SEEDS
Surrey **E**nergy **E**conomics
Discussion paper **S**eries

SURREY
ENERGY
ECONOMICS
CENTRE

What drives the change in UK household energy expenditure and associated CO2 emissions? Implication and forecast to 2020

Mona Chitnis and Lester C Hunt

December 2011

SEEDS 134
ISSN 1749-8384

School of Economics
University of Surrey

The **Surrey Energy Economics Centre (SEEC)** consists of members of the School of Economics who work on energy economics, environmental economics and regulation. The School of Economics has a long-standing tradition of energy economics research from its early origins under the leadership of Professor Colin Robinson. This was consolidated in 1983 when the University established SEEC, with Colin as the Director; to study the economics of energy and energy markets.

SEEC undertakes original energy economics research and since being established it has conducted research across the whole spectrum of energy economics, including the international oil market, North Sea oil & gas, UK & international coal, gas privatisation & regulation, electricity privatisation & regulation, measurement of efficiency in energy industries, energy & development, energy demand modelling & forecasting, and energy & the environment.

SEEC research output includes **SEEDS** - **S**urrey **E**nergy **E**conomic **D**iscussion paper **S**eries (details at www.seec.surrey.ac.uk/Research/SEEDS.htm) as well as a range of other academic papers, books and monographs. SEEC also runs workshops and conferences that bring together academics and practitioners to explore and discuss the important energy issues of the day.

SEEC also attracts a large proportion of the School's PhD students and oversees the MSc in Energy Economics & Policy. Many students have successfully completed their MSc and/or PhD in energy economics and gone on to very interesting and rewarding careers, both in academia and the energy industry.

Enquiries:

***Director of SEEC and Editor of SEEDS*:**
Lester C Hunt
SEEC,
School of Economics,
University of Surrey,
Guildford GU2 7XH,
UK.

Tel:	+44 (0)1483 686956
Fax:	+44 (0)1483 689548
Email:	L.Hunt@surrey.ac.uk

www.seec.surrey.ac.uk

Surrey Energy Economics Centre (SEEC)
School of Economics
University of Surrey

SEEDS 134
ISSN 1749-8384

WHAT DRIVES THE CHANGE IN UK HOUSEHOLD ENERGY EXPENDITURE AND ASSOCIATED CO2 EMISSIONS? IMPLICATION AND FORECAST TO 2020

Mona Chitnis and Lester C Hunt

December 2011

---

* This is a revised version of the paper previously published as RESOLVE Working Paper 08-09, University of Surrey, 2009 (www.surrey.ac.uk/resolve/).

ABSTRACT

Given the amount of direct and indirect CO2 emissions attributable to UK households, policy makers need a good understanding of the structure of household energy expenditure and the impact of both economic and non-economic factors when considering policies to reduce future emissions. To help achieve this, the Structural Time Series Model is used here to estimate UK ‘transport’ and ‘housing’ energy expenditure equations for 1964-2009. This allows for the estimation of a stochastic trend to measure the underlying energy expenditure trend and hence capture the non-trivial impact of ‘non-economic factors’ on household ‘transport’ and ‘housing’ energy expenditure; as well as the impact of the traditional ‘economic factors’ of income and price. The estimated equations are used to show that given current expectations, CO2 attributable to ‘transport’ and ‘housing’ expenditures will not fall by 29% (or 40%) in 2020 compared to 1990, and is therefore not consistent with the latest UK total CO2 reduction target. Hence, the message for policy makers is that in addition to economic incentives such as taxes, which might be needed to help restrain future energy expenditure, other policies that attempt to influence lifestyles and behaviours also need to be considered.

Key Words: Household energy expenditure; CO_2 emissions; Structural Time Series Model

What drives the change in UK household energy expenditure and associated CO_2 emissions? Implication and forecast to 2020.

Mona Chitnis* and Lester C. Hunt**

* **Corresponding author**: Research group on Lifestyles Values and Environment (RESOLVE) and Surrey Energy Economics Centre (SEEC), Centre for Environmental Strategy, University of Surrey, Guildford, Surrey, GU2 7XH, UK. Tel. +44 (0) 1483 682181, Fax. +44 (0) 1483 686671, Email: M.Chitnis@surrey.ac.uk

** Surrey Energy Economics Centre (SEEC) and Research group on Lifestyles Values and Environment (RESOLVE) , Department of Economics, University of Surrey, Guildford, Surrey, GU2 7XH, UK. Tel. +44 (0) 1483 686956, Email: L.Hunt@surrey.ac.uk

1. Introduction

UK Household total real expenditure increased by 46% between 1990 and 2004[1]. Furthermore, according to Druckman and Jackson [1], based on a consumption perspective where both direct and indirect carbon emissions (CO_2) are considered, household CO_2 emissions' were 17% above 1990 levels in 2004, and estimated to have been increasing by about 3% per annum between 1997 and 2004. The 'direct' emissions arise from energy used directly in homes and for personal transportation whereas the 'indirect' emissions arise from 'indirect energy' used in supply chains in the production and distribution of goods and services purchased by UK households. Hence, both total real household expenditure[2] and attributable carbon emissions are generally increasing over time [1]; which is not consistent with the UK CO_2 reduction target (based on a production perspective) [2]. An important aspect of the consumption perspective is that it takes account of all emissions incurred in support

---

[1] www.statistics.gov.uk

[2] Note that emissions are due to use of goods and services and not to expenditure directly. However, there is an indirect link between usage and expenditure. In this paper, when referring to emissions attributable to household (energy) expenditure implicitly refers to emissions arising from (energy) usage.

of household consumption within the UK, whether they occur in the UK or abroad. This contrasts with the production perspective, which accounts for emissions produced within UK territorial boundaries, regardless of where consumption of final goods and services occurs [1]. Moreover, the official UK emissions targets are all based upon the production perspective, however, arguably the Druckman and Jackson [1] consumption perspective figures suggests that there is a need to consider emissions from a consumption perspective to help move towards more sustainable consumption and lower future carbon emissions.

Within household consumption, however, the major contribution to emissions comes from the 'direct' consumption of (secondary) energy use in transportation and housing (as opposed to the estimated 'indirect' energy included in the above).[3] This paper therefore focuses on the energy expenditure of the UK 'transport' sector (that includes vehicle fuels and lubricants) and the 'housing (non-transport)' sector (that includes electricity, gas, solid and liquid fuels use at home), hereafter referred to as just 'housing'. Figures 1, 2 and 3 present direct real energy expenditure, attributable CO_2 and CO_2 intensities[4] for the UK 'transport' and 'housing' sectors respectively.[5]

---

[3] Emissions arising from the consumption of 'direct (secondary) energy' by households are in the form of vehicle fuels, gas, electricity and other fuels. For vehicle fuels, gas and other fuels, the emissions are also 'direct' given that the fuels are 'burnt' directly by the households. Whereas, for electricity consumed by households, the emissions are 'indirect' given that the power produces 'burn' the primary fuels. This study therefore focuses on the emissions (both direct and indirect) resulting from UK household consumption of total (direct) energy, given we are interested in analysing energy and emissions from a 'consumption' perspective. Therefore, the emissions from 'indirect energy' use that arise in supply chains in the production and distribution of goods and services purchased by UK households, are not considered here, but are part of other research being undertaken within RESOLVE.

[4] CO_2 intensity for a category is defined as CO_2 emitted divided by expenditure in each category.

[5] The different periods for Figure 1 and Figure 2 being due to data availability.

Although ‘transport’ real expenditure is more than ‘housing’ real expenditure over the period 1990 to 2009, the CO_2 related to ‘housing’ expenditure is greater than that related to ‘transport’; CO_2 related to ‘transport’ increased by 14.6% compared to its 1990 level whereas for ‘housing’ it decreased by -3.6%. In order to understand future sustainable consumption and CO_2 emissions emanating from energy expenditure, a better and clearer understanding of household energy expenditure structure is required.

There is arguably a need to try to quantify, not only the impact of key economic drivers of income and price on household energy expenditure, but also the impact of exogenous non-economic factors. Previous studies on consumer demand concentrate more on the economic factors, such as Brannlund et al. [3] who use an economic consumer demand model to examine the effect of higher energy efficiency through prices on Swedish energy consumption and emissions. Whereas a separate strand of literature, in its infancy, is starting to focus on non-economic factors. For example, Allcott [4] examines consumer behaviour and electricity consumption in Minnesota, USA and highlights the importance that non-price nudges such as information, attention, and social norms have on consumer behaviour. Another example is Weber and Perrels [5] who attempt to analyse economic and non-economic factors by introducing household lifestyles into their consumer demand model for energy consumption in West Germany, France, and the Netherlands. However, arguably these early attempts do not sufficiently capture the impact of the non-economics variables. Thus although these are worthy early attempts, more is arguably needed in this area. Overall, therefore there has not been an attempt, as far as is known, to bring all these together and try to quantify the *relative* contributions of economic versus non-economic factors to driving consumer energy expenditure. This is therefore one of the aims of this paper. [6]

Figure 1: UK household 'transport' and 'housing' real energy expenditure 1964-2009

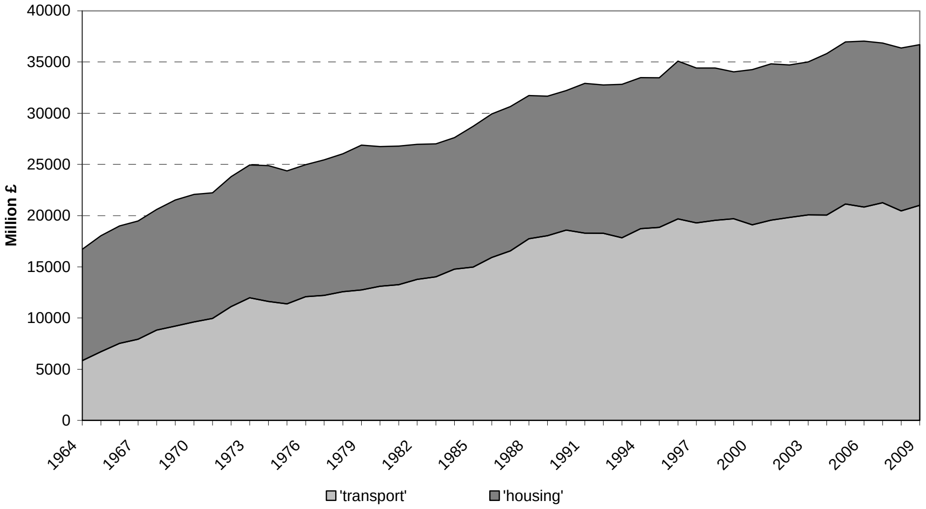
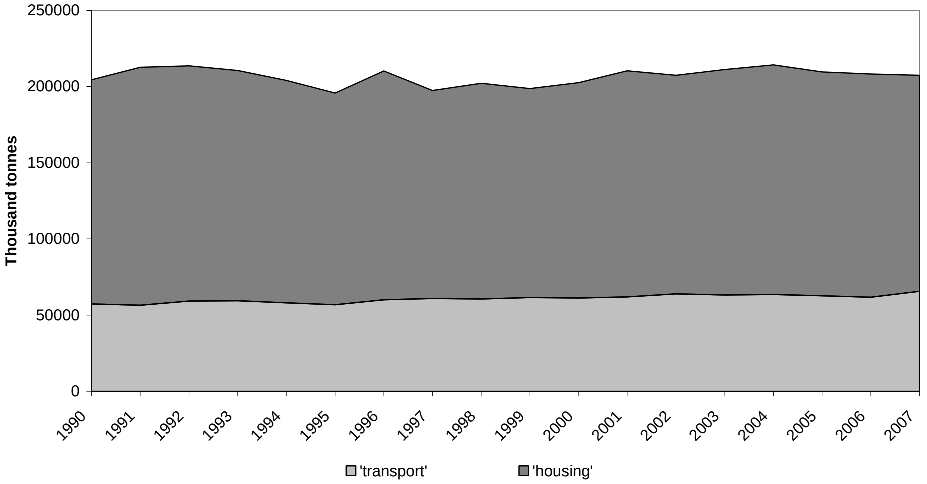


Figure 2: CO2 attributable to 'transport' and 'housing' UK household energy consumption 1990-2007



---

[6] This paper is a part of the Research group on Lifestyles Values and Environment (RESOLVE) project, part of which, requires the investigation and analysis of expenditures for different categories of UK household consumption.

Figure 3: CO_2 intensity attributable to 'transport' and 'housing' UK household energy consumption 1990-2007

A further aim of the paper is to assess whether from a 'consumption perspective' the two UK household sectors of 'transport' and 'housing' are likely to reduce CO_2 emissions in 2020 consistent with the UK 'carbon budget' system (from a 'production' perspective) established by the UK Climate Change Act 2008 [2]. This is a cap on the total quantity of greenhouse gas emissions emitted in the UK (net of European Union Allowances [EUA] purchase) over a specified time. Under a 'carbon budget' system every tonne of greenhouse gas emitted between now and 2050 will count, with an emissions rise in one sector requiring corresponding falls in other sectors. Each 'carbon budget' covers a five-year period. Following the EU framework, the UK Committee on Climate Change has proposed two set of budgets[7]: one to apply once a global deal on emissions reductions has been agreed i.e. 'intended budget'; and the other to apply for the period before there is a global deal i.e. 'interim budget'. The 'intended budget' requires a cut in CO_2 emissions of 40% below 1990 levels in 2020; whereas the 'interim budget' requires a 29% cut relative to 1990 levels (both in terms of the production perspective).[8]

---

[7] The core function of UK Committee on Climate Change is to recommend the required level of the UK's 'carbon budget'.

[8] The UK Secretary of State for Energy and Climate Change made an oral statement to the House in which he announced that Government would accept the Committee's recommendations on the 4th Carbon Budget (2023-2027) in full. See: www.decc.gov.uk/en/content/cms/news/pn11_41/pn11_41.aspx.

2. Model specification and estimation method

2.1. Expenditure

To estimate household energy expenditure functions for UK ‘transport’ and ‘housing’, the Structural Time Series Model (STSM) is applied (see [6]). This allows for the estimation of a stochastic rather than a deterministic underlying energy expenditure trend (UEET)[9], which arguably is important when estimating the elasticities of demand as discussed by Hunt and Ninomiya [7]. The UEET is likely to be strongly affected by changes in technology, tastes, consumer preferences, socio-demographic and geographic factors, lifestyles and values, which are not easily measured and/or therefore difficult to obtain any suitable data.[10] However, here, an attempt is made to separate out the effect of technical progress and energy efficiency from the UEET by incorporating an appropriate proxy variable for efficiency. Consequently, the estimated UEET should only pick up the effects of the other factors referred to by the simple economic model above; hence, it captures the effects of exogenous changes in such factors. For this reason, the stochastic trend is included in the following long-run energy expenditure model.

$$\exp_t = \mu_t + \alpha p_t + \gamma y_t + \tau f_t + \theta temp_t + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \qquad \mathbf{(1)}^{11}$$

where $\exp_t$ is the households real expenditure for each category of energy expenditure, μ_t represents the UEET, p_t is the relative price of each category of

---

[9] This has been termed the Underlying Energy Demand Trend or UEDT in previous work, for example see [7]. The UEET arguably captures the systematic non-price and non-income effects.

[10] This method is also used to model CO_2 intensities of related household expenditure.

[11] NID means that ε_t is normally and independently distributed with a mean of zero and a constant variance of σ^2_ε.

energy, y_t is real disposable income, f_t is the proxy for efficiency of each category (energy intensity) and $temp_t$[12] is the average annual temperature. α, γ, τ and θ are unknown parameters and ε_t is a random white noise disturbance term. All variables except temperature are in natural logarithms.

The trend component μ_t is assumed to have the following stochastic process:

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \qquad \eta_t \sim NID(0, \sigma_\eta^2) \qquad \textbf{(2)}$$

$$\beta_t = \beta_{t-1} + \xi_t \qquad \xi_t \sim NID(0, \sigma_\xi^2) \qquad \textbf{(3)}$$

The trend includes a level (equation 2) and a slope that is β (equation 3); η_t and ξ_t are random white noise disturbance terms. The nature of the trend depends on the variances σ_η^2 and σ_ξ^2, known as hyperparameters. In practice, to evaluate the estimated models, the equation residuals (similar to ordinary regression residuals) and a set of auxiliary residuals are estimated. The auxiliary residuals include smoothed estimates of the equation (1), (2) and (3) disturbances (known as the irregular, level and slope residuals respectively).[13]

---

[12] Temperature was included in the general model for housing expenditure. For completeness, temperature was also included in the general model for transport, but this proved not to be significant and hence excluded from the preferred model.

[13] At the extreme, if $\sigma_\eta^2 = \sigma_\xi^2 = 0$, the model will collapse to the model with a conventional deterministic linear trend: $\exp_t = a + bt + \alpha p_t + \gamma y_t + \tau f_t + \theta temp_t + \varepsilon_t$

The Maximum Likelihood (ML) procedure in conjunction with the Kalman filter[14] is used to estimate the following Autoregressive Distributed Lag (ARDL)[15] form of equation (1), starting with lags of four years of expenditure, price, income and energy intensity variables, using the software STAMP 6.3 [8]:

$$A(L)\exp_t = \mu_t + B(L)p_t + C(L)y_t + D(L)f_t + \theta temp_t + \varepsilon_t \qquad \textbf{(4)}$$

where *A(L)*, *B(L)*, *C(L)* and *D(L)* are polynomial lag operators equal to $1-\varphi_1 L - \ldots - \varphi_4 L^4$, $1+\pi_1 L + \ldots + \pi_4 L^4$, $1+\theta_1 L + \ldots + \theta_4 L^4$ and $1+\vartheta_1 L + \ldots + \vartheta_4 L^4$ respectively. *B(L)/A(L)*, *C(L)/A(L)* and *D(L)/A(L)* represent the long-run price, income and energy intensity elasticities respectively.[16] Other variables and parameters are as defined above. This general function is considered initially and the preferred model found by testing down and eliminating insignificant variables from the over parameterised ARDL model subject to a battery of diagnostic tests.[17]

2.2. Contributions of independent variables to changes in expenditure

The following equation represents the estimated version of equation 4:

$$\mathrm{e\hat{x}p}_t = \hat{\mu}_t + \hat{B}(L)p_t + \hat{C}(L)y_t + \hat{A}'(L)\exp_t + \hat{D}(L)f_t + \hat{\theta} temp_t \qquad \textbf{(5)}^{18}$$

---

[14] See [6] for more details.

[15] The advantage of ARDL model is that the long-run and short-run elasticities are estimated simultaneously.

[16] $\theta / A(L)$ represents the long-run temperature coefficient.

[17] For further details, refer to [7].

[18] ^ refers to estimated coefficients and components.

where $\hat{A}'(L)=\hat{\varphi}_1 L+\ldots+\hat{\varphi}_4 L^4$. To estimate the contribution of trend, price, income, energy intensity and temperature to expenditure, $\hat{A}'(L)\exp_t$, is continually substituted by lagged version of equation 5 until $\hat{A}'(L)$ is sufficiently close to zero, hence ignorable, i.e.:

$$\mathrm{e\hat{x}p}_t = F'(L)\hat{\mu}_t + \hat{B}'(L)p_t + \hat{C}'(L)y_t + \hat{D}'(L)f_t + \hat{E}'(L)temp_t \qquad \textbf{(6)}$$

where $F'(L)=1+\omega_1' L+\ldots+\omega_n' L^n$, $\hat{B}'(L)=1+\pi_1' L+\ldots+\pi_n' L^n$, $\hat{C}'(L)=1+\theta_1' L+\ldots+\theta_n' L^n$, $\hat{D}'(L)=1+\vartheta_1' L+\ldots+\vartheta_n' L^n$ and $\hat{E}'(L)=1+\rho_1' L+\ldots+\rho_n' L^n$. Then, taking annual differences of equation 6 gives the following:

$$\Delta\,\mathrm{e\hat{x}p}_t = F'(L)\Delta\hat{\mu}_t + \hat{B}'(L)\Delta p_t + \hat{C}'(L)\Delta y_t + \hat{D}'\Delta f_t + \hat{E}'(L)\Delta temp_t \qquad \textbf{(7)}$$

As mentioned in the introduction, an attempt is made to quantify the contributions of the economic drivers (income and price), energy intensity and exogenous non-economic factors (hereafter ExNEF for short) for household energy expenditure.[19] Indeed, what is called ExNEF here will incorporate all the issues related to the annual change in the UEET explained in Section 2.1. Therefore, $F'(L)\Delta\hat{\mu}_t$, $\hat{B}'(L)\Delta p_t$, $\hat{C}'(L)\Delta y_t$, $\hat{D}'(L)\Delta f_t$ and $\hat{E}'(L)\Delta temp_t$ are the estimated contributions of ExNEF, price, income, energy intensity and temperature respectively to changes in fitted expenditure $\Delta\,e\hat{x}p_t$.

---

[19] This work is part of on-going research attempting to quantify the impact of ExNEF on consumer expenditure and demand; see, for example [9], [10] and [11].

2.3. CO_2 intensity

Similar to Hunt and Ninomiya [12] using the STSM, CO_2 intensity is modelled as follows:

$$co2i_t = \delta_t + \psi_t \qquad \psi_t \sim NID(0, \sigma_\psi^2) \tag{8}$$

where $co2i_t$ is the CO_2 intensity for each category of energy defined as CO_2 emissions associated with each category divided by real expenditure in the same category, δ_t represents the trend component[20] and ψ_t is a random white noise disturbance term. All variables are in natural logarithms.

Again, the ML procedure in conjunction with the Kalman filter is used to estimate the following ARDL form of equation (8), starting with lags of two years of the CO_2 intensity variable:

$$G(L)co2i_t = \delta_t + \psi_t \tag{9}$$

where *G(L)* is polynomial lag operators equal to $1 - \delta_1 L - \delta_2 L^2$. The preferred model is found by testing down from the over parameterised ARDL model subject to a battery of diagnostic tests. [21]

---

[20] Assumption about trend are similar to what is explained in section 2.1.

[21] The similar methodology (STSM) is applied to predict future 'transport' and 'housing' energy intensity. Furthermore, given that the temperature is generally rising in recent years, the similar methodology is also applied to predict future temperature.

3. Data

The energy expenditure relationships, as outlined in Section 2.1 above, are estimated for the UK households using annual time series data over the period 1964 to 2009. Data for real expenditure (Figure 1), real disposable income (Figure 4) and prices (implied deflators data used to convert nominal expenditure to real expenditure for each category), are collected from the UK Office for National Statistics (ONS) online database.[22] All data are in constant terms (reference year 2003). Prices for each category are deflated by the total implied deflator to produce real prices for the same category (Figure 5). The energy intensity measures for 'transport' and 'housing' are 'road passenger energy consumption per million passenger-kilometres' and 'domestic energy consumption per household' respectively and the relevant data is collected from [13] and [14][23] (Figure 6).[24] Annual average temperature data in Degrees Celsius is obtained from [16] (Figure 7).

---

[22] www.statistics.gov.uk

[23] Energy intensity data before 1970 is obtained from DECC.

[24] According to DECC (2010) "Energy consumption per unit of output, known as energy intensity, gives a broad indication of how efficiently energy is being used over time" [15, p.36]; hence, the intensity variables used here as proxies for efficiency. However, although intensity will reflect changes in efficiency over time, it might also be influenced by some non-economic factors (such as a preference for larger cars, including SUVs, or the decline in the number of individuals in a household). Nevertheless, as DECC (2010) states, intensity it is a 'broad' indicator of efficiency so that over a long period, such as used in the estimation, the intensity trend is likely to be dominated by efficiency changes. Therefore, intensity is arguably a suitable proxy in the estimation in order to separate the contribution from efficiency and ExNef in driving real energy expenditure demand.

CO_2 annual data (Figure 2) attributable to household direct energy for 'transport' and 'housing' excluding electricity, available from 1990 to 2007, are obtained from the Environmental Accounts from the UK ONS online database. To estimate CO_2 emissions related to 'electricity', the ratio of household electricity consumption to total electricity consumption from [16] is multiplied by CO_2 emission associated with electricity production and distribution from the ONS.

Figure 4: Real household disposable income 1964-2009

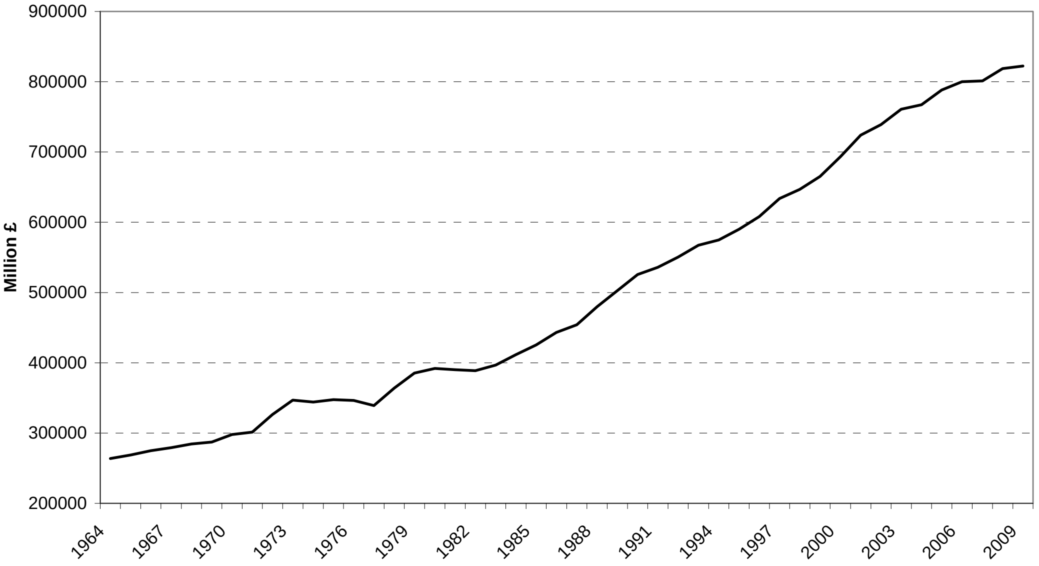
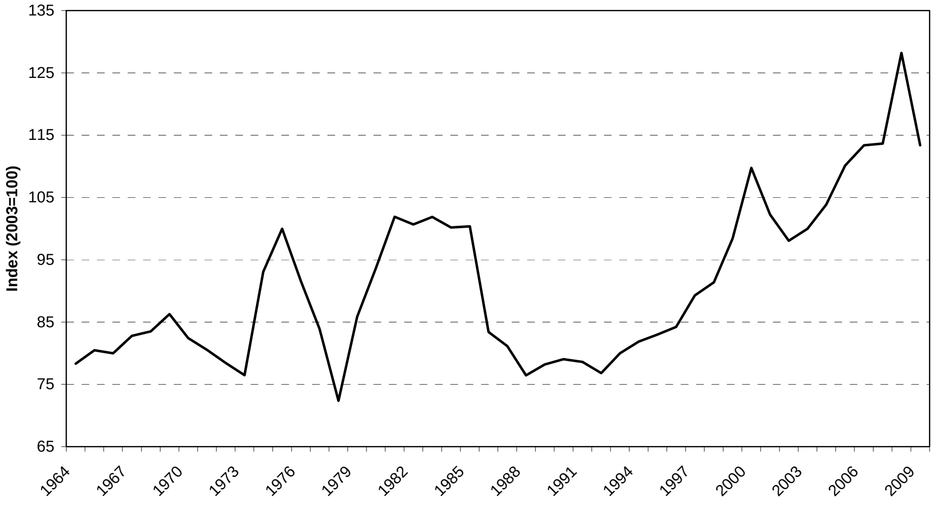


Figure 5: ‘Transport’ and ‘housing’ real prices 1964-2009

a: 'transport'



b: 'housing'

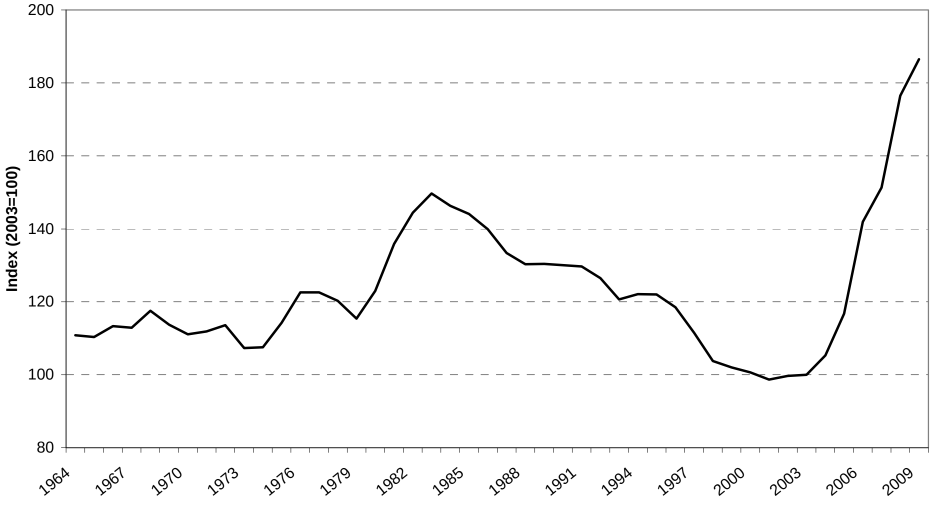


Figure 6: ‘Transport’ and ‘housing’ energy intensity 1964-2009

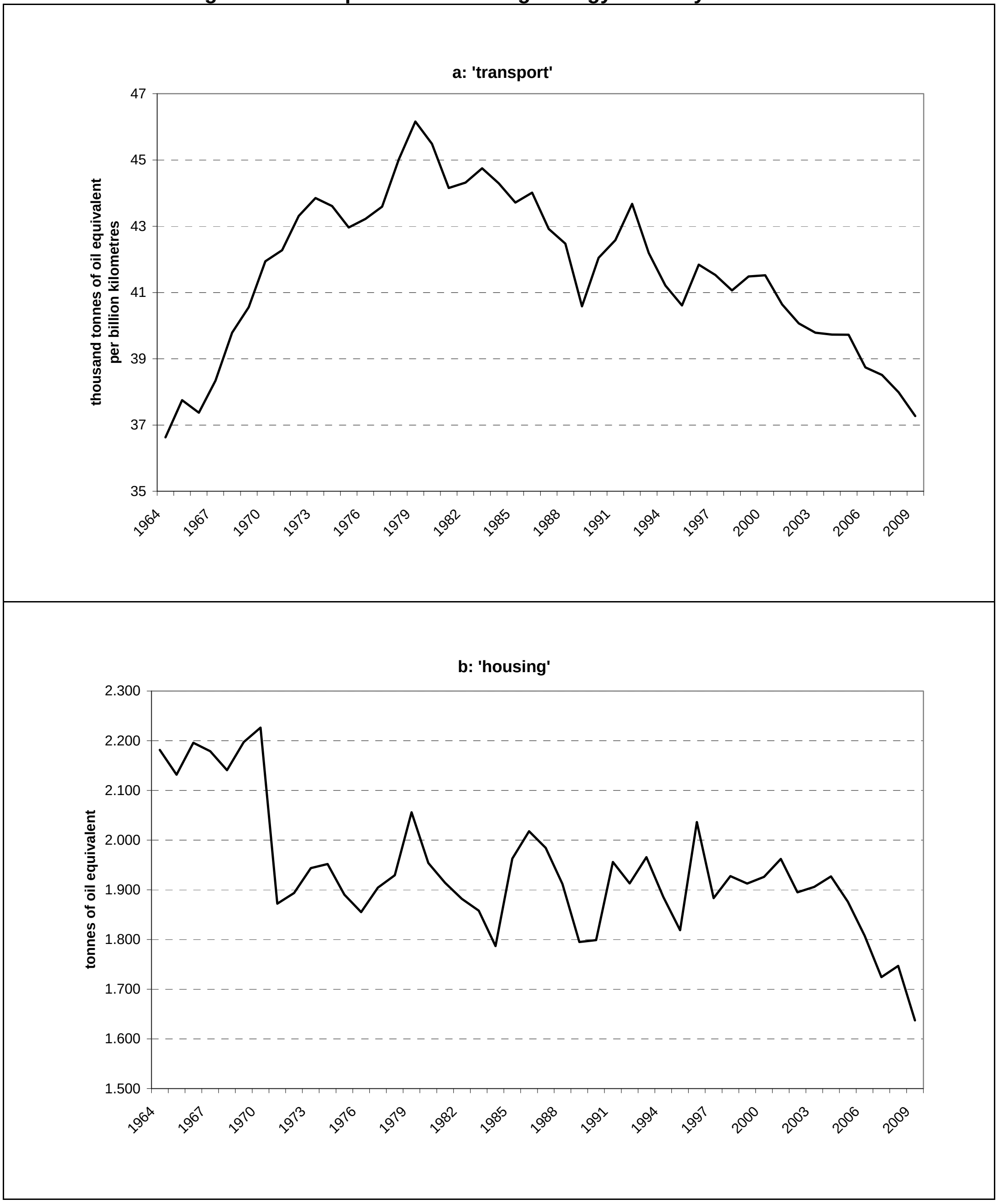
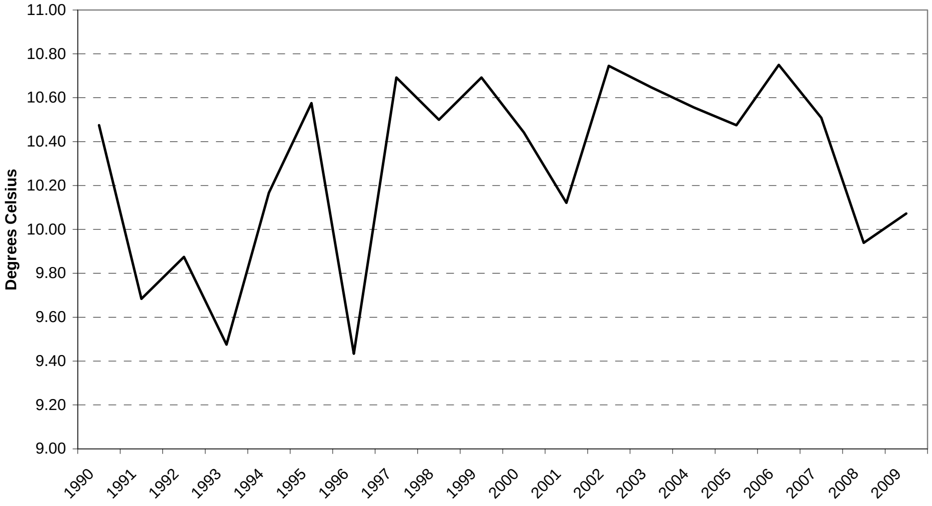


Figure 7: Annual average temperature 1990-2009



4. Results

Tables 1 and 2 show the estimation results for household ‘energy expenditure’ and ‘CO_2 intensity’ for ‘transport’ and ‘housing’ categories respectively. The models fit the data well passing all diagnostic tests indicating that there are no problems with residual serial correlation, non-normality or heteroscedasticity. Furthermore, the auxiliary residuals are found to be normal and the model is generally stable as indicated by the post sample predictive failure tests.[25]

---

[25] The reason for high predictive failure test for ‘housing’ is the irregular that exists for level in 2006.

Table 1: Estimated STSM real energy expenditure functions for UK households 1964-2004

Dependent variable: exp		
Category **Independent Variables**	**Transport**	**Housing**
y	0.65	-
	(3.79)	
$Dy(-1)$	-	0.15
		(1.71)
p	-0.11	-
	(-2.03)	
$p(-1)$	-	-0.19
		(-2.58)
$exp(-4)$	0.37	0.31
	(4.07)	(3.28)
f	-	0.20
		(2.80)
$f(-1)$	-0.35	-
	(-2.02)	
temp	-	-0.04
		(-5.31)
Estimated Variance of Hyperparameters		
Irr (10^{-5})	0	0
Lvl(10^{-5})	42.81	20.49
Slp(10^{-5})	-	-
DIAGNOSTICS		
Equation Residuals		
Std. Error	0.02	0.01
Normality	2.82	2.58
H(n)	H(11)=0.52	H(11)=3.82
$r_{(1)}$	0.27	0.09
$r_{(2)}$	0.09	0.17
$r_{(3)}$	-0.05	0.15
$r_{(4)}$	-0.17	-0.03
DW	1.38	1.55
$Q_{(n1,n2)}$	$Q_{(7,6)}$= 5.94	$Q_{(7,6)}$=7.11
Rs^2	0.63	0.82
Auxiliary Residuals		
Irregular		
Skewness	0.50	0.08
Kurtosis	0.00	1.21
Normal-BS	0.50	1.29
Normal-DH	1.07	4.77
Level		
Skewness	0.16	1.59
Kurtosis	1.55	0.34
Normal-BS	1.71	1.93
Normal-DH	2.08	2.59
Slope		
Skewness	-	-
Kurtosis	-	-
Normal-BS	-	-
Normal-DH	-	-
Predictive Failure Tests		
$\chi^2_{4)}$	7.43	17.15
Cusum $t_{(4)}$	-0.29	0.82
Likelihood Ratio Test		
LR (a)	45.79	36.97

Table 1 Notes:

Irr represent intervention dummies.
t-statistics are given in parenthesis.
The restrictions imposed for the LR test are: a) fixed level and b) fixed slope.
Normality is the Bowman-Shenton and Doornik-Hansen statistics approximately distributed as $\chi^2_{(2)}$.

Skewness and Kurtosis statistics are approximately distributed as $\chi^2_{(1)}$.

$H_{(n)}$ is the test for heteroscedasticity, approximately distributed as $F_{(n)}$.

$r_{(n)}$ is the serial correlation coefficients at the n^{th} lag, approximately distributed at N(0,1/T).
DW is the Durbin Watson statistic.
$Q_{(n1,n2)}$ is the Box-Ljung Q-statistic based on the first n2 residuals autocorrelation; distributed as $\chi^2_{(n2)}$.
Rs^2 is the coefficient of determination.
$\chi^2_{(n)}$ is the post-sample predictive failure test. The Cusum t is the test of parameter consistency, approximately distributed as the t-distribution.
5% probability level is considered for significance for each test.
Interventions for level in 2000 and outlier for 1997 are added to 'transport' and 'housing' equations respectively.
When the equation is estimated over the whole sample period (including irregular for level in 2006) *Dy(1)* is significant at 5% probability level.

Table 2: Estimated STSM CO_2 intensity functions for UK households 1990-2004

Dependent variable: ci		
Independent Variables \ Category	**Transport**	**Housing**
ci (-1)	-	-0.56
		(-2.10)
ci (-2)	-0.50	-
	(-2.10)	
Estimated Variance of Hyperparameters		
Irr (10^{-5})	13.04	30.58
Lvl(10^{-5})	44.65	-
Slp(10^{-5})	-	21.65
DIAGNOSTICS		
Equation Residuals		
Std. Error	0.02	0.03
Normality	1.29	1.57
H(n)	H(3)=0.54	H(4)=0.48
$r_{(1)}$	-0.02	-0.05
$r_{(7)}$	0.06	0.12
D.W.	1.58	1.79
$Q_{(7,6)}$	5.89	6.31
Rs^2	0.38	0.33
Auxiliary Residuals		
Irregular		
Skewness	0.88	0.02
Kurtosis	0.13	0.89
Normal-BS	1.01	0.91
Normal-DH	1.54	0.98
Level		
Skewness	0.90	-
Kurtosis	0.28	-
Normal-BS	1.18	-
Normal-DH	2.20	-
Slope		
Skewness	-	0.08
Kurtosis	-	0.27
Normal-BS	-	0.34
Normal-DH	-	0.18
Predictive Failure Tests		
$\chi^2_{(2)}$	7.74	8.02
Cusum $t_{(2)}$	-1.23	-0.34
Likelihood Ratio Tests		
Test (a)	-	7.44
Test (b)	4.95	-

Notes: see notes to Table 1.

4.1. Real expenditure and contributions of independent variables

For ‘transport’ the estimated short run and long run price elasticities are -0.11 and -0.17 respectively and the estimated short run and long run income elasticities are 0.65 and 1.03 respectively. The short run and long run elasticity for energy intensity are 0 and -0.56 respectively. For ‘housing’, the estimated elasticities with respect to price in the short run and long run are 0 and -0.28, with respect to income are both 0 and with respect to energy intensity are 0.20 and 0.29[26] respectively.[27]

The Likelihood Ratio (LR) test for both ‘transport’ and ‘housing’ equations implies that imposing the restriction of a deterministic trend (where both the level and the slope in the trend are fixed i.e. $\sigma_\eta^2 = \sigma_\xi^2$ =0) is rejected. Consequently, the estimated UEET is the local level with drift specification (where the trend is stochastic in the level but fixed in the slope i.e. $\sigma_\eta^2 \neq 0$ and $\sigma_\xi^2 = 0$) and is clearly non-linear, as shown in Figure 8[28].

Figure 9 shows the contributions of the different components, i.e. price, income, energy intensity, ExNEF and temperature to annual changes in fitted energy expenditure for ‘transport’ and ‘housing’ categories respectively. The contributions

---

[26] The positive effect of energy intensity on ‘housing’ expenditure might reflect the existence of the rebound effect.

[27] Temperature is statistically significant for ‘housing’ energy expenditure only. The estimated short run and long run temperature coefficients for ‘housing’ are -0.04 and -0.06 respectively.

[28] Note that the trend is estimated through the STSM for each year.

are also summarised for both categories in Table 3.[29] For both ‘transport’ and ‘housing’, in addition to price, income and energy intensity (and temperature for ‘housing’), ExNEF considerably affects changes in expenditure in some years. This clearly demonstrates the stochastic nature of the estimated UEET and implies that the impact of ExNEF on ‘transport’ and ‘housing’ expenditure should not be ignored.[30]

Table 3: Summary of the contribution to the average percentage per annum change in ‘transport’ and ‘housing’ real expenditure (in logs)-1989 to 2009

Category	Contribution from:(%)					Change in fitted expenditure
	Income	Price	Energy intensity	ExNEF	Temperature	
Housing	-0.04	0.38	-0.103	1.112	-0.18	1.18
Transport	2.92	-0.23	0.30	-2.25	-	0.75

Table 4: Summary of the contribution to the average percentage per annum change in forecast ‘transport’ and ‘housing’ real expenditure (in logs)-2009 to 2020 (reference scenario)

Category	Contribution from:(%)					Change in fitted expenditure
	Income	Price	Energy intensity	ExNEF	Temperature	
Housing	0.001	-0.47	-0.099	1.108	-0.03	0.51
Transport	1.43	-0.37	0.45	-1.28	-	0.23

---

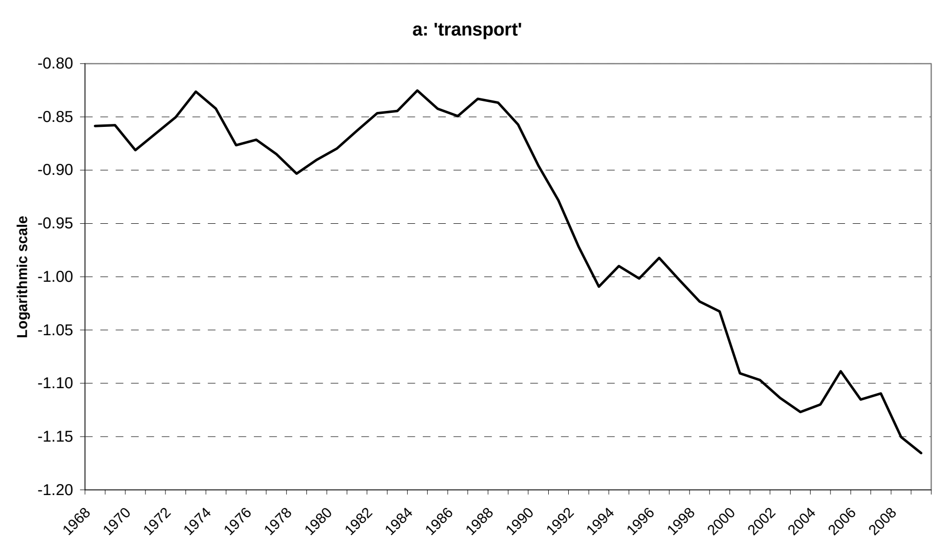
[29] Following from Equation (7), the annual changes per annum contributions are approximated as follows:

$$[\sum_{1}^{n} F'(L)(\hat{\mu}_t - \hat{\mu}_{t-1})]/n \text{ ’ } [\sum_{1}^{n} \hat{B}'(L)(p_t - p_{t-1})]/n \text{ ’ } [\sum_{1}^{n} \hat{C}'(L)(y_t - y_{t-1})]/n \text{ ’ } [\sum_{1}^{n} \hat{D}'(L)(f_t - f_{t-1})]/n \text{ ’ } [\sum_{1}^{n} \hat{E}'(L)(temp_t - temp_{t-1})]/n$$

for the contributions of ExNEF, price, household disposable income, energy intensity and temperature respectively. The total change in fitted expenditure is therefore approximated by adding up the above. *n* is the span of years that the change is calculated.

[30] Table 4 shows how the contributions of different factors would affect the changes in expenditure for each category in the future.

Figure 8: Estimated trend for 'transport' and 'housing' real energy expenditure 1968-2009



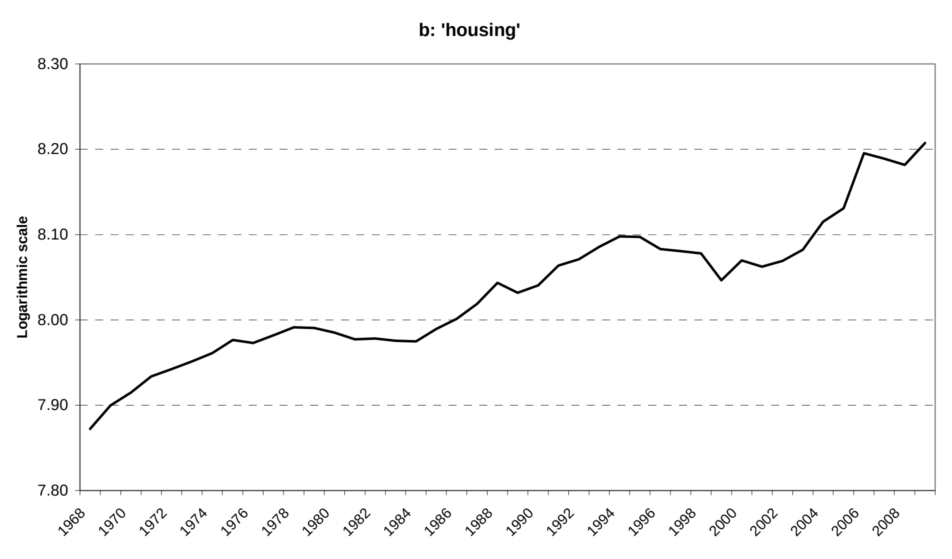
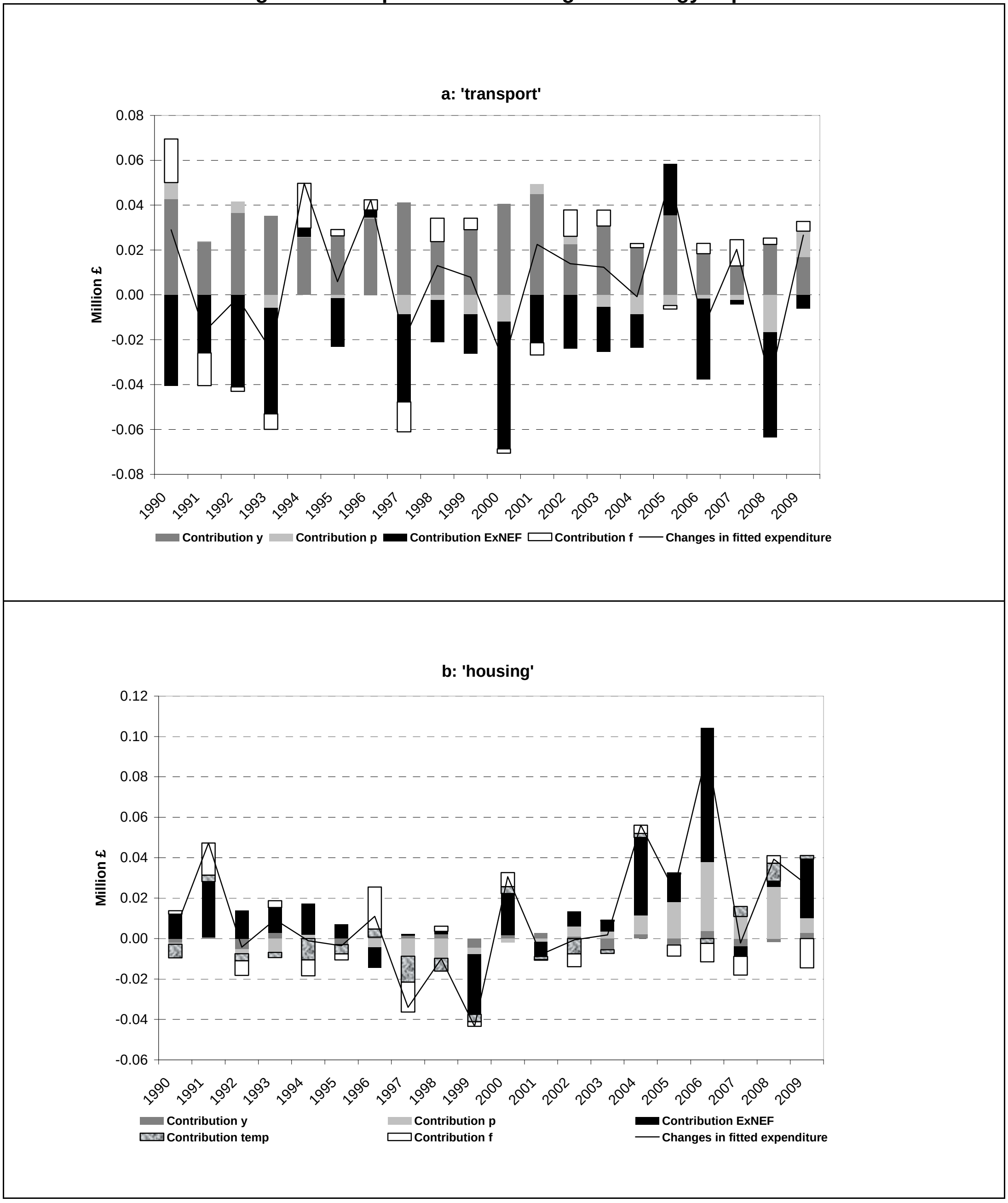


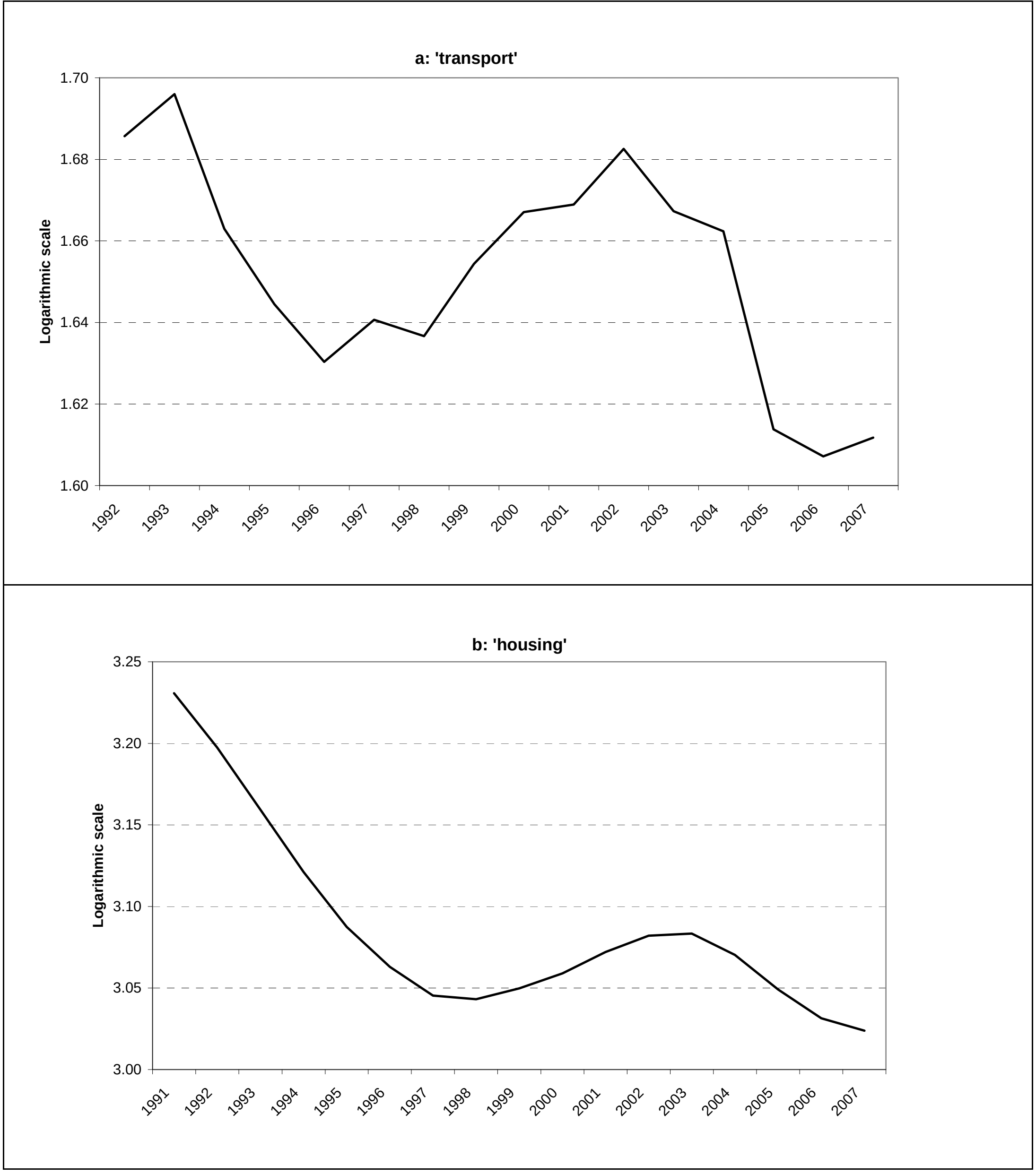
Figure 9: Contribution of income, price, energy intensity, temperature and ExNEF to changes in ‘transport’ and ‘housing’ real energy expenditure



4.2. CO$_2$ intensity

The LR tests for both equations imply that imposing the restriction of a deterministic trend is rejected. Consequently, the estimated trend is the local level with drift specification for ‘transport’ and smooth trend (where the trend is fixed in the level but stochastic in the slope i.e. $\sigma_{\eta}^{2} = 0$ and $\sigma_{\xi}^{2} \neq 0$) for ‘housing’. Hence, trends for both categories are clearly non-linear, as shown in Figure 10.

Figure 10: Estimated trend for ‘transport’ and 'housing' CO_2 intensity 1990-2007



5. Forecasting and scenarios

Future expenditure and CO_2 intensity for each category are projected using equations (4) and (9) and from these, future CO_2 emissions for each category are predicted. Three forecast scenarios are produced: a ‘low’ case, a ‘reference’ case and a ‘high’ case. For the ‘low’ and ‘high’ cases a combination of assumptions for the growth in real disposable income, real prices, energy intensity, temperature, and the UEET[31] are chosen that produce sensible lower and upper bound projections. For the ‘reference’ case the ‘most probable’ outcome for these variables are assumed (similar to ‘business as usual’ scenarios). The details are explained in more detail in this section.

5.1. Real expenditure

To guide the assumptions for the ‘reference’ scenario, average independent growth rate forecasts from 2010 to 2012 are used for real disposable income, taken from HMT [17][18]. The average independent growth rate forecasts for GDP from 2013 to 2015 are taken from HMT [19] and converted to real disposable income growth.[32] Thereafter, assuming economic conditions will return to ‘normal’ after 2015 the assumption is based upon the long run growth rate for real disposable income. For

---

[31] Therefore, implicitly giving the assumptions for ExNEF given this is equal to the annual change in the UEET (i.e. $\Delta\hat{\mu}_t$).

[32] To do this, the relationship between real household disposable income growth and GDP growth is estimated; using the UK annual time series data from 1948 to 2009:

$$\Delta y = 0.01 + 0.50\,\Delta gdp$$

(4.01) (4.27)

where y and gdp are logarithm of real household disposable income and real GDP respectively. The corresponding t-statistics are in parenthesis.

the 'low' and 'high' scenarios the assumed growth rates are 0.5% per annum lower and 0.5% per annum higher than the reference growth assumption.

For real prices, the assumptions for the 'reference', 'low' and 'high' cases are based upon Department of Energy and Climate Change (DECC) predictions[33] for 2010 to 2020.[34] For the future projection of the UEET, the slope at the end of the estimation period[35] (over the whole sample) is assumed to continue into the future for the 'reference' scenario with appropriate variation around this for the 'low' and 'high' scenarios.

For temperature, a STSM with a stochastic trend only was estimated in order to facilitate the projection of future temperature values[36] This is used for the 'reference' scenario; with the 'high' and 'low' assumptions built around this. For

---

[33] www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx, Annex F: Fossil fuel and retail price assumptions.

[34] To produce 'housing' energy price, residential 'electricity', 'gas' and 'petroleum' DECC price forecasts are used with DECC domestic 'electricity', 'gas' and 'petroleum' demand forecasts as weights. DECC forecasts for domestic demand are obtained from www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx, Annex C: Final energy demand As solid fuels have small share in 'housing' energy expenditure and the its price forecast is not available from DECC, this is ignored in the calculation.

[35] This is the estimated slope for year 2009. See equation 2.

[36] The estimated STSM for temperature for 1964-2004 is as follow:

$$temp_t = \tau_t$$

where $temp_t$ *is* temperature and τ_t is the stochastic trend with a similar format to equations 2 and 3.

Std. Error= 0.45; Normality= 0.08; H(13)= 2.09; $r_{(1)}$= 0.07; $r_{(7)}$= 0.17; D.W.= 1.80; $Q_{(7,6)}$= 9.17;

Rs^2= 0.17; $\text{Normality}_{(\text{Irr})}$= 1.19; $\text{Normality}_{(\text{Lvl})}$= 3.03; Failure= 2.81; LR= 16.78.

The nature of trend is local level with drift. The above equation is re-estimated over the whole period 1964-2009 and used for the prediction purpose.

‘transport’ and ‘housing’ energy intensity, a STSM with a stochastic trend and lags of energy intensity as explanatory variables was estimated in order to facilitate the projection of future energy intensity values.[37] This is used for the ‘reference’ scenario with the ‘high’ (higher energy intensity) and ‘low’ (lower energy intensity) assumptions built around this.[38] The assumptions for real household disposable income, prices, trend, temperature and efficiencies in each scenario are summarised in Tables 5, 6, 7, 8 and 9 respectively.

Future projections for ‘transport’ and ‘housing’ expenditure are therefore generated through the estimated energy expenditure equations.[39] Applying the assumptions in

---

[37] The estimated STSM ‘transport’ and ‘housing’ energy intensity for 1964-2004 are as follows respectively:

$$f_{transport\ t} = 0.88 - 0.001\,t + 0.73\,f_{transport\ t}(-1) - 0.35\,f_{transport\ t}(-3) + 0.38\,f_{transport\ t}(-4)$$

(3.59) (-4.27) (6.52) (-2.23) (2.89)

Std. Error= 0.01; Normality= 0.02; H(11)= 0.69; $r_{(1)}$= 0.09; $r_{(6)}$= 0.02; D.W.= 1.74; $Q_{(6,6)}$= 3.56;

Rs^2= 0.45; $Normality_{(Irr)}$= 1.59; Failure= 3.31.

and

$$F_{housing\ t} = 0.15 - 0.001\,t + 0.72\,f_{housing\ t}(-1)$$

(2.13) (-2.79) (6.39)

Std. Error= 0.03; Normality= 5.24; H(12)= 1.69; $r_{(1)}$= 0.07; $r_{(6)}$= 0.19; D.W.= 1.78; $Q_{(6,6)}$= 7.36;

Rs^2= 0.55; $Normality_{(Irr)}$= 0.61; Failure= 5.03.

Irregular interventions for 1971 and 1996 are also included in the equation.

t is the time trend. The nature of trend in both equations is deterministic. t statistic is in parenthesis. The above equations are re-estimated over the whole period 1964-2009 and used for the prediction purpose.

[38] Low and high assumptions are achieved by appropriate variations in the trend component from the ‘transport’ and ‘housing’ equations.

[39] The preferred specifications for the two expenditure equations in Table 1 are re-estimated over the whole period 1964-2009 and used for this purpose.

Tables 5 to 9 to the explanatory variables in the estimated household expenditure equations in Table 1, gives the forecasts for 'transport' and 'housing' energy expenditure, which are shown in Figure 11 according to the three scenarios discussed above.

Table 5: Real household disposable income growth rate assumptions (% p.a.)

	2010	2011	2012	2013	2014-2015	2016-2020
Low	-0.85	-1.15	0.75	1.35	1.41	2.45
Reference	-0.80	-1.10	0.80	1.40	1.46	2.50
High	-0.75	-1.05	0.85	1.45	1.51	2.55

Table 6: Real 'transport', and 'housing' energy prices growth rate assumptions (%p.a.)

	2010	2011	2012	2013	2014
Housing					
Low	-22.27	0.94	2.04	0.13	2.47
Reference	-6.45	2.12	1.53	0.06	1.82
High	2.05	2.91	2.69	1.29	2.75
Transport					
Low	0.41	2.40	3.66	2.39	1.89
Reference	10.61	2.64	2.86	1.75	1.31
High	17.57	3.63	3.77	2.68	2.23

Table 6: (continued)

	2015	2016	2017	2018	2019	2020
Housing						
Low	-0.15	-1.15	-1.92	-2.36	-3.09	-2.04
Reference	-0.33	-1.28	-1.63	-2.22	-2.88	-2.07
High	0.63	-0.39	-0.70	-1.85	-2.48	-1.61
Transport						
Low	1.11	0.88	-0.03	-0.03	-0.03	-0.03
Reference	0.60	0.39	0.39	0.39	0.39	0.39
High	1.56	1.35	1.33	1.31	1.30	1.28

Table 7: Average annual UEET growth assumptions for ‘transport’ and ‘housing’ 2010-2020 (% p.a.)

	Low	Reference	High
Housing	0.26	0.68	1.10
Transport	-1.25	-0.62	-0.02

Table 8: Temperature average annual growth assumptions 2010-2020 (% p.a.)

	Low	Reference	High
Temperature	0.10	0.15	0.20

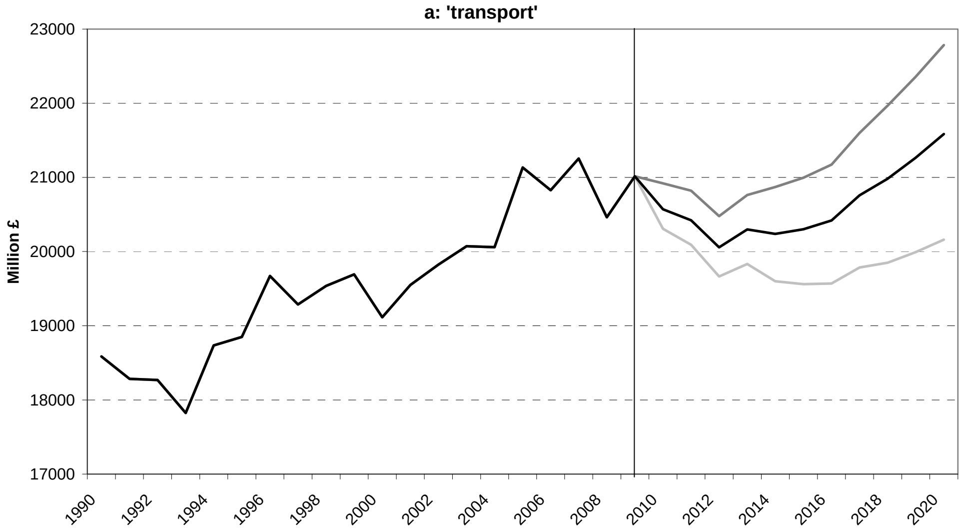
Table 9: Annual energy intensity growth assumptions for ‘transport’ and ‘housing’ (% p.a.)

	2010	**2011**	**2012**	**2013**	**2014**
Housing					
Low	0.75	0.35	0.07	-0.13	-0.28
Reference	0.90	0.51	0.22	0.02	-0.13
High	1.05	0.66	0.38	0.17	0.03
Transport					
Low	-1.43	-1.26	-1.25	-1.94	-1.92
Reference	-0.35	-0.18	-0.18	-0.89	-0.88
High	0.74	0.91	0.91	0.19	0.20

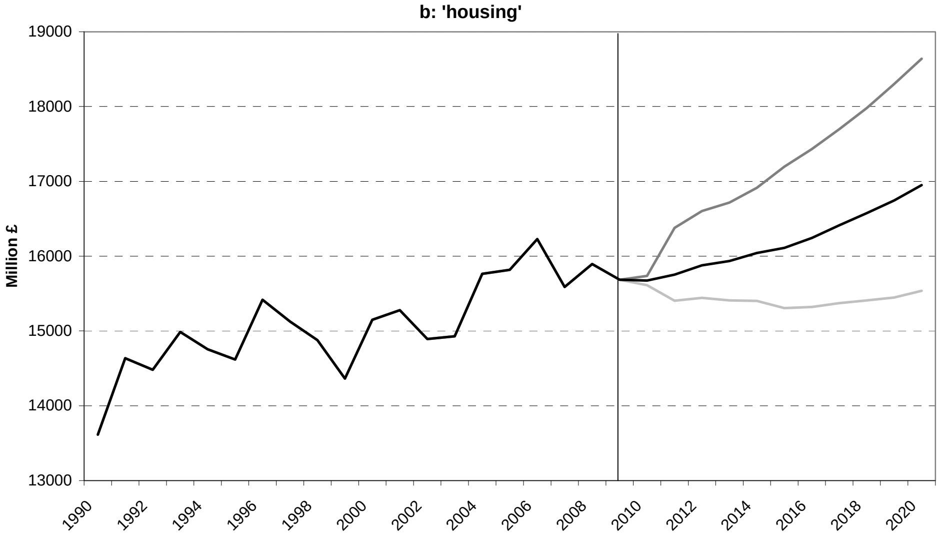
Table 9: (continued)

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
Housing						
Low	-0.38	-0.45	-0.50	-0.54	-0.57	-0.58
Reference	-0.23	-0.31	-0.37	-0.41	-0.43	-0.46
High	-0.08	-0.16	-0.22	-0.26	-0.29	-0.32
Transport						
Low	-1.85	-1.56	-1.62	-1.67	-1.78	-1.73
Reference	-0.81	-0.53	-0.59	-0.65	-0.77	-0.73
High	0.27	0.56	0.49	0.43	0.31	0.35

Figure 11: ‘Transport’ and ‘housing’ real energy expenditure 1990-2020



Note: The actual values are shown up to 2009.



Note: The actual values are shown up to 2009.

5.2. CO_2 emissions

For CO_2 intensities, a STSM with a stochastic trend and lags of CO_2 intensities was estimated in order to project future CO_2 intensities values.[40] This is used for the 'reference' scenario with the 'high' (higher CO_2 intensity) and 'low' (lower CO_2 intensity) assumptions built around this.[41] Given the above assumptions along with the three different scenarios for expenditure explained in earlier section, CO_2 emission attributable to each category is estimated for 2008-2020.[42]

Figure 12 shows projected emitted CO_2 for both categories of 'transport' and 'housing' expenditure. CO_2 emissions related to 'transport' are much lower than 'housing' expenditure but increasing whereas for 'housing' it tends to decrease in recent years and near future.

---

[40] Arguably, forecasting future emissions requires insights on technology, fuel and electricity generation mix. For instance, energy demand could be reduced by fuel switching from oil/gas to electricity but emissions could increase or decrease depending on future electricity generation pathways. Similarly, in the transport sector, deployment of electric/hybrid or bio-fuel cars might have a different implication on energy demand and emissions. However, in practice this is very difficult to achieve, especially when considering both direct and indirect energy and emissions. Therefore, given the approach adopted here, such changes are captured within the stochastic trend.

[41] Low and high assumptions are actually made for the trend component in CO_2 intensity equations.

[42] The following equation is used:

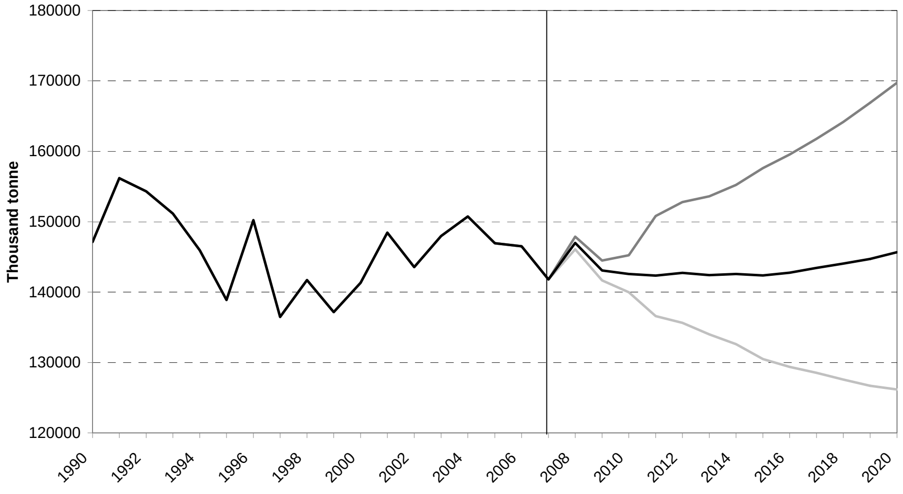
CO_2 emission (reference, low, high)= CO_2 intensity (reference, low, high)*expenditure (reference, low, high)

Figure 12: CO_2 emission attributable to household ‘transport’ and ‘housing’ real energy expenditure 1990-2020

a: 'transport'

Note: The actual values are shown up to 2007.

b: 'housing'



Note: The actual values are shown up to 2007.

Table 10 shows that CO_2 emissions in 2020 compared to 1990 from a consumption perspective are projected to *increase* for ‘transport’ under the reference and high case scenarios whereas for ‘housing’ to increase under high case scenario only. This is not consistent with the recent UK target of a reduction in CO_2 emissions in 2020 compared to its 1990 level (based on the production perspective). Furthermore, even in the scenarios where CO_2 emissions are predicted to decrease for both ‘transport’ and ‘housing’, the reductions are not consistent with the UK interim and intended budget targets.

Table 10: Percentage change in 2020 CO_2 emissions attributable to household real energy expenditure compared to 1990 level (%)

Category	Transport	Housing
Low	-0.67	-14.25
Reference	9.45	-1.00
High	18.99	15.35

6. Conclusions

This paper has attempted to estimate the relative importance of economic and non-economic drivers for UK ‘transport’ and ‘housing’ energy expenditure and the results suggest that the non-economic factors, ExNEF are relatively important for both ‘transport’ and ‘housing’. This has important implications (discussed further below) in a world, where policy makers are searching for ways to try to curtail energy expenditure in order to contribute to CO_2 reductions.

This paper has also attempted to understand how UK ‘transport’ and ‘housing’ energy expenditure might evolve by generating future scenarios to 2020. The ‘high’ scenario suggests that for both ‘transport’ and ‘housing’ energy expenditure and associated CO_2 emissions (from a consumption perspective) will be somewhat higher in 2020 than at present. Whereas the ‘low’ scenario suggests that energy expenditure and associated CO_2 emissions (from a consumption perspective) will be lower. However, even in this ‘low’ scenario the projected associated CO_2 emissions reduction (from a consumption perspective) ***will not*** be consistent with the UK target of a total CO_2 reduction by 2020 compared to its 1990 level (from a production perspective).

This suggests that UK policy makers might need to concentrate their efforts in attempting to curtail the growth in ‘transport’ and ‘housing’ energy consumption and expenditure. Assuming they do not wish to reduce the rate of economic growth as a way to curtail the growth in expenditure there is a clear message for policy makers. In addition to economic incentives, such as taxes, and energy intensity improvements for both categories, policies attempting to influence lifestyles, behaviours and expectations might also be considered in order to restrain future ‘transport’ and ‘housing’ expenditure and associated emissions, given the *relative* importance of ExNEF.

To help achieve this, future research should attempt to further disaggregate ExNef into more specific behavioural factors. This is consistent with Martiskainen (2008) [20] who argues that the UK’s inefficient housing stock is partly responsible for households emissions, but people’s ‘behaviour’ is another influencing factor. Martiskainen (2008) [20] concludes that the challenge for policy makers in the UK is about which intervention measures will provide long-term behavioural changes. A more specific disaggregated ExNef factor that might be considered is ‘comfort’.

Chappells and Shove (2005) [21], argue that by searching for more efficient ways of delivering standardised indoor environmental conditions, policy makers inadvertently sustain a narrow and uniquely demanding concept of ‘comfort’. Hence, more quantified information on the ‘comfort’ needs of consumers would aid policy makers in this area. Given the framework adopted here, the challenge will be on acquiring appropriate disaggregated data and modelling accordingly.

Acknowledgements

This work is part of the interdisciplinary research group RESOLVE[43] funded by the ESRC (Award Reference: RES-152-25-1004) and their support is gratefully acknowledged. The authors are grateful for comments on earlier draft of the work presented at the 2nd Asian Conference of the International Association for Energy Economics, Perth, 5-7 November, 2008 and members of RESOLVE for many discussions about the work, in particular David C Broadstock, Angela Druckman and Tim Jackson. Of course, the authors are responsible for any errors or omissions.

---

[43] www.surrey.ac.uk/resolve/.

References

[1] A. Druckman, T. Jackson, The carbon footprint of UK households 1990-2004: a socio-economically disaggregated; quasi-multiregional input-output model, Ecological Economics 68 (7) (2009) 2066-2077.

[2] Committee on Climate Change (2008), Building a low-carbon economy-the UK's contribution to tackling climate change, London, December.

[3] R. Brannlund, T. Ghalwash, J. Nordstrom, Increased energy efficiency and the rebound effect: Effects on consumption and emissions, Energy Economics 29 (2007) 1-17.

[4] H. Allcott, Social norms and energy conservation, MIT Centre for Energy and Environmental Policy Research (MIT CEEPR), (2009) WP-2009-014.

[5] C. Weber, A. Perrels, Modelling lifestyle effects on energy demand and related emissions, Energy Policy 28 (2000) 549-566.

[6] A.C. Harvey, Forecasting, Structural Time Series Model and the Kalman Filter, Cambridge University Press, Cambridge, UK, 1989.

[7] L.C. Hunt, Y. Ninomiya, Unravelling Trends and Seasonality: A Structural Time Series Analysis of Transport Oil Demand in the UK and Japan, Energy Journal 24(3) (2003) 63-96.

[8] S.J. Koopman, A.C. Harvey, J.A.Doornik, N. Shephard, Stamp: Structural Time Series Analyser; Modeller and Predictor, Timberlake Consultants Press, London, 2000.

[9] M. Chitnis, L.C. Hunt, Modelling UK Household Expenditure: Economic Versus Non-economic Drivers, RESOLVE Working Paper Series 07–09 (2009a), University of Surrey.

[10] M. Chitnis, L. C. Hunt, Modelling UK household expenditure: economic versus noneconomic drivers, Applied Economics Letters, 18(8) (2011) 753 – 767.

[11] D. C. Broadstock, L. C. Hunt, Quantifying the Impact of Exogenous Non-Economic Factors on UK Transport Oil Demand**,** Energy Policy 38(3) (2010) 1559-1565**.**

[12] L.C. Hunt, Y. Ninomiya, Primary Energy Demand in Japan: An Empirical Analysis of Long-term Trends and Future CO_2 Emissions, Energy Policy 33(3) (2005) 1409-1424.

[13] DECC, 2010. Energy Consumption in the UK: Transport data tables, URN 10D/755, London.

[14] DECC, 2010. Energy Consumption in the UK: Domestic data tables, URN 10D/802, London.

[15] DECC, 2010. UK Energy Brief 2010, Department of Energy and Climate Change, London.

[16] DECC, 2010. Digest of United Kingdom Energy Statistics 2010: internet content only. Department of Energy and Climate Change, London.

[17] HMT, Forecasts for the UK economy: A comparison of independent forecasts, No.290 (2011) June, H.M. Treasury, London.

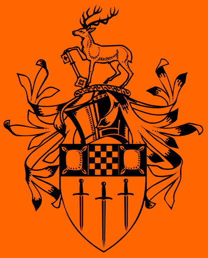
[18] HMT, Forecasts for the UK economy: A comparison of independent forecasts, No.286 (2011) February, H.M. Treasury, London.

[19] HMT, Forecasts for the UK economy: A comparison of independent forecasts, No.289 (2011) May, H.M. Treasury, London.

[20] M. Martiskainen, Household energy consumption and behavioural change – the UK perspective, 2nd Conference of the Sustainable Consumption Research Exchange (SCORE!) Network: Sustainable Consumption and Production: Framework for Action, March 2008, Brussels, Belgium.

[21] H. Chappells, E. Shove, Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment, Building Research & Information 33(1) (2005), 32–40.

Surrey Energy Economics Centre (SEEC)
School of Economics
University of Surrey
Guildford
Surrey GU2 7XH



SURREY

ENERGY

ECONOMICS

DISCUSSION PAPER

SERIES

For further information about SEEC please go to:

www.seec.surrey.ac.uk