WHAT DRIVES THE CHANGE IN UK HOUSEHOLD ENERGY EXPENDITURE AND ASSOCIATED CO2 EMISSIONS, ECONOMIC OR NON-ECONOMIC FACTORS?

by

Mona Chitnis and Lester C. Hunt

RESOLVE Working Paper 08-09

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Abstract

Households are responsible for a large proportion of CO2 emission in the UK. For policy makers to lower future emissions they therefore need a better understanding of the structure of household energy expenditure and the impact of both economic and non-economic factors. Applying the Structural Time Series Model, UK 'transport' and 'housing' energy expenditure equations are estimated for 1964-2008 This allows for the estimation of a stochastic trend to measure the underlying energy expenditure trend and hence capture the impact of 'non-economic factors' on household energy expenditure; as well as the impact of the traditional 'economic factors' of income and price. The results suggest that the non-economic factors play a non-trivial role for household 'transport' expenditure. The estimated equations are also used to show that given current expectations, CO2 attributable to 'transport' category 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 that 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; CO2 emissions; Structural Time Series Model, Exogenous non-economic factors.

1. Introduction

Household expenditure increased by 46% between 1990 and 2004 and according to Druckman and Jackson (2008), carbon emissions (CO2) attributable to households were 17% above 1990 levels in 2004, and are estimated to have been increasing by about 3% per annum between 1997 and 2004. Hence, both real household expenditure and related carbon emissions are generally increasing over time; which is not consistent with the view that the UK must cut emissions by around 6% per annum.[1] This emphasizes the need to develop the 'carbon footprint' concept from a consumption perspective in order to understand 'sustainable consumption'. Within this, however, the major contribution to emissions comes from 'direct' energy use in transportation and housing (as opposed to the estimated 'indirect' energy included in the above). UK total real household direct energy expenditure (at 2003 prices) increased by 118% from 1964 to 2008 and within this, 'transport' and 'housing (non-transport)' energy expenditure increased from 1964 to 2008 by 251% and 46% respectively.

Figure 1 presents UK household energy expenditure for 'transport' and 'housing' from 1990 to 2008. Figures 2 and 3 show CO2 and CO2 intensities attributable to these two categories of household energy expenditure from 1990 to 2006.[2] Although, 'transport' expenditure is more than 'housing' expenditure during 1990-2006 the CO2 related to 'housing' sector is greater than that related to 'transport'. However, CO2 related to 'transport' increased by 7.8% compared to its 1990 level whereas for 'housing' it decreased by 0.4%. Therefore, a better and clearer understanding of household energy expenditure structure is required in order to understand future 'sustainable consumption' and CO2 emissions from direct energy expenditure.

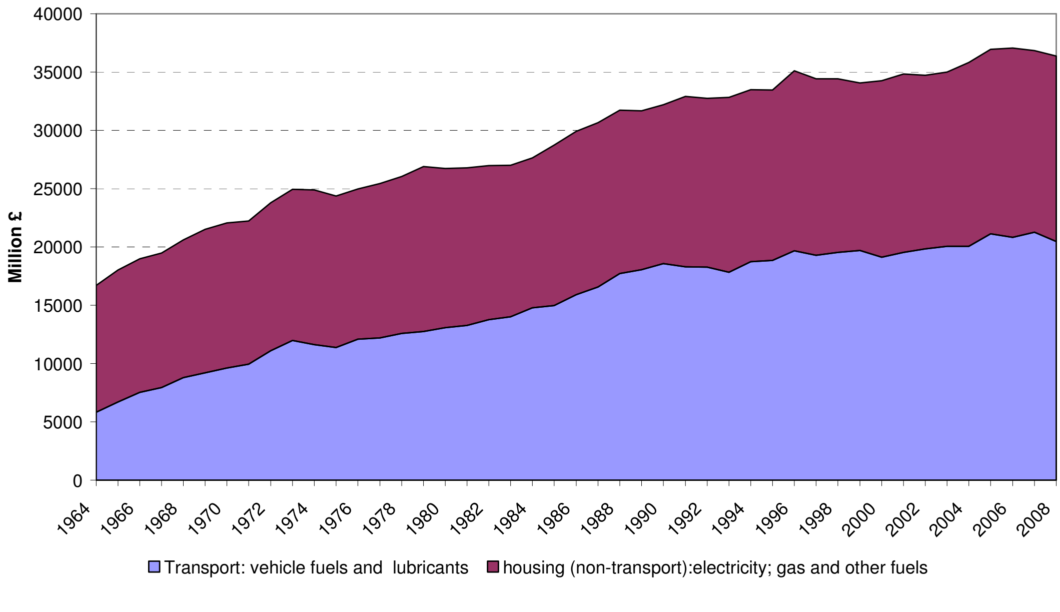

Figure 1: UK household direct energy expenditure 1964-2008

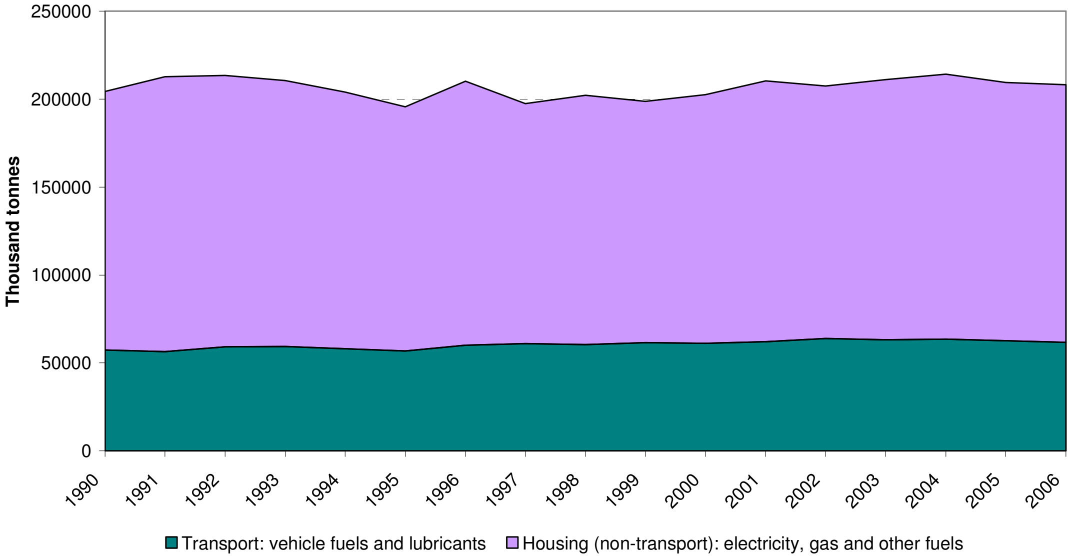

Figure 2: CO2 attributable to 'transport' and 'housing' non-transport UK household energy consumption 1990-2006

Figure 3: CO2 intensity attributable to 'transport' and 'housing' (non-transport) UK household energy consumption 1990-2006

There is arguably therefore a need to try to quantify, not only the key economic drivers of income and price, but also exogenous non-economic factors such as technical progress, consumer taste and preferences, socio-demographic and geographic factors, lifestyle and value changes. Previous econometric work on energy demand has tended to concentrate on the economic factors whereas a separate strand of literature has focused on the non-economic factors, but there has not been an attempt, as far as is known, to bring these together and try to quantify their relative contributions to driving consumer energy expenditure. This is therefore one of the aims of this paper.

To do this the Structural Time Series Model (STSM) is used since it allows for the examination of the relationship between household energy expenditure, income, prices ***and*** a stochastic underlying trend. The stochastic trend is the underlying energy expenditure trend and arguably captures the systematic non-price and income effects discussed above that are not easily measured and/or difficult to obtain any suitable data. In other words, the underlying energy expenditure trend shows the effect of other (non-price and non-income) variables affecting demand.[3]

In this paper, the STSM is therefore employed to estimate UK household energy expenditure functions for two different categories of energy consumption: a) 'transport', which includes vehicle fuels and lubricants and b) 'housing (non-transport, which includes electricity, gas, solid and liquid fuels use at home) using annual time series data for the period of 1964-2008. Hence, the effect of price, income and stochastic trend (other components) on household energy expenditure for each of these two categories are estimated and compared in order to determine the main drivers of demand for each group. Furthermore, using annual data for 1990-2005, CO2 intensities are projected to construct future scenarios for CO2 emission attributable to households' energy expenditure for each group of expenditure until 2020. High, low and reference scenarios for energy expenditures and CO2 are constructed in order to assess whether the overall target of CO2 reduction compared to its 1990 level will be achieved for each of these two categories.

The Committee on Climate Change became a statutory committee in December 2008 when the Climate Change Bill became law. Its core function is to recommend what the level of the UK's 'carbon budgets' should be. These budgets, established by the Climate Change Act, define the maximum level of CO2 and other greenhouse gases (GHG) that the UK will emit. Following the EU framework, two sets of budgets are proposed by the Committee on Climate Change: one to apply following a global deal on emissions reductions i.e. 'Intended' budgets; and the other to apply for the period before a global deal is reached i.e. 'Interim' budgets. The Intended and Interim budgets require CO2 reductions of 29% and 40% in 2020 relative to its 1990 level respectively. Consistent with this, the GHG emissions reduction according to Intended and Interim budgets are 42% and 34% in 2020 relative to 1990 respectively.

The paper is organized as follows. After the introduction, the second section describes the data and the third section introduces the methodology and estimation technique employed. The estimation results and scenarios for expenditure and CO2 are given in section four, with a summary and conclusion in section five.

2. Data

The initial general ARDL energy expenditure relationships, as outlined in section 3.1 below, are estimated for the UK using annual time series data over the period 1964 to 2008. Data for household expenditure (see Figure 1), household real disposable income and real prices (implied deflators), which are illustrated in Figures 4 and 5, are collected from the UK Office for National Statistics (ONS) online database.[4] All data are in terms of chained volume measures (reference year 2003). Real household disposable income data, which are used, include non-profit institutions serving households (NPISH) expenditures. There is no separate time series data for household disposable income in national statistics. Implied deflators for each category are deflated by the total implied deflator to produce real prices for the same category. Annual average temperature data in Degrees Celsius is obtained from the BERR 'Digest of United Kingdom Energy Statistics' (DUKES). This is illustrated in Figure 6.

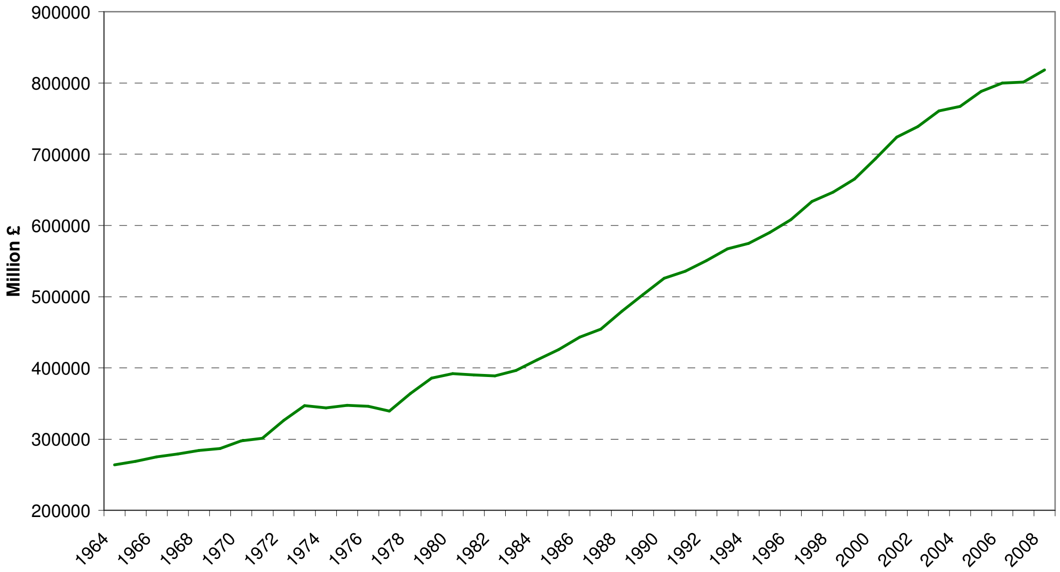

Figure 4: Real household disposable income 1964-2008

Figure 5: 'Transport' and 'housing' (non-transport) real prices 1964-2008

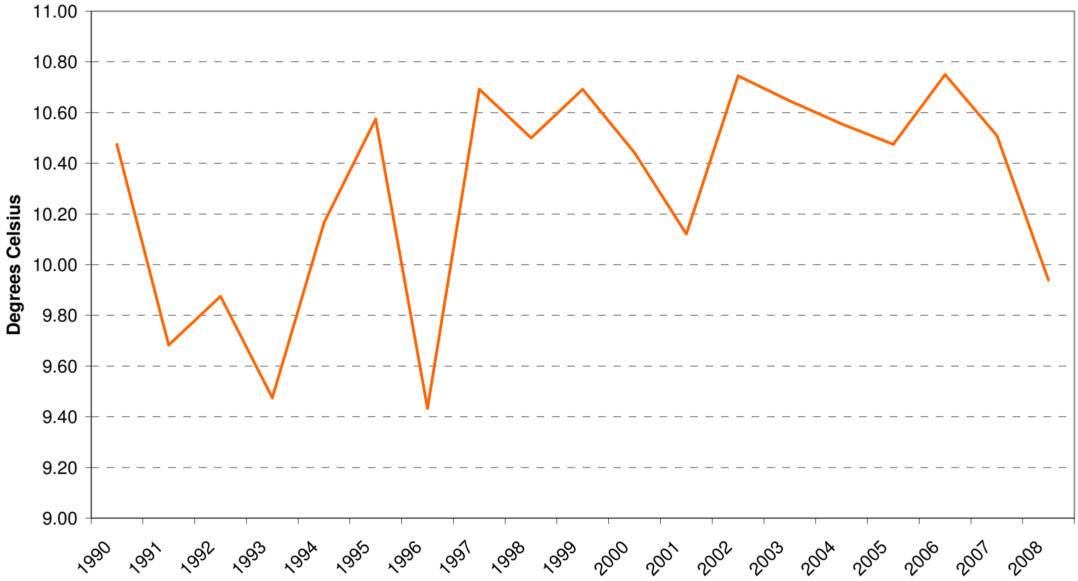

Figure 6: Annual average temperature 1990-2008

CO2 annual data (see Figure 2) attributable to household direct energy for 'transport' and 'housing' excluding electricity, available from 1990 to 2006, are obtained from Environmental Accounts from the UK Office for National Statistics (ONS) online database.[5] To estimate CO2 emissions related to 'electricity', the ratio of household electricity consumption to total electricity consumption from DUKES is multiplied by CO2 emission associated to electricity production and distribution from the ONS.

3. Model specification and estimation method

3.1. Expenditure

To estimate household energy expenditure for 'transport' and 'housing' categories, the STSM is applied (see Harvey 1989). This allows for the estimation of a stochastic rather than a deterministic underlying trend, which arguably is important when estimating the elasticities of demand as discussed by Hunt and Ninomiya (2003). In addition to technical progress, the underlying trends are likely to be strongly affected by changes in tastes, consumer preferences, socio-demographic and geographic factors, lifestyles and values, which are not easily measured, and therefore it is difficult to obtain any suitable data. Hence, the stochastic trend is included in the following long-run energy expenditure model.[6]

$$\exp_t = \mu_t + \alpha p_t + \delta y_t + \theta temp_t + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \qquad \textbf{(1)}^7$$

where $\exp_t$ is the households expenditure for each category of energy, μ_t represents the underlying energy expenditure trend (UEET), p_t is the relative price of each category of energy, y_t is real household disposable income. α, δ and θ are unknown parameters and ε_t is a random white noise disturbance term. All variables are in natural logarithms.

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

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

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

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).

At the extreme, if they are both equal to zero, the model will collapse to the model with a conventional deterministic linear trend as follow:

$$\exp_t = a + bt + \alpha p_t + \xi y_t + \theta tem_t + \varepsilon_t \tag{4}$$

The Maximum Likelihood (ML) procedure in conjunction with the Kalman filter is used to estimate following Autoregressive Distributed Lag (ARDL) form of equation (1), starting with lags of four years of expenditure, price and income variables, using the software STAMP 6.3 (Koopmans, et al., 2000);

$$A(L)\exp_t = \mu_t + B(L)p_t + C(L)y_t + \theta temp_t + \varepsilon_t \tag{5}$$

where *A(L)*, *B(L)* and *C(L)* are polynomial lag operators equal to $1 - \varphi_1 L - ... - \varphi_4 L^4$, $1 + \pi_1 L + ... + \pi_4 L^4$ and $1 + \theta_1 L + ... + \theta_4 L^4$ respectively. *B(L)/A(L)* and *C(L)/A(L)* represent the long-run price and income elasticities respectively.[8] 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.[9]

3.2. Contributions of independent variables to changes in expenditure

The following equation presents the estimated version of equation 5:

$$\hat{\exp}_t = \hat{\mu}_t + \hat{B}(L)p_t + \hat{C}(L)y_t + \hat{A}'(L)\exp_t + \hat{\theta} temp_t$$ **(6)**[10]

where $\hat{A}'(L) = \hat{\varphi}_1 L - ... - \hat{\varphi}_4 L^4$. To estimate the contribution of trend, price, income and temperature to demand, $\hat{A}'(L)\exp_t$ for lags of demand is continually substituted by equation 6 until $\hat{A}'(L)$ is sufficiently close to zero in order to ignore, i.e.:

$$\hat{\exp}_t = D'(L)\hat{\mu}_t + \hat{B}'(L)p_t + \hat{C}'(L)y_t + \hat{E}'(L)temp_t \quad \textbf{(7)}$$

where $D'(L) = 1 + \omega_1' L + ... + \omega_n' L^n$, $\hat{B}'(L) = 1 + \pi_1' L + ... + \pi_n' L^n$, $\hat{C}'(L) = 1 + \theta_1' L + ... + \theta_n' L^n$ and $\hat{E}'(L) = 1 + \rho_1' L + ... + \rho_n' L^n$. Then, the annual change of equation 7 is constructed as follow:

$$\Delta \hat{\exp}_t = D'(L)\Delta\hat{\mu}_t + \hat{B}'(L)\Delta p_t + \hat{C}'(L)\Delta y_t + \hat{E}'(L)\Delta temp_t \quad \textbf{(8)}$$

As mentioned in the introduction, an attempt is made to quantify the contributions of the economic drivers (income and price) and exogenous non-economic factors (hereafter ExNEF for short) for household energy expenditure.[11] Indeed, what is called ExNEF here will incorporate all the issues related to the annual change in the underlying energy expenditure trend (UEET) explained in section 3.1. Therefore, $D'(L)\Delta\hat{\mu}_t$, $\hat{B}'(L)\Delta p_t$, $\hat{C}'(L)\Delta y_t$, and $\hat{E}'(L)\Delta temp_t$ are the estimated contributions of ExNEF, price, income, and temperature respectively to changes in fitted expenditure $\Delta \hat{\exp}_t$.

3.3. CO2 intensity

In order to predict CO2 emissions using the projected household energy expenditure for 'transport' and 'housing', the ratio of emitted CO2 to related expenditure for each category i.e. CO2 intensity needs to be considered and estimated for the future. To do this, similar to Hunt and Ninomiya (2005) using the STSM, CO2 intensity is modelled as follow:

$$co2i_t = \delta_t + \psi_t \qquad \psi_t \sim NID(0, \sigma_\psi^2) \quad \textbf{(9)}$$

where $co2i_t$ is the CO2 intensity for each category of energy, δ_t represents the trend component and ψ_t is a random white noise disturbance term. All variables are in natural logarithm.

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

$$\delta_t = \delta_{t-1} + \kappa_{t-1} + \vartheta_t \qquad \vartheta_t \sim NID(0, \sigma_\vartheta^2) \quad \textbf{(10)}$$

$$\kappa_t = \kappa_{t-1} + \varsigma_t \qquad \varsigma_t \sim NID(0, \sigma_\varsigma^2) \quad \textbf{(11)}$$

Equations 10 and 11 represent the level (δ_t) and slop (κ_t) of trend respectively. ϑ_t and ς_t are random white noise disturbance terms. σ_ϑ^2 and σ_ς^2 are hyperparameters.

Again, the ML procedure in conjunction with the Kalman filter is used to estimate the following Autoregressive Distributed Lag (ARDL) form of equation (9), starting with lags of two years of the CO2 intensity variable:

$$F(L)co2i_t = \delta_t + \psi_t \quad \textbf{(12)}$$

where *F(L)* is polynomial lag operators equal to $1 - \delta_1 L - \delta_2 L^2$. This general function is considered initially and the preferred model found by testing down from the over parameterised ARDL model subject to a battery of diagnostic tests. [12]

Future expenditure and CO2 intensity for each category are predicted using equations (5) and (12). From this, CO2 emission for each category is predicted. These are explained in more details in section 5.

4. Results

4.1. Expenditure and contributions of independent variables

Table 1 shows the estimation results for household 'transport' and 'housing' energy expenditure categories. Both 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 stable as indicated by the post sample predictive failure tests.

The estimated short run and long run price elasticities for 'transport' are -0.17 and -0.24 and estimated income elasticities are 0.50 and 0.71 respectively. For the 'housing' category, the estimated elasticities with respect to price in the short run and long run are -0.09 and -0.20 and with respect to income are 0.14 and 0.32 respectively.[13]

The Likelihood Ratio (LR) test in the 'transport' equation implies that imposing the restriction of a deterministic trend (where both the level and the slope in the trend are fixed) 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 and is clearly non-linear, as shown in Figure 7; whereas, for 'housing' the preferred trend is linear (with a fixed level and no slope).

Table 1: Estimated STSM energy expenditure functions for UK households 1964-2005

Dependent variable: exp		
Independent Variables \ Category	**Transport**	**Housing (non-transport)**
y	0.50	0.14
	(2.77)	(5.06)
p	-0.17	-0.09
	(-3.12)	(-2.41)
exp(-1)	-	0.56
		(5.85)
exp(-4)	0.30	-
	(3.08)	
temp	-	-0.04
		(-4.93)
Estimated Variance of Hyperparameters		
Irr (10^{-5})	0	40.04
Lvl(10^{-5})	52.84	-
Slp(10^{-5})	-	-
DIAGNOSTICS		
Equation Residuals		
Std. Error	0.02	0.02
Normality	1.05	0.27
H(n)	H(11)=1.22	H(13)=1.86
$r_{(1)}$	0.20	0.23
$r_{(2)}$	0.07	0.13
$r_{(3)}$	-0.14	0.04
$r_{(4)}$	-0.28	0.16
DW	1.53	1.44
$Q_{(n1,n2)}$	$Q_{(7,6)}$= 7.74	$Q_{(6,6)}$=4.37
Rs^2	0.52	0.95
Auxiliary Residuals		
Irregular		
Skewness	0.57	0.27
Kurtosis	0.03	0.92
Normal-BS	0.60	1.19
Normal-DH	1.36	1.05
Level		
Skewness	0.30	-
Kurtosis	0.65	-
Normal-BS	0.95	-
Normal-DH	0.74	-
Slope		
Skewness	-	-
Kurtosis	-	-
Normal-BS	-	-
Normal-DH	-	-
Predictive Failure Tests (2004q2-2006q1)		
$\chi^2_{4)}$	6.11	7.03
Cusum $t_{(4)}$	0.11	1.36
Likelihood Ratio Test		
LR	46.13	-

Notes:

exp, y, p and temp represent energy expenditure, income, real price (all in logs) and temperature. Irr represent intervention dummies.

t-statistics are given in parenthesis.

The restrictions imposed for the LR test is fixed level.

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 $F_{(n)}$.

$r_{(1)}$, $r_{(2)}$, $r_{(3)}$ and $r_{(4)}$ are the serial correlation coefficients at the 1st, 2nd, 3rd and 4th lags respectively, 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.

$\chi^2_{(4)}$ 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.

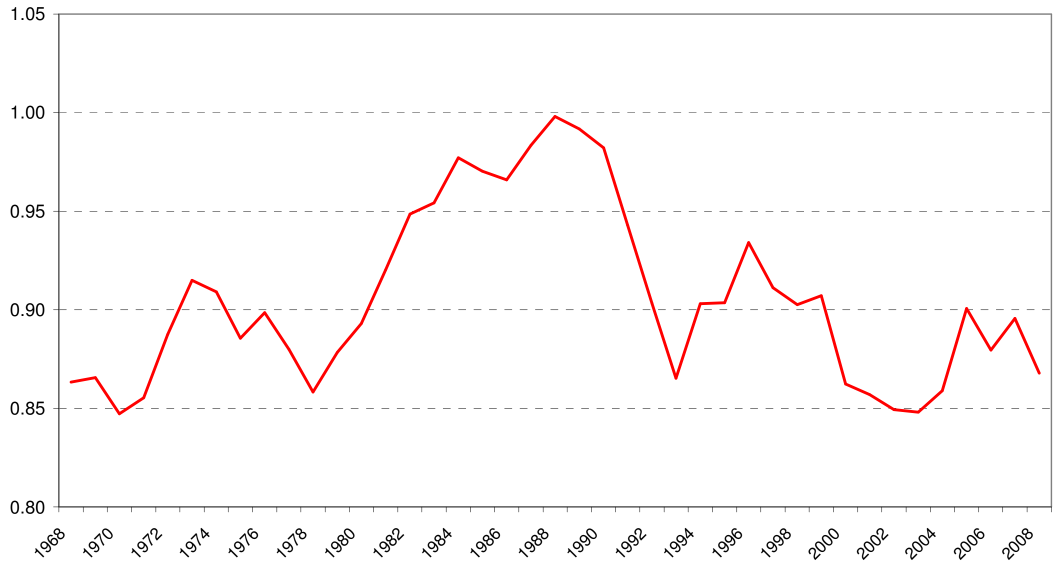

Figure 7: Estimated trend for 'transport' energy expenditure 1968-2008

Figure 8 shows the contributions of the different components, i.e. price, income, ExNEF and temperature[14] to annual changes in fitted energy expenditure for 'transport' and 'housing' categories respectively. In the case of 'transport', in addition to price and income, ExNEF in some years considerably affects changes in expenditure. This clearly presents the stochastic nature of the estimated UEET and implies that the impact of ExNEF on transport expenditure should not be ignored.

For ‘housing’, however, there is no estimated contribution of ExNEF to changes in expenditure given that there is no UEET in the preferred equation. Temperature, however, does has a significant contribution in some years.

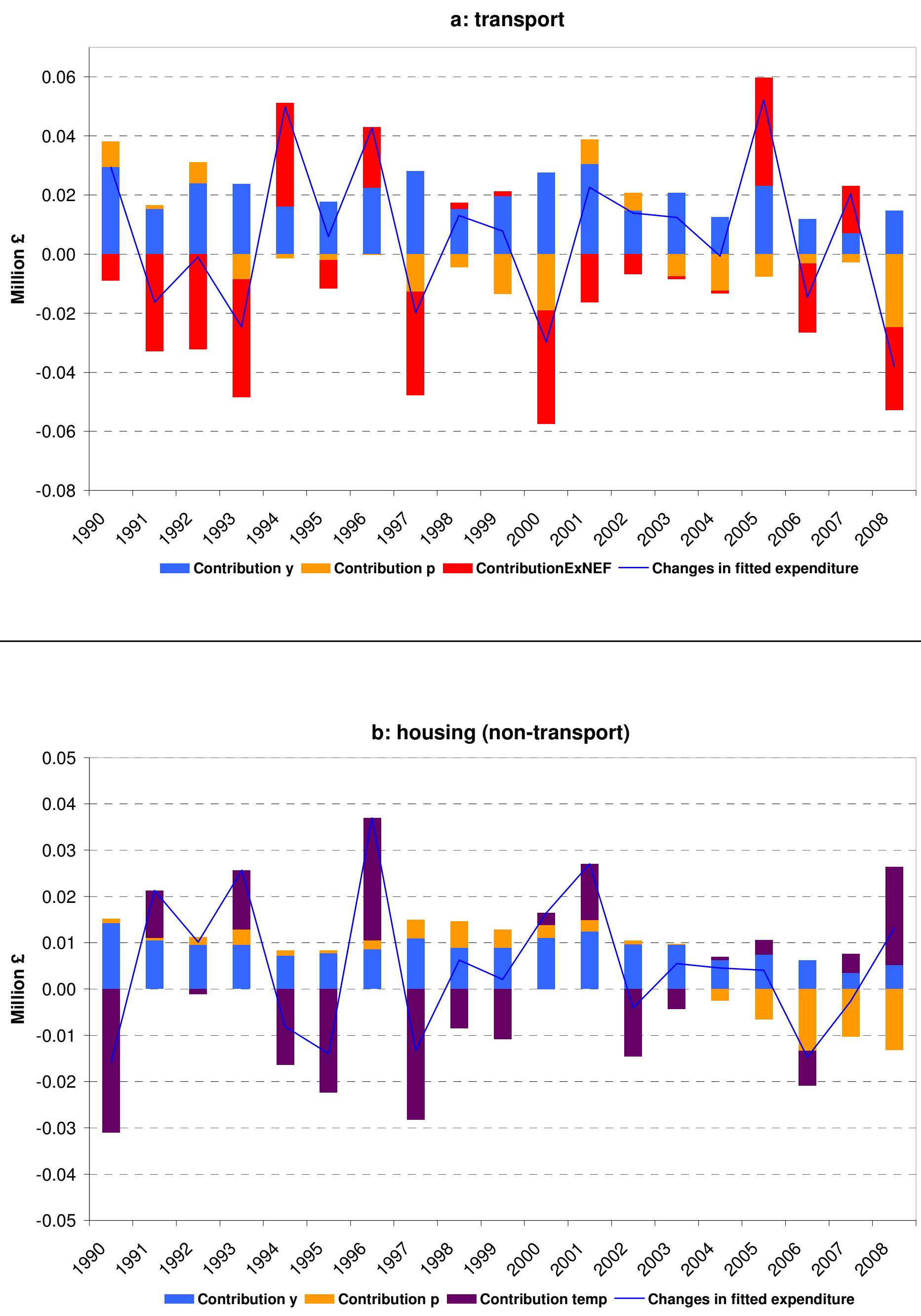

Figure 8: Contribution of income, price and ExNEF to changes in ‘transport’ and ‘housing’ (non-transport) energy expenditure

4.2. CO2 intensity

Table 2 shows the estimation results for CO2 intensity of household 'transport' and 'housing' energy categories. Both 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 stable as indicated by the post sample predictive failure tests.

The Likelihood Ratio (LR) tests for both equations imply that imposing the restriction of a deterministic trend is rejected. Consequently, the estimated underlying 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 for 'housing'. Hence, trends for both categories are clearly non-linear, as shown in Figure 9.[15]

Table 2: Estimated STSM CO2 intensity functions for UK households 1990-2006

Dependent variable: ci		
Category / Independent Variables	**Transport**	**Housing (non-transport)**
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 (2004q2-2006q1)		
$\chi^2_{(2)}$	7.25	3.81
Cusum $t_{(2)}$	-2.01	-1.87
Likelihood Ratio Tests		
Test (a)	-	7.44
Test (b)	4.95	-

Notes:

ci represent CO" intensity (in logs).
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 $F_{(n)}$.
$r_{(1)}$ and $r_{(7)}$ are the serial correlation coefficients at the 1st and 7th lags respectively, approximately distributed at N(0,1/T).
DW is the Durbin Watson statistic.
$Q_{(7,6)}$ is the Box-Ljung Q-statistic based on the first 6 residuals autocorrelation; distributed as $\chi^2_{(6)}$.
Rs^2 is the coefficient of determination.
$\chi^2_{(2)}$ 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.

Figure 9: Estimated trend for 'transport' and 'housing' (non-transport) CO2 intensity 1990-2006

5. Forecasting and scenarios

5.1. Expenditure

To forecast household energy expenditure for 'transport' and 'housing', three cases are considered as follows:

* *'Reference' Case*: This is like a 'business as usual' scenario, where the assumptions for the growth in real household disposable income, real prices, temperature, and the UEET represent the 'consensus' or 'most probable' outcomes as explained below; i.e. resulting in 'business as usual' or 'reference' real expenditure growth

* *'Low' Case:* Here, household disposable income growth is low, real price growth is low, temperature growth is low, and the growth in the UEET is low; i.e. resulting in 'low' real expenditure growth.

* *'High' case:* Here real household disposable income growth is high, real price growth is low, temperature growth is high, and the growth in the UEET is high; i.e. resulting in 'high' real expenditure growth

To guide the assumptions for the 'reference' scenario, the average independent growth rate forecasts from 2009 to 2013 are used for real household disposable income, taken from HMT(2009). Thereafter, assuming economic condition will return to 'normal' after 2013 the assumption is based upon the long run growth rate of for real household disposable income. For 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' assumptions for 2010, 2015 and 2020 are based upon the predictions in DECC (2009).[16] For the future projection of the UEET, the slope at the end of the estimation (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 future temperature, the estimated future trend of temperature equation[17] is used as the 'reference' scenario; with the 'high' and 'low' assumptions built around this. The assumptions for real household disposable income, prices, trend and temperature in each scenario are summarised in Tables 3, 4, 5 and 6 respectively.

Future predictions for 'transport' and 'housing' expenditure are therefore generated through the estimated energy expenditure equations.[18] Applying the assumptions in Tables 3 to 6 to the explanatory variables in the estimated household expenditure equations in Table 1[19], gives the forecasts for 'transport' and 'housing' energy expenditure, which are shown in Figure 10 according to the three scenarios discussed above. It can be seen that 'transport' expenditure is greater than 'housing' expenditure since 1990 and has a higher increasing growth over time.

Table 3: Real household disposable income growth rate assumptions (% p.a.)

	2009	2010	2011	2012-2013	2013-2025
Low	0.60	0.70	1.30	2.30	2
Reference	1.10	1.20	1.80	2.80	2.50
High	1.60	1.70	2.30	3.30	3

Table 4: Real 'transport', and 'housing' energy prices growth rate assumptions (% p.a.)

	2009-2010	2011-2015	2016-2020
Housing (non-transport)			
Low	0.55	0.55	1.71
Reference	0.02	0.02	1.16
High	0.26	0.26	1.31
Transport			
Low	0.23	0.23	0.00
Reference	2.01	0.21	0.41
High	3.67	0.39	0.38

Table 5: Average annual UEET growth assumptions for 'transport' and 'housing' (% p.a.)

	2009-2010	2011-2015	2016-2020
Housing (non-transport)			
Low	0.00	0.00	0.00
Reference	0.00	0.00	0.00
High	0.00	0.00	0.00
Transport			
Low	0.01	0.01	0.01
Reference	0.01	0.01	0.01
High	0.01	0.01	0.01

Table 6: Temperature average annual growth assumptions (% p.a.)

	2009-2010	2011-2015	2016-2020
Low	0.183	0.182	0.181
Reference	0.174	0.173	0.172
High	0.166	0.165	0.164

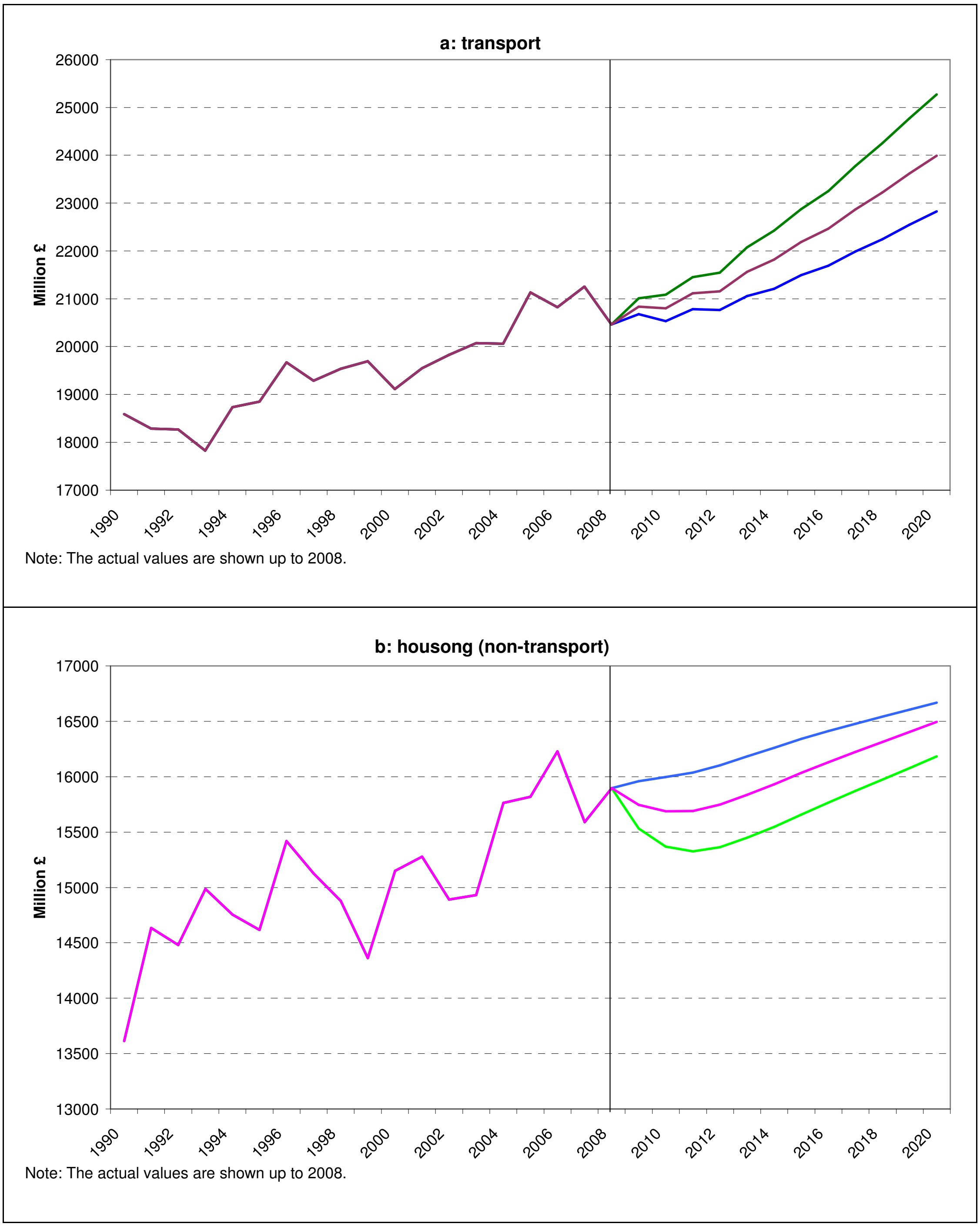

Figure 10: 'Transport' and 'housing' (non-transport) energy expenditure 1990-2020

5.2. CO2 emissions

Future CO2 intensities for 'reference' scenario are estimated by using the CO2 intensity equations in a similar way to the temperature equations, with the 'high' and 'low' assumptions are built around this.[20]

Given the above assumptions along with the three different scenarios for expenditure explained in earlier section, CO2 emission attributable to each category is estimated for 2009-2020.[21]

Figure 11 shows emitted CO2 for both categories of 'transport' and 'housing' expenditure. CO2 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.

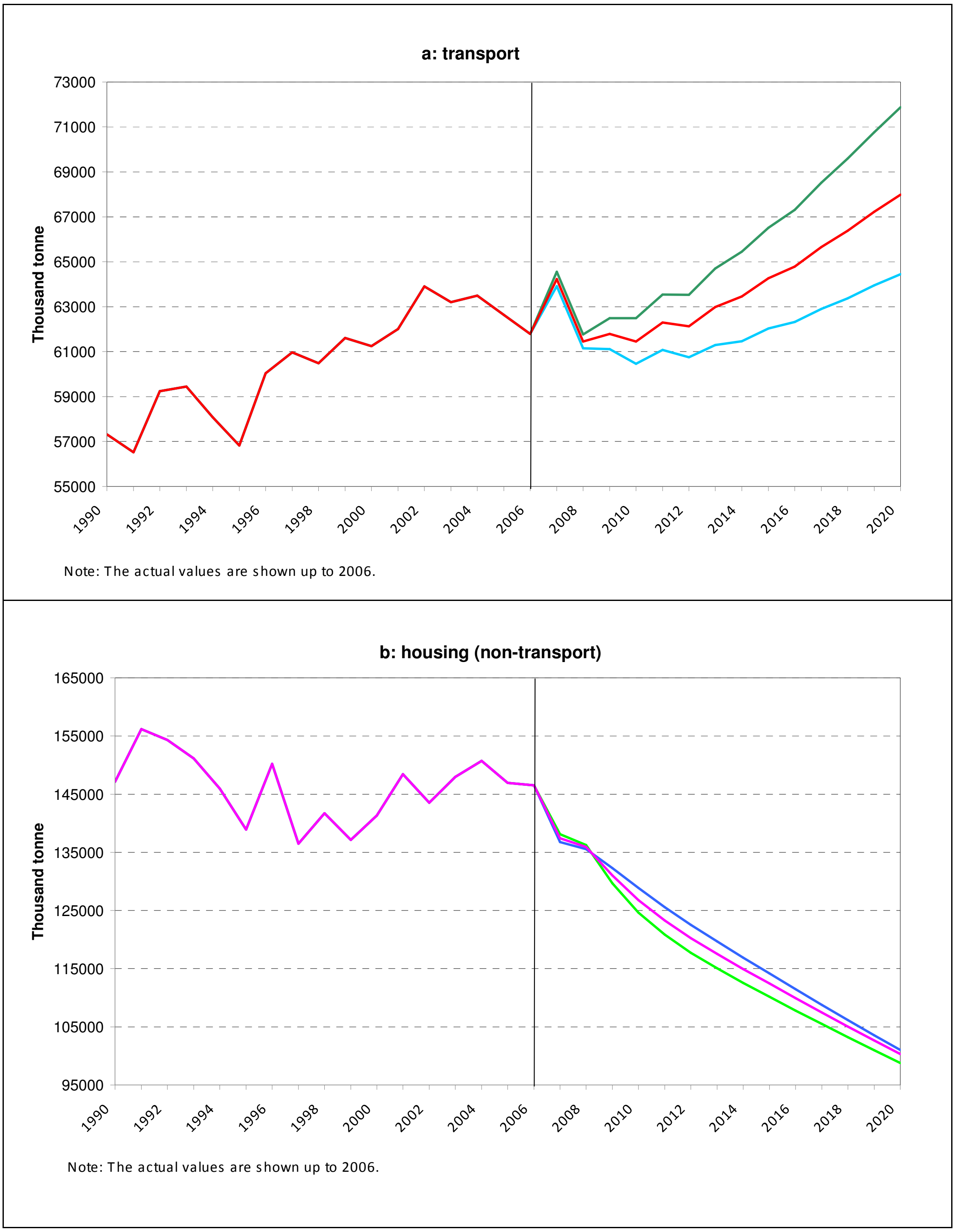

Figure 11: CO2 emission attributable to household 'transport' and 'housing' (non-transport) energy expenditure 1990-2020

Table 7 shows that CO_2 emissions from 'transport' is predicted to increase by between 12.61 to 25.23 % in 2020 compared to 1990 and for 'housing' to fall by between 39.07 to 37.50 %. This is in contrast with the recent UK target of reduction in CO_2 emissions in 2020 compared to its 1990 level for 'transport' category under all three assumptions; which CO_2 will tend to increase rather than decrease. However, 'housing' sector will meet the CO_2 reduction target according to interim budget and almost the one for intended budget as well.

Table 7: Percentage change in 2020 CO_2 emissions attributable to household energy expenditure compared to 1990 level (%)

Category	Transport	Housing (non-transport)
Low	12.61	-37.50
Reference	18.62	-38.02
High	25.23	-39.07

6. Summary and conclusions

In this study, the household expenditure functions are estimated for energy used in the 'transport' and 'housing' categories. The Structural Time Series Model is applied to energy expenditure estimation using UK annual time series data for the period of 1964-2008. Both estimated equations pass all the diagnostic tests and are stable for both categories; expenditure is inelastic with respect to price and income both in the short and long run. The nature of the energy expenditure trend is stochastic for the 'transport' energy expenditure function indicating that imposing a deterministic assumption for the trend is not accepted by the data; however, for 'housing' energy expenditure a deterministic trend is accepted by the data. Consequently, the results suggest that in general ExNEF (given by the changes in the estimated underlying trend) is important in the case of 'transport'. However, ExNEF does not exist in the case of 'housing' but temperature does, at times, have a relatively large impact compared to the key economic factors of price and income.

Given current expectations about income and prices policies, the future scenarios suggest that energy expenditure and hence CO_2 emissions will continue to grow and decrease for 'transport' and 'housing' sectors respectively. Despite the 'transport' category, CO_2 attributable to 'housing' sector is estimated to meet UK target of total CO_2 reduction in year 2020 compared to its 1990 level. Furthermore, as mentioned above, ExNEF is also important in forming UK household 'transport' expenditure and hence CO_2 emissions.

Therefore, assuming policy makers do not wish to reduce the rate of economic growth as a way to curtail the growth in 'transport' and 'housing' energy expenditure the message for policy makers is clear. For 'transport' energy expenditure, in addition to an economic incentive, such as taxes, other policies that attempt to influence lifestyles might need to be used and hence might be considered if they wish to restrain future expenditure and emissions. For 'housing' energy expenditure, it is found that ExNEF does not exist to have any effect on past changes in expenditure and the temperature is not under the control of policy makers. This suggests that the primary policy option to reduce expenditure is to increase significantly 'housing' energy prices; however, such a policy needs careful consideration given its side effects for households (such as fuel poverty). Therefore, a challenge remains for government on how to bring about significant behaviour change in 'housing' expenditure, although, even without any further policy changes 'housing' sector will meet UK target for CO2 reduction.

References

BERR, 2008. Quarterly Energy Prices. Department of Business and Regulatory Reform, London, September.

BERR, 2008. Digest of United Kingdom Energy Statistics 2008. Department of Business and Regulatory Reform, London, July.

Broadstock, D. C. and L. C. Hunt (2009). Quantifying the Impact of Exogenous Non-Economic Factors on UK Transport Oil Demand, Surrey Energy Economics Discussion Papers, SEEDS123, University of Surrey.

Chitnis, M. and Hunt, L. C., (2009). Modelling UK household expenditure: economic versus non-economic drivers, RESOLVE working paper series, University of Surrey, 07-09, September.

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

DECC, 2008. Updated energy and carbon emissions projections, London, November.

Druckman, A., Jackson, T., 2008. The carbon footprint of UK households 1990-2004: a socio-economically disaggregated, quasi-multi-regional input-output model. The 2008 International Input-Output Meeting on Managing the Environment Seville, Spain, 9th – 11th July.

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

HMT , 2009. Forecasts for the UK economy: A comparison of independent forecasts. H.M. Treasury, London.

Hunt, L.C., Ninomiya, Y., 2005. Primary Energy Demand in Japan: An Empirical Analysis of Long-term Trends and Future CO2 Emissions. Energy Policy, 33, 1409-1424.

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

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

Notes:

[1] For further information see: Druckman and Jackson (2008).
[2] The different time periods for Figure 1 and Figure 2 being due to data availability.
[3] This method can also be used to model CO2 intensities of related household expenditure.
[4] http://www.statistics.gov.uk/statbase/tsdtimezone.asp.
See "Consumer Trends" for time series data on expenditure and implied deflators and for more information http://www.statistics.gov.uk/downloads/theme_economy/CT2008q2.pdf.
See "Economic Trends Annual Supplement" for time series data on real household disposable income and for more information http://www.statistics.gov.uk/downloads/theme_economy/ETSupp2006.pdf.
[5] http://www.statistics.gov.uk/statbase/explorer.asp?CTG=3&SL=&D=4261&DCT=32&DT=32#4261
[6] This has been termed the Underlying Energy Demand Trend or UEDT in previous work, for example see Hunt and Ninomiya (2003).
[7] NID means that ε_t is normally and independently distributed with a mean of zero and a constant variance of σ^2_ε.
[8] $\theta / A(L)$ represents the long-run temperature coefficient.
[9] For further details, refer to Hunt and Ninomiya (2003).
[10] ^ refers to estimated coefficients and components.
[11] This work is part of on-going research attempting to quantify the impact of ExNEF on consumer demand and expenditure; see, for example, Chitnis and Hunt (2009) and Broadstock and Hunt (2009).
[12] Given that the temperature is generally rising in recent years, the similar methodology (STSM) is also applied to predict future temperature.
[13] Temperature is statistically significant for 'housing' energy expenditure only. The estimated short run and long run temperature coefficients for 'housing' are -0.04 and -0.09 respectively.
[14] Temperature is for 'housing' energy expenditure only.
[15] The estimated STSM for temperature is as follow:

$$temp_t = \tau_t$$

where $temp_t$ *is* temperature and τ_t is the stochastic trend.

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; $Normality_{(Irr)}$= 1.19; Normality $_{(Lvl)}$= 3.03; Failure= 2.62; LR= 16.78.
The nature of trend is local level with drift.
[16] To produce 'housing' energy price, residential 'electricity' and 'gas' price forecasts are used with total demand forecast with medium assumption (residential and non-residential) as weights. Demand forecasts under other assumptions and for residential sector only, are not available from DECC. As other fuels have small share in 'housing' energy demand and the price forecast is not available from DECC, this is ignored in the calculation.
[17] See footnotes 11 and 14.
[18] The preferred specifications for the two expenditure equations in Table 1 are re-estimated over the whole period 1964-2008 and used for this purpose.
[19] The expenditure equations in Table 1 are estimated over the whole period of 1964-2008 and used for this purpose.
[20] Low and high assumptions are actually made for the trend component in CO2 intensity equations.

[21] The following equation is used:

CO2 emission = CO2 coefficient*expenditure