.82	0.79	0.69	0.77
Other housing	0.73	0.73	0.68	0.68	0.56	0.66
Furnishings	1.60	1.56	1.44	1.40	1.30	1.38
Health	1.82	1.69	1.59	1.50	1.38	1.48
Vehicle fuels & lubricants	1.20	1.13	1.12	1.13	1.17	1.14
Other transport	2.31	1.80	1.61	1.52	1.40	1.52
Communication	0.63	0.54	0.47	0.39	0.06	0.38
Recreation & culture	1.39	1.37	1.31	1.30	1.23	1.28
Education	9.96	5.63	3.97	2.37	1.47	1.90
Restaurants & hotels	1.34	1.27	1.24	1.22	1.22	1.23
Miscellaneous goods & services	1.10	1.10	1.10	1.09	1.09	1.09

Simple ‘abatement actions’ – GHG savings for average household

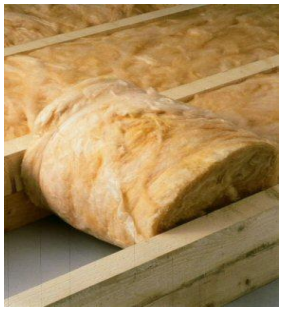
1. **Household heating:** reduce thermostat by 1^{o}C

2. **Food:** reduce food waste by one third

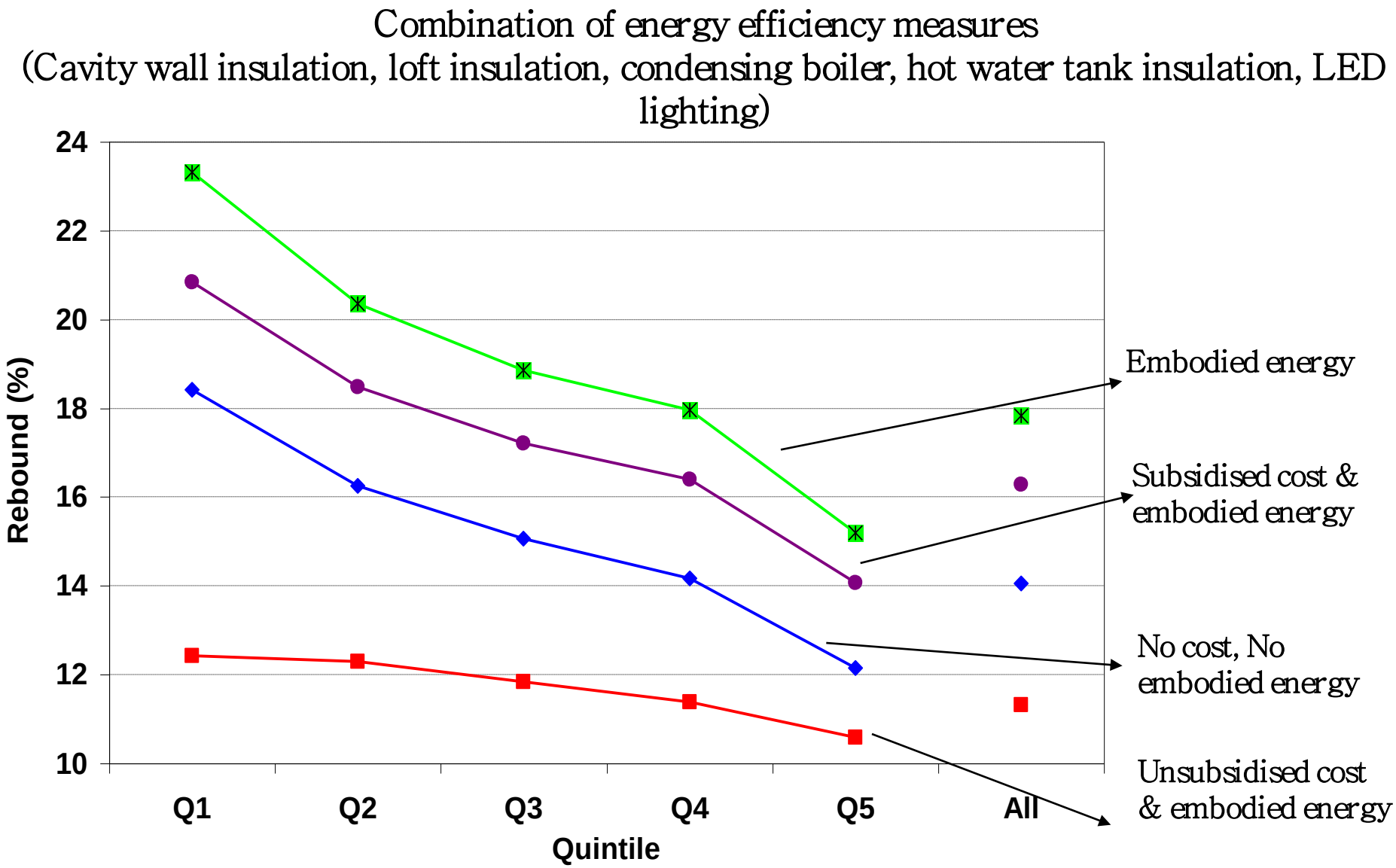
3. **Transport**: replace car journeys <2miles by walking/cycling

Energy efficiency measures – GHG savings for average UK household

1. Cavity wall insulation
2. Loft top-up insulation
3. Condensing boiler
4. Hot water tank insulation
5. CFL lighting
6. LED lighting
7. Solar thermal
8. 1-5 combined
9. 1-4 and 6 combined
10. Fuel efficient car



Estimated rebound effects for UK households averaged over a ten year period (2009-2018)



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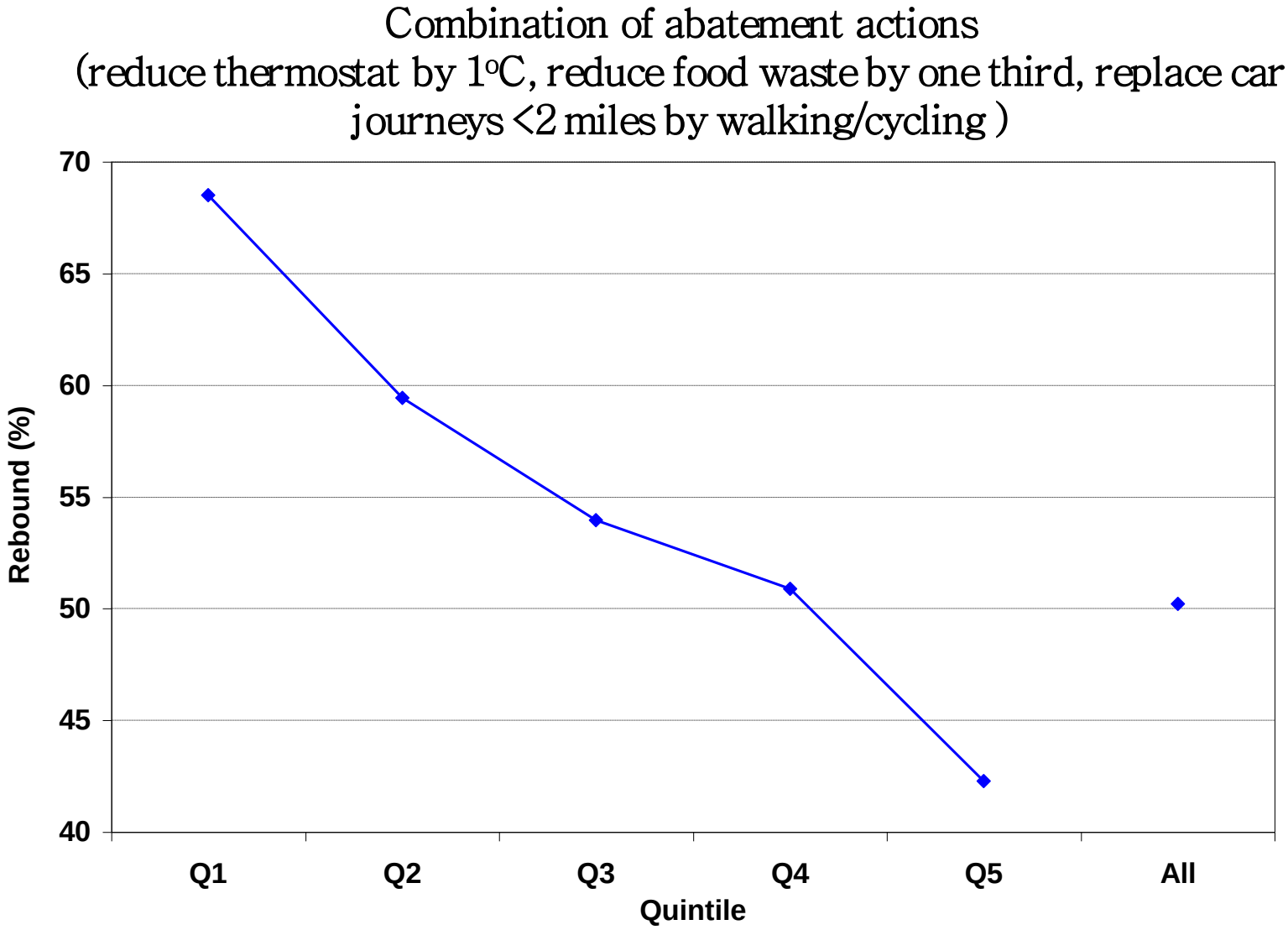

Rebound effect estimation: alternative definition

- The below definition treats the embodied effect as offsetting some of the engineering effect hence contributing to an increase in the rebound effect.

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

- Some policy-makers might be aware of the embodied energy and take account of it when they set the targets. In these cases the alternative definition of the rebound effect is more appropriate:

$$\text{Rebound}^* = -\frac{\Delta G}{(\Delta H - \Delta M)}$$

Discussion

- **Rebound generally higher for:**
  - **Lower income groups;**
  - **Where action in a less GHG intensive category**
- **Fuel poverty considerations**
- **No backfire.**
- **As electricity generation is decarbonised, rebound for electricity measures will increase.**
- **Substitution effects & economy wide effects are not considered.**
- **Assumptions are for UK average household.**

Extreme backfire

Policy suggestions

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

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