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A Model for Forecasting Energy Demand and Greenhouse Gas Emissions in Ireland

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1 INTRODUCTION

The energy transformation industry - electricity and gas, is a capital-intensive business. The investment process - from planning to production - is often very long. The uncertainty about the future adds significantly to costs in the sector, raising the long-run cost of energy to the economy. Overprovision or underprovision of necessary infrastructure can impose significant extra costs on consumers and on the economy as a whole. As a result, forecasts about future medium-term demand are of considerable importance.

A second reason for preparing forecasts of energy demand is the requirement that Ireland, along with other developed economies, reduces its emissions of greenhouse gases. The single biggest source of emissions of greenhouse gases arises from the combustion of fossil fuels. Once again action to achieve such reduction in greenhouse gas emissions - in this case of carbon dioxide - will require considerable investment and can only take place over the long term. To understand the extent to which action must be taken to reduce emissions it is also important to have reliable forecasts of future consumption of all kinds of energy generated from fossil fuels.

In the late 1970s and the early 1980s the overestimation of demand for the coming decade resulted in substantial investments being undertaken in Ireland that resulted in spare capacity in the electricity sector over most of the 1980s. The result of this spare capacity was that consumers throughout the 1980s paid higher prices for their energy than consumers elsewhere in the EU.[1] This had a direct negative effect on welfare, as well as having a negative impact on Ireland's competitiveness.

Over the last 20 years a number of different models have been used to forecast energy demand. Early work by Scott, 1980, and Conniffe and Scott,1990, Scott, 1991, and Conniffe, 2000b, made important contributions to our understanding of the factors driving energy demand in Ireland, in particular demand by households. More recently, in Fitz Gerald, 2000, we published forecasts for energy demand out to 2015. These forecasts were based on a fairly simple model of the Irish energy sector that was, in turn, linked to the macro-economic forecasts set out in the Duffy *et al.*, 1999. This model was developed further using the recent work on household behaviour, and used more recently, Duffy *et al.*, 2001, to provide revised forecasts for energy demand.

As a result, of the completion of a database of data on energy demand and energy prices going back to the 1960s (Scott, Curtis and Fitz Gerald, 2001) it is now possible to improve this model of energy demand. This note sets out some of the simple modifications made to that model, modifications that take some account of the potential effects of changes in energy prices on medium-term demand. It is intended that this energy sub-model will be linked directly to the ESRI's macro-economic model - HERMES - to allow integrated forecasting of the economy, including forecasting of energy demand. This energy demand model also includes a simple model of carbon dioxide emissions linked to energy use, to facilitate the undertaking of exercises to examine policy on global warming.

The structure of the paper is as follows. Section 2 briefly outlines the methodology used to develop this new model of energy demand. Section 3 contains a description of the model

[1] Scott, 1980, produced energy forecasts for 1990 that were significantly lower than the official forecasts. The outturn was, in fact, even lower than the conservative Scott forecasts and use of the Scott forecasts could have resulted in significant savings over the 1980s.

equations used to determine the sectoral demand for energy. Section 4 details the set of engineering relationships in the electricity generation block, while Section 5 details the determination of carbon dioxide (CO_2) emission levels. Section 6 then outlines the links between this energy model and the main HERMES macroeconomic model. Section 7 looks at the performance of the energy model within sample, while Section 8 contains some preliminary estimates of the links between energy prices and taxes and the level of carbon dioxide emissions. Section 9 concludes. In the appendices, Appendix 1 details the notation used in the databank, while Appendix 2 lists the full set of equations included in the current version of the energy model.

2 METHODOLOGY

The new version of the energy model is built up as four separate, though interrelated, blocks. The first block models the demand for different fuels in five different sectors of the economy. Given the demand for energy, the second block then models the electricity generation sector based on a series of exogenous engineering relationships. The third block generates the carbon dioxide emissions associated with the levels of energy consumption and production required. Finally the fourth block develops a series of relationships that provide a direct link between the energy model and the HERMES model. Price determination for different fuels is included within this block.

In Section 3 we estimate separate energy demand equations for five sectors of the economy, household, commercial and public, industry, transport and agriculture. The basic approach we use is to model energy consumption in each sector as a simple function of demand and prices. Most of the specifications allow the demand elasticity for energy to fall over time, this is consistent with the findings in many other studies on household demand[2] and with the trend towards the use of more energy-efficient technologies and fuels. Our estimates suggest that demand elasticities for energy in Ireland have indeed fallen over time, however for the future there is no reason to expect that they will continue to fall or to fall at the same pace. They may stabilise at current estimates or even rise slightly as technical advances peter out and the process of inter-fuel substitution is completed. This is an important consideration in using the model for forecasting purposes.

The absence of consistent price data spanning the period of major oil price shocks in the 1970s has, in the past, proved a major obstacle to modelling the sensitivity of energy demand to price shocks. However, a separate study (Scott, Fitz Gerald and Curtis, 2001) has put together a set of price data that go back to the 1960s, allowing more sophisticated analysis of the forces driving energy demand. As with any such exercise carried out long after the event, these price data, while more satisfactory than those previously available, are still not fully reliable. Nevertheless they allow us to estimate key price elasticities of demand for the energy sector.

Using these price data we have also tested for evidence of so-called "irreversible efficiency improvements"[3]. These are designed to capture the fact that rises in real energy prices in the

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[2] These studies suggest that for households energy is a necessity with a low income elasticity of demand (Conniffe, 2000a and 2000b). As a result, low income households spend a higher than average share of their income on energy. See also Duffy *et al.*, 1999, p.75.

[3] See for example Conniffe (1993) "Energy Elasticity Estimates and the Stabilitiy of the Relationship with GDP" in *Issues in Irish Energy Policy*, ESRI Policy Research Series No 20; Haas and Schipper (1998) "Residential

past, such as the major increases in 1973-4 and 1979-80, encouraged research and development into more energy-efficient technologies, which subsequently led to a permanent decline in the consumption of energy for any given level of demand and prices.

While this approach to the inclusion of price variables in determining energy demand is a significant improvement on past modelling work, there is scope for further improvement in methodology. This is reflected in the fact that statistical tests on the estimated equations indicated a change in behaviour in demand in the 1970s. This change in behaviour is clearly related to the energy price shocks of that decade but the simple models estimated have not fully captured the changes that the price shocks produced. As a result, where the estimated model excludes the 1970s data, it will only be valid for a future in which there are no further energy price shocks. This is another important caveat to bear in mind in using the model to produce forecasts.

Section 4 sets out the block determining electricity generation. Many of the decisions affecting the demand and supply of energy have been the result of discrete investment decisions, such as the decision to build the Moneypoint power station. In such cases there is no point in estimating a demand equation. Instead identities are included to describe the basic engineering relationships determining the behaviour of many key variables. (For example, the efficiency with which the electricity sector converts primary energy into electricity.) A substantial number of important relationships are treated in this fashion. This means that to produce any forecast of energy demand, these engineering relationships will have to be forecast separately by any user of the model, and incorporated as basic assumptions in the economic model.

Section 6 outlines the links between the energy model and the HERMES macroeconomic model. Once further testing has been completed these links should allow the energy model to be incorporated in later versions of the HERMES model. The first set of changes occurs within the utilities sector in HERMES, which is the domestic producer of energy. These link the engineering data on the consumption and production of energy, measured in tonnes of oil equivalent (TOEs) from Sections 2 and 3, into economic variables determining output, inputs and prices in the utilities sector. A second set of changes occurs in the determination of household consumption in HERMES, where the consumption of energy is now separated from non-energy consumption, and a personal consumption deflator for energy is derived. Another set of links is the determination of a set of energy prices for different fuels. In particular, this provides a link between the individual fuel prices used in the energy model and the price of energy inputs in the manufacturing sector. Finally an equation is added to estimate the fiscal consequences of an energy and carbon tax.

3 SECTORAL DEMAND FOR ENERGY

3.1 Household demand for energy

In modelling the demand for energy in the residential sector we have estimated two behavioural equations based on the real price of energy for households and real disposable income. The first estimates the demand for electricity and the second the aggregate demand for energy other than electricity. We then model the shares of gas, coal and peat within

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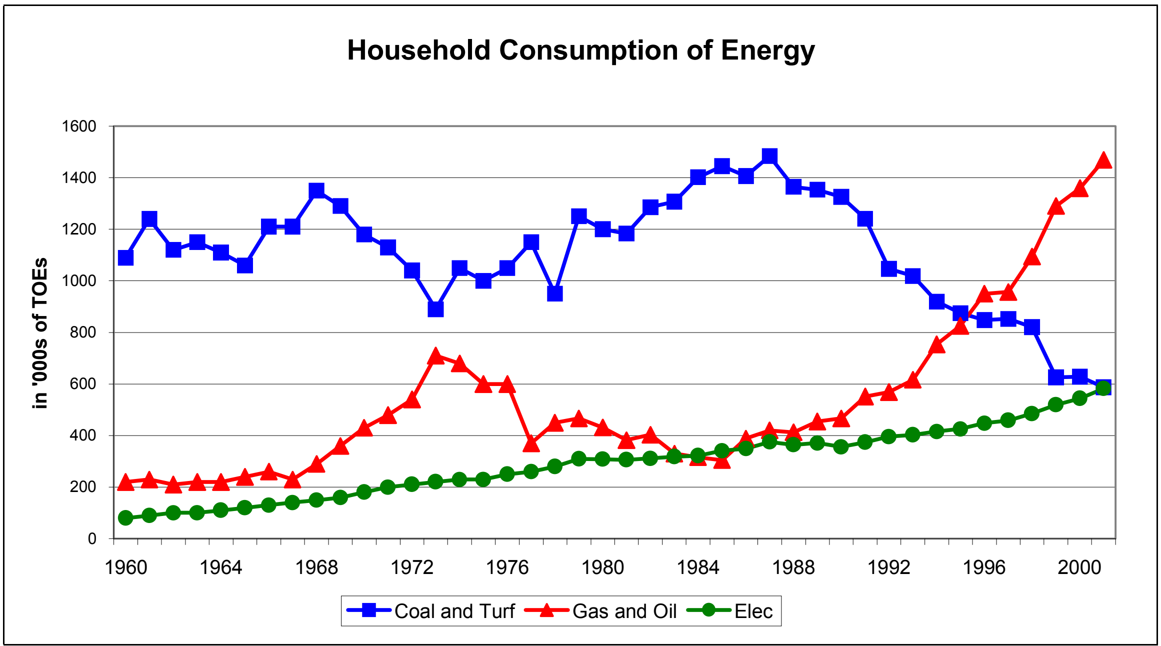
Energy Demand in OECD Countries and the Role of Irreversible Efficiency Improvements: Evidence from the period 1970-1993". *Energy Economics* 20.

aggregate non-electricity energy demand using a simple time trend. The demand for oil is determined residually.

Figure 1



The demand for electricity in the household sector has been rising steadily over the past four decades, with an annual average growth rate between 1960-2001 of 5 per cent. By contrast, the demand for non-electricity energy has grown at a much slower and more volatile pace, with an annual average growth rate of 1.2 per cent. In the mid-1970s the demand for oil plummeted following the first oil price shock, and since the mid-1980s there has been strong substitution of gas and oil for coal and turf as households switched from open fire central heating to boilers (Figure 1). The introduction of natural gas to households in the mid-1980s on a widespread basis, and the banning of the domestic burning of bituminous coal in the late 1980s in Dublin, sped up this process.

3.1.1 Household demand for electricity

Household electricity demand is modelled as a function of a demand variable and a price effect. We estimate two alternative specifications of the demand variable, the first uses the stock of housing (HSTOCK1) and the second uses real disposable income (YRPERD)[4]. In both cases the demand variable is expressed as a reciprocal, this allows for the elasticity of demand for electricity with respect to demand to fall over time.[5] The price variable measures the price of electricity to the consumer (PEN7C) deflated by the deflator on personal consumption (PC).

```
1 :  LOG(EN7C_T) =
   EN7C_C1+EN7C_C2/HSTOCK1+EN7C_C3*LOG(PEN7C_T/PC)+EN7C_C4*LOG(EN7C_T(-1))

NOB = 30     NOVAR = 4   NCOEF = 4
RANGE: 1971A to 2000A
RSQ =                0.99093          CRSQ =                0.989884
F(3/26) =          946.875398         PROB>F =              0
```

[4] We also tested the volume of consumption as the demand variable driving household electricity consumption. However, despite testing over a range of price variables, the price effect in all cases was incorrectly signed.

[5] The elasticity is defined as the percentage change in energy for a one per cent change in the activity variable. In this case the elasticity is –EN7C_C2/HSTOCK1.

```
SER =              0.027177        SSR =             0.019203
DW(0) =            1.706225        COND =          679.996817
MAX:HAT =          0.332063        RSTUDENT =       -3.195679
DFFITS =           0.770758

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

EN7C_C1       5.164165        1.353671        3.814935       0.000756
EN7C_C2    -961.965376      286.645697       -3.355939       0.002441
EN7C_C3      -0.122013        0.032585       -3.744463       0.000907
EN7C_C4       0.425362        0.169761        2.505645       0.018815
```

The first specification was estimated over the period 1971-2000[6], all the variables were significant and the equation is well specified with a standard error for the equation of 2.7 per cent. The coefficient on the lagged dependent variable indicates relatively slow adjustment to changes in demand and price. Both the short run and long run price elasticities are very low at –0.12 and -0.21 respectively[7]. Such a low price elasticity for electricity is to be expected since electricity is not easily substituted for in the consumption of energy and the demand for energy is therefore expected to be relatively unresponsive to marginal price changes.

The long-run elasticity with respect to the housing stock falls from 2.2 in the early 1970s to 1.2 by 2000. With an expected further increase in the housing stock in the period 2001-2015, we estimate that this elasticity could fall further to approximately 0.90 by 2015[8].

```
2 :  LOG(EN7C_T) =
   EN7C_C5+EN7C_C6/YRPERD+EN7C_C7*LOG(PEN7C_T/PC)+EN7C_C8*LOG(EN7C_T(-1))

NOB = 38    NOVAR = 4  NCOEF = 4
RANGE: 1962A to 1999A
RSQ =              0.995716        CRSQ =            0.995338
F(3/34) =       2634.399488        PROB>F =          0
SER =              0.032064        SSR =             0.034956
DW(0) =            2.07933         COND =          335.981446
MAX:HAT =          0.243733        RSTUDENT =       -2.283018
DFFITS =          -1.023082

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

EN7C_C5       1.403945        0.619312        2.266942       0.029869
EN7C_C6   -3101.368692     2739.534096       -1.132079       0.265523
EN7C_C7      -0.050418        0.039423       -1.278922       0.209585
EN7C_C8       0.847513        0.112066        7.562598       0
```

The second specification using real disposable income as the demand variable was estimated over the period 1962-1999[9], this equation is less well specified, the estimated demand and price effects are not well defined and the equation has a somewhat higher standard error for the equation of 3.2 per cent. The coefficient on the lagged dependent variable indicates much more rapid adjustment to changes in demand and price than in the first specification. The short run and long run price elasticities are again very low at –0.05 and -0.33 respectively.

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6 Data for the housing stock (HSTOCK1) begin in 1971 so estimation cannot take place before that year.

7 The statistical results can be read as follows. The equation specification is highlighted in bold, and includes the names given to the estimated coefficients. So EN7C_C6 is the coefficient on real personal disposable income and has a value of –3101.36. Long-run coefficients are derived by dividing by one minus the coefficient on the lagged dependent variable (1-EN7C_C8). NOB is the number of observations, NOVAR is the number of variables, NCOEF is the number of coefficients, RSQ and CRSQ are the R squared and corrected R-squared statistics, F(/) is the F-test for the regression and PROB>F is the significance of the F-test, SER gives the standard error of the equation, , SSR is the sum of squared residuals, DW (0) is the Durban-Watson statistic. The statistics COND, MAX:HAT , RSTUDENT and DFFITS are all based on row deletion tests (see TROLL reference manual for details).

8 Based on Duffy *et al.*, 2001, forecasts of the housing stock.

9 Data on real disposable income (YRPERD) end in 1999.

The long-run elasticity with respect to real disposable income falls from 1.3 in the early 1970s to 0.5 by the late 1990s. We estimate that this elasticity could fall further to approximately 0.25 by 2015[10].

In the model we use the first specification, using housing stock as the demand variable, as the default equation in modeling household demand for electricity.

3.1.2 Household demand for energy other than electricity

We model the residential sector's demand for non-electricity energy based on real personal disposable income (YRPERD) and a price variable (PENC_MOD). We also test for evidence of improvements in technical efficiency using an irreversible price effects variable (PENCR_MAX)[11].

```
4 :  LOG(ENCW_T) =
   ENCW_C1+ENCW_C2*LOG(YRPERD)+ENCW_C3*LOG(PENC_MOD/PC)+ENCW_C4*LOG(ENCW_T(-1))

NOB = 30    NOVAR = 4  NCOEF = 4
RANGE: 1970A to 1999A
RSQ =              0.687813        CRSQ =             0.651791
F(3/26) =         19.094449        PROB>F =           0
SER =              0.05833         SSR =              0.088463
DW(0) =            2.17685         COND =           538.32677
MAX:HAT =          0.340664        RSTUDENT =         2.410846
DFFITS =           1.601466

   COEF      ESTIMATE          STER           TSTAT          PROB>|T|

ENCW_C1        4.848598        1.9624          2.470748        0.020358
ENCW_C2        0.223495        0.079322        2.817577        0.009121
ENCW_C3       -0.139766        0.110182       -1.2685          0.21586
ENCW_C4        0.457332        0.188711        2.423455        0.022636
```

In the equation the dependent variable ENCW_T is the sum of energy volumes (other than electricity and renewables) weighted by their price in 1995[12], while the price variable PENC_MOD is derived as a log-linear price index of individual fuel prices and fuel shares[13]. The irreversible price effects variable proved insignificant in estimation and was excluded from the final specification. The equation was estimated over the period 1970-1999. The estimated equation is not as well specified as the equation for electricity, with a standard error of 5.8 per cent. Also the estimated price effect, although correctly signed, is not very well defined. This is not surprising since we are estimating over a period of significant structural change, including two large discrete energy price shocks, improvements in technical efficiency and dramatic changes in the fuel mix due to the introduction of natural gas (see Figure 1 above). These changes are difficult to parameterise with a small number of variables.

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[10] Based on MTR 2001 forecasts of the housing stock.

[11] PENCR_MAX is the maximum recorded price in to date (since the early 1960s) for the real price of energy PENCR, where PENCR is the CSO Consumer Price Index (CPI) fuel and light price index PENC deflated by the personal consumption deflator PC. See Haas and Schipper (199?).

[12] ENCW_T is derived as follows:

```
A1_ENCW_T      =       values(PEN1C_T,1995a::1995a),
A4_ENCW_T      =       values(PEN422C_T,1995a::1995a),
A6_ENCW_T      =       values(PEN6C_T,1995a::1995a),
A8_ENCW_T      =       values(PEN81C_T,1995a::1995a),
ENCW_T         =       EN1C_T*A1_ENCW_T+EN4C_T*A4_ENCW_T+EN6C_T*A6_ENCW_T+EN8C_T*A8_ENCW_T,
```

Conniffe (1993) argued that this volume aggregate performs better than weighting by calorific values.

[13] The prices used are the price of coal, gas, oil and peat to households.

The coefficient on the income term is low - the short-run elasticity is 0.22 and the long-run elasticity is 0.41 indicating that the demand for energy rises more slowly than income as would be expected (consumption of energy is moving towards saturation levels for certain products like central heating, together with product change toward more energy-saving devices). Nevertheless the specification ensures that rising affluence does increase the demand for energy. The long-run price elasticity at -0.26 is low indicating limited sensitivity to price changes. It is of a similar order of magnitude to the estimated price elasticity for electricity.

3.1.3 Household fuel mix

Having estimated the demand for aggregate energy we now need to consider the issue of the fuel mix in consumption. As discussed above, there has been large-scale substitution of gas and oil for coal and turf in Ireland over the past 15 years. This has arisen for a variety of reasons including rising affluence, changing lifestyles, technical change, government discouragement of the use of "dirty fuels" and the introduction of natural gas. All of these factors have led to a move towards the use of central heating boilers rather than open-fire heating. We attempted to estimate price and demand effects for coal, peat, gas and oil for the residential sector, focusing especially on inter-fuel substitution. However the very rapid and occasionally very large discrete changes (introduction of natural gas in mid-1980s) that have occurred in individual fuel consumption over the estimation period meant that we were unable to estimate a stable set of equations capturing the key substitution effects which have characterised demand over the period.

Instead we determine the share of three individual fuels in aggregate non-electricity demand (ENC_T-EN7C_T), namely coal (EN1C_T) gas (EN6C_T) and peat (EN8C_T), as simple functions of time and then determine the demand for oil (EN4C_T) as a residual. The demand for renewables (EN9C_T) is treated as exogenous. The equations below show the estimated results, the variable "Time" denotes an equation-specific time trend. The results reflect the fact that shares of both coal and peat in non-electricity energy consumption are declining over time while the share of gas is rising.

```
 44 :  LOG(EN1C_T/(ENC_T-EN7C_T)) = EN1C_C1+EN1C_C2*Time

NOB = 19    NOVAR = 3  NCOEF = 3
RANGE: 1980A to 1999A
RSQ =              0.904749        CRSQ =            0.892843
F(1/0) =          75.988822        PROB>F =          0
SER =              0.127012        SSR =             0.258113
DW(0) =            1.9826          COND =          727.227947
MAX:HAT =          0.194737        RSTUDENT =       -2.152334
DFFITS =          -0.672196

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|
EN1C_C1      149.943257       26.642726        5.627925        0
EN1C_C2       -0.075941        0.013378       -5.676755        0
AR1.44         0.614196        0.120495        5.097264        0

 5 :  LOG(EN6C_T/(ENC_T-EN7C_T)) = EN6C_C1+EN6C_C2*Time

NOB = 9    NOVAR = 2  NCOEF = 2
RANGE: 1992A to 2000A
RSQ =              0.955502        CRSQ =            0.949146
F(1/7) =         150.311956        PROB>F =          0
SER =              0.046303        SSR =             0.015007
DW(0) =            2.041304        COND =         1546.095599
MAX:HAT =          0.377778        RSTUDENT =       -2.412183
DFFITS =          -0.923261

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|
```

```
EN6C_C1     -148.138833       11.931367      -12.415914 5.04504382e-006
EN6C_C2        0.073287        0.005978       12.260178 5.49315114e-006

   6 :  LOG(EN8C_T/(ENC_T-EN7C_T)) = EN8C_C1+EN8C_C2*Time

NOB = 19    NOVAR = 3  NCOEF = 3
RANGE: 1980A to 1999A
RSQ =              0.743167        CRSQ =             0.711063
F(1/0) =          23.148634        PROB>F =           0
SER =              0.124455        SSR =              0.247826
DW(0) =            2.056193        COND =           730.273676
MAX:HAT =          0.194737        RSTUDENT =        -2.577668
DFFITS =          -1.2676

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|
EN8C_C1      244.976668      110.578694        2.215406        0.041584
EN8C_C2       -0.123271        0.055291       -2.229497        0.040459
AR1.6          0.908534        0.027815       32.66374         0
```

The demand for oil (EN4C_T) is then determined as a residual:

EN4C_T = (ENCW_T-(EN1C_T*A1_ENCW_T+EN6C_T*A6_ENCW_T+EN8C_T*A8_ENCW_T))/A4_ENCW_T

The total household demand for energy (ENC_T) is derived as:

ENC_T = EN1C_T+EN4C_T+EN6C_T+EN7C_T+EN8C_T+EN9C_T

Finally we estimate the share of LPG oil (EN45C_T) as a function of time (see below) and then determine the demand for non-LPG oil (EN48C_T) as a residual:

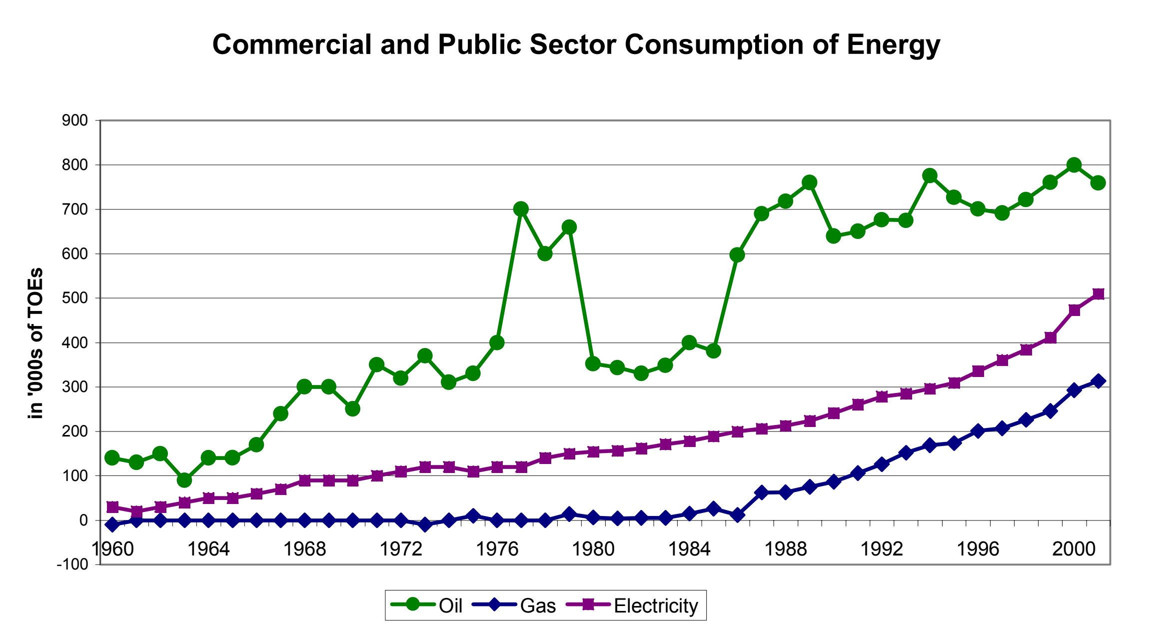
EN48C_T = EN4C_T-EN45C_T

```
   45 :  LOG(EN45C_T/EN4C_T) = EN45C_C1+EN45C_C2*Time

NOB = 9    NOVAR = 2  NCOEF = 2
RANGE: 1991A to 1999A
RSQ =              0.966362        CRSQ =             0.961557
F(1/7) =         201.099294        PROB>F =           0
SER =              0.064918        SSR =              0.0295
DW(0) =            1.58254         COND =          1545.321002
MAX:HAT =          0.377778        RSTUDENT =         2.419187
DFFITS =           1.124899

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

EN45C_C1      235.008324       16.719881       14.055621 2.17457945e-006
EN45C_C2       -0.118849        0.008381      -14.180948 2.04670104e-006
```

3.2 Commercial and public sector demand for energy

In the commercial and public sector energy demand is broadly accounted for by oil and electricity consumption (Figure 2). In more recent years – since the late 1980s - gas has begun to replace oil for central heating purposes. The demand for coal, peat and renewables in this sector is negligible.

Figure 2



Because the data for energy use in the commercial and public sectors of the economy are essentially residually determined, all the errors in the data are likely to be concentrated here. In addition, this sector is very heterogeneous in character. As a result, it is likely to be more difficult to model energy consumption behaviour in this sector than in the other sectors in the economy.

We estimate three behavioural equations for this sector. The first models the demand for electricity as a function of GDP in the sector and the real price of electricity. The second models aggregate non-electricity demand as a function of GDP in the sector and the real price of non-electricity energy. The third equation estimates a price elasticity of substitution between gas and oil in the sector.

3.2.1 Commercial and public demand for electricity

We model demand for electricity as a function of GDP arising in the market and the non-market sectors (OSM+OSN), of the price of electricity to industrial consumers (PEN71_T) relative to the deflator for personal expenditure (PC), and a lagged dependent variable. An irreversible price effects variable was not significant. A chow test on the data suggested a change in behaviour around the mid-1970s so the equation is estimated from 1974 to 1999.

```
   8 :  LOG(EN7S_T) =
   EN7S_C1+EN7S_C2/(OSM+OSN)+EN7S_C3*LOG(PEN71_T/PC)+EN7S_C4*LOG(EN7S_T(-1))

NOB = 26     NOVAR = 4   NCOEF = 4
RANGE: 1974A to 1999A
RSQ =              0.99612           CRSQ =              0.995591
F(3/22) =      1882.719894           PROB>F =            0
SER =              0.025888          SSR =               0.014744
DW(0) =            2.587628          COND =            389.440661
MAX:HAT =          0.480674          RSTUDENT =         -2.764161
DFFITS =           2.453124

   COEF      ESTIMATE            STER           TSTAT            PROB>|T|

EN7S_C1         4.74815        0.830439         5.71764   9.45359131e-006
EN7S_C2   -15968.217505     2564.804718        -6.2259    2.88636643e-006
EN7S_C3       -0.156744        0.043957       -3.565815          0.001728
EN7S_C4        0.458556        0.092512        4.956704  5.85105673e-005
```

The equation is well-specified and all variables are significant. While the results imply a long-run elasticity of demand for electricity with respect to GDP arising in the sector of just over 2 in 1974, by 1999 it had fallen to 0.82. The long-run elasticity of demand for electricity with respect to its price is –0.28, similar to estimates for the household sector. In both cases the long-run elasticities are roughly double the short-run elasticities.

3.2.2 Commercial and public demand for energy other than electricity

The demand for non-electricity energy in the sector is modelled as a declining function of GDP in the sector (OSM+OSN) and the real price of energy (PENS_MOD)[14]. A lagged dependent variable proved insignificant. A maximum price variable, capturing irreversible effects, did not prove significant.

```
  7 :  LOG(ENS_T-EN7S_T) =
   ENS_C1+ENS_C2/(OSM+OSN)+ENS_C3*LOG(PENS_MOD/PC)

NOB = 30    NOVAR = 4  NCOEF = 4
RANGE: 1970A to 2000A
RSQ =              0.85833         CRSQ =             0.841983
F(2/0) =          52.508249        PROB>F =           0
SER =              0.159127        SSR =              0.658353
DW(0) =            2.038181        COND =             7.420458
MAX:HAT =          0.341896        RSTUDENT =         3.629108
DFFITS =           0.923437

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

ENS_C1         7.733714        0.246468       31.378117        0
ENS_C2    -25437.782461     4909.543588       -5.181293        0
ENS_C3        -0.342359        0.150631       -2.272837        0.031537
AR1.7          0.563995        0.148743        3.791732        0
```

The standard error of the equation is very high at 15.9 per cent, however the estimated coefficients are plausible and the very large error is not surprising considering the data difficulties in this sector alluded to above. The own price elasticity is low at –0.34, which is in the range estimated for electricity and for the household sector. The implied elasticity of demand for non-electrical energy with respect to output is estimated to have fallen from 1.75 in 1975 to 0.65 in 2000.

3.2.3 Commercial and public sector inter-fuel mix

We model the demand for gas relative to oil (EN6S_T/EN4S_T) based on the relative price of gas and oil to consumers (PEN6C_T/PEN422C_T). Because gas consumption only began in the late 1980s we estimate from 1990 onwards. Most of the oil consumed in the commercial sector is gasoil, therefore we use the price series PEN422C_T. The results suggest a long-run cross price elasticity of –1.5.

```
   9 :  LOG(EN6S_T/EN4S_T) =
   EN6S_C1+EN6S_C3*LOG(PEN6C_T/PEN422C_T)+EN6S_C4*LOG(EN6S_T(-1)/EN4S_T(-1))

NOB = 11    NOVAR = 3  NCOEF = 3
RANGE: 1990A to 2000A
RSQ =              0.970764        CRSQ =             0.963455
F(2/8) =         132.816716        PROB>F =           0
SER =              0.059656        SSR =              0.02847
DW(0) =            2.653615        COND =             9.836976
MAX:HAT =          0.902745        RSTUDENT =        -2.79189
DFFITS =          -2.149094

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|
```

[14] PENS_MOD is derived as a log-linear price index of individual fuel prices and fuel shares. The prices used are the price of gas and oil to consumers, while for electricity the price used is the industrial price.

EN6S_C1	-0.188123	0.079507	-2.366133	0.04552
EN6S_C3	-0.321646	0.15822	-2.032905	0.076512
EN6S_C4	0.783926	0.051432	15.242123	0

The estimated cross-price elasticity in this equation is very high, probably due to the short period available for estimation. Because of this we use an alternative equation as the default in the energy model while retaining this behavioural equation for the future when the elasticity may be expected to stabilise.

The alternative equation models the demand for gas as an increasing share of non-electricity energy demand in the commercial and public sector. The share of non-electrical energy assumed to be met from gas is EN6SSH. Then the demand for gas from the commercial and public sector is given by

```
EN6S_T  =       (ENS_T-EN7S_T)*EN6SSH
```

It is assumed that the bulk of the non-electrical energy consumed in the sector is for the purposes of providing heat. As a result, heat generated as part of CHP (Combined Heat and Power Plant) generation in the sector must be taken into account. The proportion of total CHP generation accounted for by the commercial sector is given by ENCHS. Then the energy displaced by the heat from CHP in this sector is

```
EN6SCH_T        =       EN6CH_T*ENCHS
```

All the displacement of energy is assumed to be in the gas heating sector. The demand for non-CHP gas is then given by

```
EN6SNH_T        =       EN6S_T-EN6SCH_T
```

The demand for coal (EN1S_T), peat (EN8S_T) and renewables (EN9S_T) in the commercial and public sector is very low, these are all assumed to be exogenous. The demand for oil (EN4S_T) is then determined as a residual in the model as follows:

```
EN4S_T          =       ENS_T-EN7S_T-EN6S_T-EN1S_T-EN8S_T-EN9S_T
```

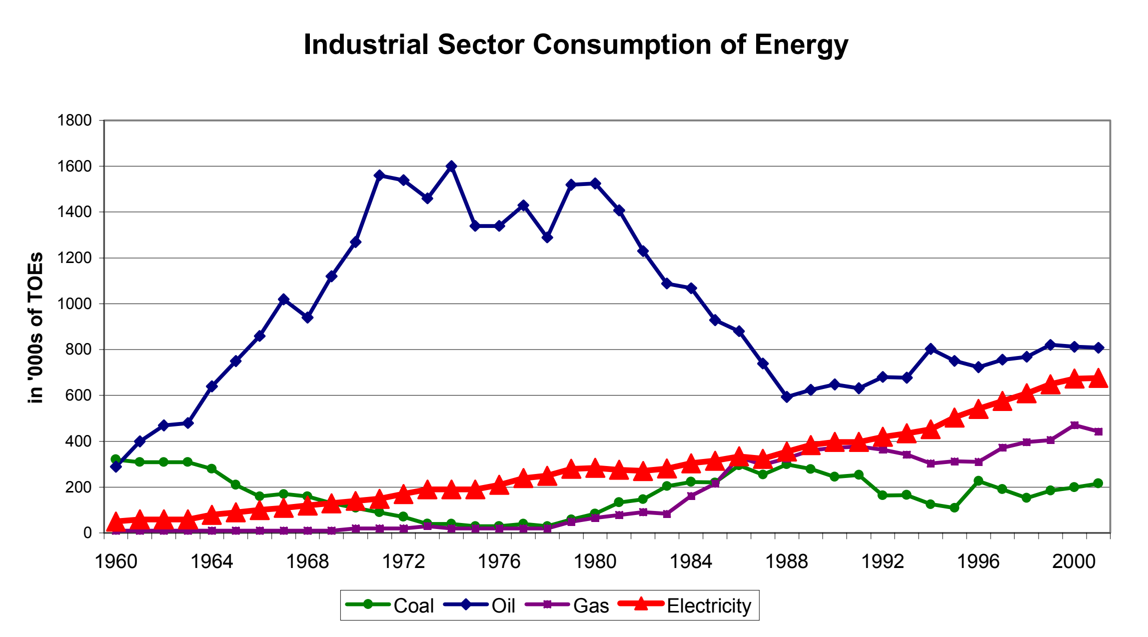
The demand for LPG oil (EN45S_T) is assumed exogenous, then the demand for non-LPG oil (EN48S_T) is determined as:

```
EN48S_T =       EN4S_T-EN45S_T
```

3.3 Industrial energy demand

In the industrial sector the restructuring away from traditional energy-intensive production towards more high-tech industries, together with the two oil price shocks, led to a sustained decline in the consumption of oil in the 1980s. This meant that despite the dramatic growth in the industrial sector over this twenty-five year period total consumption of energy in 1995 was the same as in 1971. Since then energy consumption in the industrial sector has risen steadily, with rises recorded in the consumption of all fuels important in the sector, namely coal, oil, gas and electricity (see Figure 3).

Figure 3



In the model for the industrial sector we estimate three behavioural equations, modelling the demand for coal, electricity and total energy. The demand for gas is modelled based on its share in total non-electricity energy consumption and the demand for oil is determined as a residual.

3.3.1 Industrial sector demand for coal

The demand for coal in the industrial sector has remained fairly stable, in contrast to the household sector where consumption of coal has fallen dramatically over the past few decades. In 2001 industrial consumption of coal in TOEs was at the same level as in 1965, while over the same period household consumption of coal had more than halved. Because of the continued importance of coal to the industrial sector we estimate a behavioural equation for the demand for coal in the industrial sector. In the equation the demand for coal is a function of the real price of coal (PEN1I_T/PQGIMT) and a time trend (Time).

```
47 :  LOG(EN1I_T) = EN1I_C1+EN1I_C2*LOG(PEN1I_T/PQGIMT)+EN1I_C3*Time

NOB = 19     NOVAR = 4   NCOEF = 4
RANGE: 1980A to 1999A
RSQ =                  0.59233          CRSQ =               0.510796
F(2/0) =               7.264833         PROB>F =             0.003098
SER =                  0.208868         SSR =                0.654388
DW(0) =                1.829814         COND =            1076.676485
MAX:HAT =              0.398981         RSTUDENT =           2.937963
DFFITS =               1.071128

   COEF      ESTIMATE           STER           TSTAT           PROB>|T|

EN1I_C1        96.6484        36.12558         2.675345        0.017292
EN1I_C2        -1.236283       0.552641       -2.237044        0.040892
EN1I_C3        -0.043097       0.017447       -2.470137        0.025992
AR1.47          0.424387       0.141315        3.003132        0.008916
```

The estimated coefficients in the equation are well-specified, however the standard error of the equation is very large at 20.8 per cent. The equation is estimated from 1980 onwards and the results suggest a high price elasticity of –1.23 and a negative time trend.

3.3.2 *Industrial sector demand for aggregate energy*

The equation determining consumption of energy in the industrial sector (excluding feedstock) is shown below. Demand is modelled as a declining function of value added arising in industry (OI) and relative prices (PQEIMT/PQGIMT)[15]. The equation also includes the value-added intensity of gross output (QNIMT/QGIMT) and an irreversible efficiency improvements effect (PQEIMTR_MAX)[16].

```
   10 :  LOG(ENI_T) = ENI_C1+ENI_C2/OI+ENI_C3*LOG(QNIMT/QGIMT)+ENI_C4*LOG(PQEIMT
   R_MAX)+ENI_C5*LOG(ENI_T(-1))

NOB = 22    NOVAR = 5  NCOEF = 5
RANGE: 1978A to 1999A
RSQ =              0.607243        CRSQ =            0.514829
F(4/17) =          6.570934        PROB>F =          0.002186
SER =              0.058262        SSR =             0.057705
DW(0) =            2.446805        COND =          323.808802
MAX:HAT =          0.592124        RSTUDENT =       -2.715634
DFFITS =          -3.272001

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

ENI_C1         2.210236        1.383802        1.59722        0.128637
ENI_C2     -5688.979846     2389.677069       -2.380648       0.029248
ENI_C3        -0.549108        0.282454       -1.944064       0.068628
ENI_C4        -0.377168        0.145652       -2.589526       0.019089
ENI_C5         0.708399        0.182939        3.872323       0.001223
```

The results indicate a well-specified equation although the standard error of the equation is quite high at 5.8 per cent. The relative price effect proved insignificant in estimation and is excluded from the final specification. The implied long-run elasticity on industrial GDP is falling rapidly over time from 2.56 in 1980 to 0.57 in 2000. In addition, the long-run coefficient –1.88 on value-added intensity indicates that the shift towards higher value-added production has reduced the demand for energy in the industrial sector for a given level of output. This latter effect captures the results of significant structural change within the industrial sector over the last thirty years. Finally, the long-run coefficient on the maximum price variable –1.29 indicates that sharp energy price hikes have triggered the introduction of energy-saving technologies in the past.[17]

3.3.3 *Industrial sector demand for electricity*

The demand for electricity in the industrial sector (EN7I_T) is a declining function of GDP arising in industry (OI), relative prices (the price of electricity for industry, PEN71_T, relative to the price of manufacturing output, PQGIMT) and a lagged dependent variable.

```
   11 :  LOG(EN7I_T) =
   EN7I_C1+EN7I_C2/OI+EN7I_C3*LOG(PEN71_T/PQGIMT)+EN7I_C4*LOG(EN7I_T(-1))

NOB = 25    NOVAR = 4  NCOEF = 4
RANGE: 1975A to 1999A
RSQ =              0.990484        CRSQ =            0.989125
F(3/21) =        728.633966        PROB>F =          0
SER =              0.034593        SSR =             0.02513
DW(0) =            1.507367        COND =          425.806154
```

[15] PQEIMT is the price of energy inputs into manufacturing and PQGIMT is the price of manufacturing output. QNIMT is the volume of net output in manufacturing and QGIMT is the volume of gross output.

[16] PQEIMTR_MAX is the maximum price series for the real price of energy to the manufacturing sector (PQEIMT/PQGIMT).

[17] However, these price shocks affected industry world-wide and led to major research into energy efficiency. If a future price shock only affected Ireland there would be no change in the incentive to undertake research world-wide and the effects through this channel would be negligible.

```
MAX:HAT =           0.414724        RSTUDENT =         2.051539
DFFITS =            0.962032

   COEF      ESTIMATE           STER           TSTAT           PROB>|T|

EN7I_C1        4.471704        1.151545        3.883221        0.000859
EN7I_C2    -4272.473561     1339.797149       -3.188896        0.004416
EN7I_C3       -0.149523        0.05701        -2.622771        0.015902
EN7I_C4        0.482925        0.167259        2.887282        0.008815
```

The estimation results are good as are the equation diagnostics. The short run elasticity of demand for electricity in the industrial sector with respect to GDP arising in the sector is estimated to fall from 0.78 in the mid-1970s to 0.14 in 1999. The long-run elasticity falls from 1.5 to 0.28. The elasticity of demand for electricity with respect to its own price is –0.15 in the short run and –0.29 in the long run. This is much lower than the elasticity with respect to GDP in industry of 0.57 (see Fitz Gerald, 2000) and is more in line with estimates for the household and commercial and public sector. The addition of a relative price term in this specification has made a significant difference to the result, as has the change in specification to allow the elasticity with respect to output to change over time.

3.3.4 Industrial sector fuel mix

The demand for gas in the industrial sector is determined using a series of share projections. The proportion of total CHP generation accounted for by the industrial sector is given by ENCHI. Then the energy displaced by the heat from CHP in this sector is

```
EN6ICH_T       =      EN6CH_T*ENCHI,
```

All the displacement of energy is assumed to be in the gas heating sector. The demand for non-CHP gas (EN6INH_T) is assumed to rise in line with the overall demand for non-electricity energy subject to an adjustment for the proportion of industry that has gas available to it (EN6ISH) and the deduction of the heat available from CHP plants. Thus the demand for gas from the industrial sector (other than gas for CHP) is given by

```
EN6INH_T       =      (ENI_T-EN7I_T)*EN6ISH-EN6ICH_T
```

The total demand for gas in the industrial sector is then simply

```
EN6I_T         =      EN6ICH_T+EN6INH_T
```

The demand for peat (EN8I_T) and renewables (EN9I_T), which are both very small, are treated as exogenous. The share of LPG oil in total industrial oil consumption (EN45I_T/EN4I_T) is modelled as a simple time trend (Time):

```
   46 :  LOG(EN45I_T/EN4I_T) = EN45I_C1+EN45I_C2*Time

NOB = 14    NOVAR = 3  NCOEF = 3
RANGE: 1985A to 1999A
RSQ =               0.632818        CRSQ =             0.566058
F(1/0) =            9.478951        PROB>F =           0.004044
SER =               0.085274        SSR =              0.079988
DW(0) =             2.569558        COND =           988.804832
MAX:HAT =           0.257143        RSTUDENT =        -2.678359
DFFITS =           -1.35755

    COEF      ESTIMATE           STER           TSTAT           PROB>|T|

EN45I_C1       52.689142       16.158374        3.260795        0.007588
EN45I_C2       -0.027649        0.008108       -3.410333        0.005822
AR1.46          0.332361        0.069712        4.767659        0
```

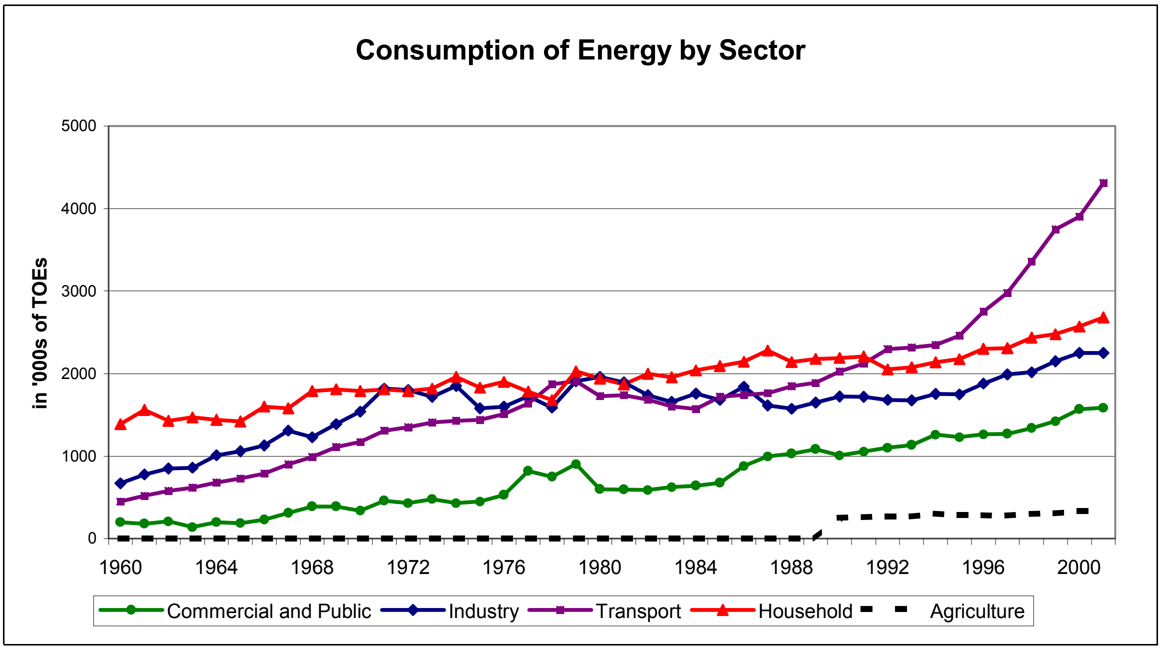
The demand for non-LPG oil (EN48I_T) is treated in the model as a residual:

```
EN48I_T        =      ENI_T-EN1I_T-EN6I_T-EN7I_T-EN8I_T-EN9I_T-EN45I_T
EN4I_T         =      EN45I_T+EN48I_T
```

3.4 Transport energy demand

The transport sector has been the largest single consumer of energy in the economy since the beginning of the 1990s as shown in Figure 4. Energy consumption in the transport sector is mainly accounted for by gasoline (38% in 2001), gasoil (45% in 2001) and kerosene (16% in 2001) with negligible amounts of electricity and LPG. Most of the kerosene used in the transport sector is to fuel jet aircraft.

Figure 4



We estimate three behavioural equations for the transport sector. The first models the demand for private cars, following the model developed in DKM (1998). The demand for cars is used as the driving variable in the next behavioural equation, which models the demand for oil, other than kerosene and LPG, as a function of the stock of cars and relative prices. The third equation models the demand for kerosene in the transport sector as a function of relative prices.

3.4.1 Transport sector demand for cars

We model the demand for private cars (SCARS) following the methodology used by DKM (1998). In their study DKM adopt a logistic functional form which specifies a saturation rate on ownership rates. They model ownership per adult (age group 20-74; N2074) as a function of real domestic demand (RDDA) per adult and choose a saturation rate of 0.80[18] based on a consideration of international experience. This chosen saturation rate means that the demand for cars will stabilize on reaching an 80% ownership rate, from then onwards growth in the stock of cars will be driven by growth in the adult population. The functional form they use, in logarithms, is given as

[18] i.e. that in the long run 80% of adults aged 20 to 74 will own cars.

```
LOG(0.8/(SCARS/N2074)-1) = SCARS_C1+SCARS_C2*RDDA/N2074
```

They specify a first-order error correction process in estimation, we re-estimate this model using real disposable income (YRPERD) in place of real domestic demand. The results are given below. While the R^2 is quite low, the standard error is reasonable. The sharp dip in the number of private cars in 1982 is the reason behind the very high DFFITS.

```
   11 :  DEL(1: LOG(0.8/(SCARS/N2074)-1)) = SCARS_C1+SCARS_C2*DEL(1: YRPERD/N207
   4)+SCARS_C3*LOG(0.8/(SCARS(-1)/N2074(-1))-1)+SCARS_C4*YRPERD(-1)/N2074(-1)

NOB = 39    NOVAR = 4  NCOEF = 4
RANGE: 1961A to 1999A
RSQ =              0.571105        CRSQ =            0.534342
F(3/35) =         15.535003        PROB>F =          0
SER =              0.042894        SSR =             0.064395
DW(0) =            1.824564        COND =           53.893568
MAX:HAT =          0.296072        RSTUDENT =        4.063399
DFFITS =           2.437257

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

SCARS_C1       0.523203        0.162292        3.223829        0.002738
SCARS_C2      -0.074454        0.018851       -3.949541        0.000361
SCARS_C3      -0.212103        0.053607       -3.956627        0.000354
SCARS_C4      -0.041566        0.012441       -3.340997        0.001995
```

We re-estimated this model using the population aged 15-64 as the relevant adult population. If accepted this would be more convenient since N1564 is a behavioural variable within the current HERMES model. The change should be uncontroversial since this is the critical group within which change in demand for cars can be expected to occur. As can be seen below, the results are very similar. This is the default equation for SCARS used in the model.

```
   13 :  DEL(1: LOG(0.8/(SCARS/N1564)-1)) = A1_SCARS+A2_SCARS*DEL(1: YRPERD/N156
   4)+A3_SCARS*LOG(0.8/(SCARS(-1)/N1564(-1))-1)+A4_SCARS*YRPERD(-1)/N1564(-1)

NOB = 39    NOVAR = 4  NCOEF = 4
RANGE: 1961A to 1999A
RSQ =              0.567547        CRSQ =            0.53048
F(3/35) =         15.31124         PROB>F =          0
SER =              0.041305        SSR =             0.059713
DW(0) =            1.843154        COND =           53.975083
MAX:HAT =          0.304052        RSTUDENT =        4.161173
DFFITS =           2.463084

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_SCARS       0.497452        0.156031        3.188165        0.003013
A2_SCARS      -0.072711        0.018911       -3.844914        0.000488
A3_SCARS      -0.202922        0.05119        -3.96411         0.000346
A4_SCARS      -0.039912        0.012149       -3.285142        0.002321
```

Comparing these results with the DKM study, the estimated coefficient on the lagged dependent variable A3_SCARS=–0.20 is of a similar order of magnitude to that reported in the DKM study (-0.25), however the coefficient on the lagged demand variable A4_SCARS is of a very different order of magnitude, -0.04 here, -0.003 in the DKM study.

3.4.2 Transport sector demand for gasoline and gasoil

We model the demand for oil, other than LPG and kerosene (EN49ST_T), as a function of the stock of cars (SCARS), the price of unleaded petrol relative to UK prices - PEN41U_T/(PEN41U_T_UK*REX_UK) - and the maximum real price of unleaded petrol (PEN41UR_MAX). A lagged dependent variable proved insignificant.

```
   12 :  LOG(EN49ST_T) = EN4ST_C1+EN4ST_C2*LOG(SCARS)+EN4ST_C3*LOG(PEN41U_T/(PEN
   41U_T_UK*REX_UK))+EN4ST_C4*LOG(PEN41UR_MAX)
```

```
NOB = 31    NOVAR = 4  NCOEF = 4
RANGE: 1970A to 2000A
RSQ =              0.982352        CRSQ =            0.980391
F(3/27) =        500.970229        PROB>F =          0
SER =              0.046192        SSR =             0.057609
DW(0) =            1.404636        COND =          312.810688
MAX:HAT =          0.304037        RSTUDENT =       -2.44608
DFFITS =           1.243109

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

EN4ST_C1        2.78536        0.630265        4.419348        0.000145
EN4ST_C2        1.179551       0.074808       15.767721        0
EN4ST_C3       -0.192359       0.079034       -2.433871        0.021833
EN4ST_C4       -0.442961       0.153369       -2.888196        0.007543
```

The coefficient on the stock of cars is greater than one, implying that at the margin new cars consume more petrol than older models. This probably reflects the increase in the size of cars and the intensity of usage. The coefficient on the maximum price captures fuel-efficiency improvements made as a result of sharp rises in the price of petrol in the mid-1970s and the early 1980s. This does not mean that a major price increase in petrol in Ireland on its own would have anything like such an effect. As research into vehicle efficiency is a world-wide phenomenon, similar efficiency gains could only be anticipated where there was a world-wide rise in the real cost of motor fuel. The elasticity with respect to the price of petrol relative to the UK is –0.19. This reflects the importance of cross-border trade in petrol driven by differences in taxes.

3.4.3 Transport sector demand for other fuels

For the purposes of calculating greenhouse gas emissions it is necessary to separately identify kerosene used by aircraft (EN46ST_T) from the total of oil used in the transport sector. This is modelled as a function of the real price of kerosene to the consumer (PEN46C_T/PC) and a lagged dependent variable. We use the price to consumers since we have no consistent time series data available on the price of kerosene to the airline industry.

```
   48 :  LOG(EN46ST_T) =
   EN46ST_C1+EN46ST_C2*LOG(EN46ST_T(-1))+EN46ST_C3*LOG(PEN46C_T/PC)

NOB = 15    NOVAR = 3  NCOEF = 3
RANGE: 1985A to 1999A
RSQ =              0.931951        CRSQ =            0.920609
F(2/12) =         82.171376        PROB>F =          0
SER =              0.066218        SSR =             0.052618
DW(0) =            1.685585        COND =          125.535755
MAX:HAT =          0.465091        RSTUDENT =       -2.13491
DFFITS =          -0.979733

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

EN46ST_C1        3.440554        1.01005         3.406322        0.005209
EN46ST_C2        0.674687        0.085843        7.859594 4.50504729e-006
EN46ST_C3       -0.24568         0.101523       -2.419953        0.03232
```

Despite the problems with the price variable, the estimated long-run price elasticity at –0.36 is plausible, within the range of energy price elasticities estimated elsewhere in this model.

For calculating emissions it is also necessary to net out the small amount of LPG consumed in the private transport sector (EN45ST_T). This is treated as exogenous in the model. Total oil consumed (EN4ST_T) is then derived as

```
EN4ST_T =       EN49ST_T+EN45ST_T+EN46ST_T
```

The small volume of electricity consumed by public transport (EN7ST_T) is treated as exogenous. Total consumption of energy in the transport sector is given by ENST_T

```
ENST_T          =       EN4ST_T+EN7ST_T
```

3.5 Agriculture energy demand

Data for energy use in the agricultural sector are only available from 1990. The demand for energy from the agricultural sector represents a tiny fraction of total energy consumption in the economy (3% in 2001). Furthermore, the share of energy in total agricultural inputs fell in the 1990s, so energy inputs are rising less rapidly than total inputs. Most of the energy consumed in the agricultural sector is diesel oil, accounting for 83% of total energy demand in 2001, the remainder is electricity (15% in 2001) and a very small amount of renewables.

We estimate an equation for total energy demand and an equation for the demand for electricity in the agricultural sector. The demand for oil is then determined residually.

3.5.1 Agricultural sector demand for energy

In the energy model the share of the agricultural sector's energy consumption in total agricultural inputs (ENA_T/QMA) is modelled as a function of the real price of energy inputs. The price variable used is the price of energy inputs in manufacturing (PQEIMT) deflated by the deflator for agricultural inputs (PQMA).

```
   49 :  LOG(ENA_T/QMA) = ENA_C1+ENA_C2*LOG(PQEIMT/PQMA)

NOB = 10    NOVAR = 2  NCOEF = 2
RANGE: 1990A to 1999A
RSQ =              0.352537        CRSQ =             0.271604
F(1/8) =           4.355913        PROB>F =           0.070336
SER =              0.037147        SSR =              0.011039
DW(0) =            1.657188        COND =             1.449134
MAX:HAT =          0.707771        RSTUDENT =         1.860369
DFFITS =           2.895236

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

ENA_C1        -1.955257        0.012565     -155.616066        0
ENA_C2        -0.70606         0.3383         -2.087082        0.070336
```

The equation is estimated from 1990 onwards because there are no consistent data on agricultural energy consumption prior to 1990. Given the small number of observations, the equation is well-specified with a relatively high price elasticity for energy inputs in the agricultural sector.

3.5.2 Agricultural sector demand for electricity

The demand for electricity in the agricultural sector (EN7A_T) is modeled as a function of the real price of electricity to the consumer (PEN7C_T/PC). The implied price elasticity is implausibly high, at –1.5, however because electricity consumption in the agricultural sector is such a small component of total electricity consumption we proceed with this as the default equation in the model.

```
   50 :  LOG(EN7A_T) = EN7A_C1+EN7A_C2*LOG(PEN7C_T/PC)

NOB = 10    NOVAR = 2  NCOEF = 2
RANGE: 1990A to 1999A
RSQ =              0.82142         CRSQ =             0.799098
F(1/8) =          36.797855        PROB>F =           0.000301
```

```
SER =               0.043461        SSR =             0.015111
DW(0) =             1.71002         COND =          257.232903
MAX:HAT =           0.399426        RSTUDENT =        -2.343031
DFFITS =           -1.910788

   COEF      ESTIMATE          STER           TSTAT          PROB>|T|

EN7A_C1       14.476663        1.767694        8.189575 3.68791030e-005
EN7A_C2       -1.504319        0.247987       -6.066124        0.000301
```

Demand for renewables in agriculture (EN9A_T) is exogenous, then the demand for oil (EN4A_T) is the residual:

```
EN4A_T          =       ENA_T-EN7A_T-EN9A_T
```

3.6 Identities used to aggregate sectoral data

Having determined the demand for different types of energy by sector, these are then aggregated up to total final consumption (suffix FC) by fuel (see Appendix 2) and total final consumption for the economy is then generated as follows:

```
ENFC_T          =       EN1FC_T+EN4FC_T+EN6FC_T+EN7FC_T+EN8FC_T+EN9FC_T,
```

Because there are losses in the transmission of energy for certain fuels (the exceptions are coal and renewables) total final consumption does not always equal the total primary energy requirement (TD) for each fuel. An adjustment has to be made to allow for these transmission losses (TRLOS). So for example total primary energy requirement of oil in the household sector (EN4CTD_T) is derived as total demand for oil in the household sector (EN4C_T) adjusted for transmission losses (EN4TRLOS_T)[19]:

```
EN4CTD_T        =       EN4C_T*(1+EN4TRLOS_T/EN4FC_T)
```

Total primary energy requirement by fuel by sector is determined by adjusting final consumption by the amount of the transmission loss as shown in Appendix 2. The data are then aggregated up to give total primary energy requirement for the economy (ENTD_T). The demand for gas used as feedstock in industry (EN6IMCHF_T), which is treated as exogenous in the energy model, is included in total primary energy requirement:

```
ENTD_T          =       EN1TD_T+EN4TD_T+EN6TD_T+EN8TD_T+EN9TD_T+EN6IMCHF_T+EN7TD_T
```

Total domestic production of energy (ENQD_T) sums the domestic production of individual fuels. These are all treated as exogenous in the model.

```
ENQD_T          =       EN1QD_T+EN6QD_T+EN7QD_T+EN8QD_T+EN9QD_T
```

Given exogenous (and currently very small) exports (ENX_T) and stock changes (ENBA_T), imports of energy are then derived as the residual between domestic production (ENQD_T) and total domestic energy requirement (ENTD_T):

```
ENM_T           =       ENX_T+ENTD_T-ENQD_T-ENBA_T
```

Finally imports of oil (M3) are linked to energy imports using a simple adjustment factor M3_DIS:

```
M3              =       ENM_T*M3_DIS
```

[19] In the case of oil these losses arise from the conversion of crude oil into petrol etc. in the refinery.

4 ELECTRICITY GENERATION

The electricity generation sector covers all electricity generated, including electricity generated from renewable sources (hydro and wind) and electricity generated in combined heat and power plants (CHPs). The output of the sector is driven by demand for electricity EN7FC_T and the set of equations given below relate this demand to the fuels consumed to meet that demand.

In the current model we confine ourselves to parameterising the engineering relationships that underpin the sector and the fuel mix is not treated as being sensitive to fuel prices. Because of the complexities of the sector, with demand varying considerably over the course of a normal day, a special model is being developed of the electricity sector (Fitz Gerald, 2002). When this model becomes available it will allow simulations to be undertaken of how the electricity sector would react to changes in fuel prices, especially to changes in fuel prices driven by taxes or auctioning of emissions permits.

We begin this section by presenting the engineering relationships which derive the electricity generated by fuel type. Total domestic electricity generated is driven by total demand for electricity so that the electricity generated by non-CHP gas is treated as the residual, setting demand equal to supply. However this relationship is complicated due to differences between actual electricity generated domestically and total electricity consumed domestically. We use a series of technical identities to describe these losses in conversion, generation and transmission. These are described in the latter part of this section.

The total coal consumed in electricity generation is exogenous (EN1E_T) and the conversion factor is applied to give the electricity generated by coal (EN7G1_T).

```
EN7G1_T        =       EN1E_T*ENGEFF1
```

The total gasoil consumed in electricity generation is exogenous (EN42E_T) and the conversion factor is applied to give the electricity generated by gasoil (EN7G42_T). Similarly total fuel oil consumed in electricity generation is exogenous (EN43E_T) and the conversion factor is applied to give the electricity generated by fuel oil (EN7G43_T). Total electricity generated by oil (EN7G4_T) is then the sum of these two.

```
EN7G42_T       =       EN42E_T*ENGEFF42,
EN7G43_T       =       EN43E_T*ENGEFF43,
EN7G4_T        =       EN7G42_T+EN7G43_T,
```

The total peat consumed in electricity generation is exogenous (EN8E_T) and the conversion factor is applied to give the electricity generated by peat (EN7G8_T).

```
EN7G8_T        =       EN8E_T*ENGEFF8,
```

The model includes a switch so that EN7G9_T, electricity generated from renewables can be forecast exogenously or driven by policy on renewables, where renewables here excludes hydro (EN7QD_T). The exogenous forecast uses the efficiency of conversion (ENGEFF9, generally unity) and the amount of electricity generated from renewables, to determine the input of renewable electricity (EN9E_T). Alternatively the proportion of total electricity generated from renewables (ENRENSH) is included as a policy variable to determine total electricity produced from renewables (EN7G9_T). The default in the model is the exogenous forecast.

```
EN7G9_T        =       IF Z_EN7G9 == ONE THEN
                       EN9E_T*ENGEFF9
                       ELSE
```

```
                    EN7GENES_T*ENRENSH
```

The total gas from CHP plants is exogenous (EN6CH_T). The proportion used in electricity generation is derived as one minus the shares used in the commercial and industrial sectors (1-ENCHS-ENCHI). The conversion factor for CHP gas (ENGEFF6C) is then applied to give the electricity generated by gas from CHP plants (EN7GCH6_T). This assumes that the Department of Public Enterprise statistics treat the electricity generated through CHP as part of total electricity generated, and the use of the electricity by the producers is also included in total national demand for electricity.

```
EN7GCH6_T     =     EN6CH_T*(1-ENCHS-ENCHI)*ENGEFF6C
```

Total electricity generated (EN7GENES_T) is the sum of the electricity generated from the different fuels. Given that total output is demand driven, and given the need for electricity from gas to balance the system, this equation determines residually the quantity of electricity generated from gas, excluding CHP (EN7GNH6_T).

```
EN7GNH6_T     =     EN7GENES_T-(EN7G1_T+EN7G8_T+EN7G4_T+EN7GCH6_T+EN7TD_T+EN7G9_T)
EN7G6_T       =     EN7GCH6_T+EN7GNH6_T
```

Total gas used in electricity generation (EN6E_T) can then be derived as the sum of CHP gas used in electricity generation and the implied non-CHP gas used in electricity generation – the latter is derived using the conversion factor for non-CHP gas (ENGEFF6N).

```
EN6E_T        =     (EN6CH_T*(1-ENCHS-ENCHI)+(EN7GNH6_T/ENGEFF6N))
```

Finally total energy used in electricity generation (ENE_T) is derived by aggregating as follows:

```
EN4E_T        =     EN42E_T+EN43E_T
ENE_T         =     EN1E_T+EN4E_T+EN6E_T+EN7QD_T+EN8E_T+EN9E_T
```

In the model total electricity generated is called EN7GENES_T. This must be adjusted for losses due to approximation of the estimated conversion of individual fuels into electricity (EN7GENAD_T). Because precise numbers are not available on the conversion of energy into electricity, the total for electricity generated as determined in the model is not precisely equal to that actually generated (EN7GEN_T) and an adjustment must be made:

```
EN7GENAD_T    =     EN7GENES_T-EN7GEN_T
EN7GENES_T    =     EN7GEN_T/EN7GENAD_FIX
```

where

```
EN7GENAD_FIX=EN7GEN_T/EN7GENES_T
```

Total electricity available to the economy is EN7AVAIL_T, so total domestic electricity generated (EN7GEN_T) is given by subtracting imports and adding exports:

```
EN7GEN_T      =     EN7AVAIL_T-EN7M_T+EN7X_T,
```

Some of the available electricity is used by the generating stations as own use (EN7OUSE_T) while the rest is sent out for consumption (ENGSO_T).

```
EN7AVAIL_T    =     EN7GSO_T+EN7OUSE_T,
EN7OUSE_T     =     EN7GSO_T*EN7OUSE_FIX,
```

where

```
EN7OUSE_FIX   =     EN7OUSE_T/EN7GSO_T
```

Finally transmission losses mean that the total amount of electricity sent out by the generating stations (EN7GSO_T) is not equal to total consumption of electricity (EN7FC_T), these transmission losses are estimated equal to 9% (EN7TRL_FIX=0.09):

```
EN7GSO_T        =       EN7FC_T/(1-EN7TRL_FIX)
```

This section of the model also generates an overall transmission loss for electricity EN7TRLOS_T which is used to link final consumption of electricity to total primary energy requirement of electricity as described in Section 3 above.

```
EN7TRLOS_T      =       EN1E_T+EN4E_T+EN6E_T+EN8E_T+EN9E_T+EN7QD_T+EN7M_T-EN7X_T-EN7FC_T,
```

The model also generates an estimated transmission loss EN7TRL_T and conversion loss EN7CONL_T, these variables are not used at present in the model.

```
EN7TRL_T        =       EN7GSO_T-EN7FC_T,
EN7CONL_T       =       ENE_T-EN7GEN_T,
```

5 CARBON DIOXIDE EMISSIONS

The derivation of carbon dioxide emissions by sector and by fuel is a straightforward application of emission factors by fuel. These emission factors are based on the following data from the DOE:

		Tonnes of CO2 per TOE
Coal	A1_CARB	3.586
Oil - air transport: Kerosene	A46_CARB	2.980
Oil - Electricity	A4E_CARB	3.180
Oil - other	A49_CARB	3.050
LPG	A45_CARB	2.660
Gas	A6_CARB	2.300
Gas - NET	A6IMCHF_CARB	2.300
Peat - domestic	A8_CARB	4.140
Peat - electricity	A8E_CARB	4.830

,
The emission factor for electricity (A7_CARB) is derived as a variable based on the emissions of individual fuels used in electricity generation in each year.

```
A7_CARB =       (EN1E_T*A1_CARB+EN4E_T*A4E_CARB+EN6E_T*A6_CARB+EN8E_T*A8E_CARB)/EN7FC_T
```

Total carbon dioxide emissions are then generated by sector and by fuel as shown below (with more detail in Appendix 2):

```
CO2             =       CO2LOS+CO2C+CO2S+CO2I+CO2A+CO2ST+CO2IMCHF
```

6 LINKS WITH THE HERMES MACROECONOMIC MODEL

The first set of links is in the utilities sector. These link the engineering data on the consumption and production of energy measured in tonnes of oil equivalent (TOEs) into economic variables determining output, inputs and prices in the utilities sector. A second set of links are in the determination of household consumption, where the consumption of energy is now separated from non-energy consumption, and a personal consumption deflator for energy is derived. A third set of links is the determination of a set of energy prices for different fuels. Finally an equation is added to estimate the fiscal consequences of an energy and carbon tax.

6.1 Utilities Sector

The first set of links occurs within the utilities sector in HERMES, which is the domestic producer of energy. These link the energy data on the consumption and production of energy measured in tonnes of oil equivalent (TOEs) into economic variables determining output, inputs and prices in the utilities sector.

6.1.1 Utilities Output

Utilities output (QGIU) is driven by the demand for electricity EN7FC_T. Tests indicated that a time trend was insignificant. The equation is well-specified and indicates an elasticity of one with respect to electricity demand.

```
   15 :  LOG(QGIU) = A1_QGIU+A2_QGIU*LOG(EN7FC_T)

NOB = 30    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =              0.992565        CRSQ =            0.992014
F(1/0) =        1802.263281        PROB>F =          0
SER =              0.032287        SSR =             0.028147
DW(0) =            1.552054        COND =           36.705776
MAX:HAT =          0.158983        RSTUDENT =        3.22579
DFFITS =           0.772527

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_QGIU        0.696887        0.330416        2.109124        0.044349
A2_QGIU        0.952946        0.047981       19.860976        0
AR1.15         0.678234        0.122028        5.558029        0
```

6.1.2 Utilities Output Prices

The price of utilities output (PQGIU) is modeled as a function of the price of electricity, where PEN71_T is based on wholesale price index data for the price of electricity to industry. The estimated coefficient at 0.83 is close to but significantly different from one.

```
   16 :  LOG(PQGIU) = A1_PQGIU+A2_PQGIU*LOG(PEN71_T)

NOB = 27    NOVAR = 3  NCOEF = 3
RANGE: 1972A to 1999A
RSQ =              0.996926        CRSQ =            0.99667
F(1/0) =        3891.417912        PROB>F =          0
SER =              0.030575        SSR =             0.022436
DW(0) =            2.345704        COND =            6.323779
MAX:HAT =          0.31404         RSTUDENT =        2.266221
DFFITS =           0.794307

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_PQGIU       -5.211633        0.440451      -11.832502        0
A2_PQGIU        0.831278        0.052938       15.702747        0
AR1.16          0.957577        0.015967       59.973406        0
```

6.1.3 Utilities Energy Inputs

Energy inputs used in the utilities sector (QEIU) are modelled as a function of total energy used in electricity generation (ENE_T) and the capital stock in the utilities sector (KIU).

```
   17 :  LOG(QEIU) = A1_QEIU+A2_QEIU*LOG(ENE_T)+A3_QEIU*LOG(KIU)

NOB = 20    NOVAR = 3  NCOEF = 3
RANGE: 1980A to 1999A
RSQ =              0.942615        CRSQ =            0.935864
F(2/17) =        139.622061        PROB>F =          0
SER =              0.059913        SSR =             0.061023
DW(0) =            1.482043        COND =          247.536359
```

```
MAX:HAT =           0.572287        RSTUDENT =          2.630345
DFFITS =            1.2375

   COEF     ESTIMATE          STER            TSTAT          PROB>|T|

A1_QEIU       0.281207        1.139614         0.246756        0.808052
A2_QEIU       1.129292        0.085221        13.251299        0
A3_QEIU      -0.424948        0.176259        -2.410927        0.027511
```

6.1.4 Utilities Labour Inputs

The share of employment in total output (LIU/QGIU) is modelled as a function of the real wage (WIU/PQGIU) and a time trend (Time). The wage elasticity is low at –0.34 and the negative time trend indicates that labour intensity is falling over time in the utilities sector.

```
   18 :  LOG(LIU/QGIU) = A1_LIU+A2_LIU*LOG(WIU/PQGIU)+A3_LIU*Time

NOB = 28    NOVAR = 3  NCOEF = 3
RANGE: 1972A to 1999A
RSQ =               0.975832        CRSQ =              0.973899
F(2/25) =         504.71597         PROB>F =            0
SER =               0.061096        SSR =               0.093317
DW(0) =             1.348963        COND =           1381.854789
MAX:HAT =           0.210772        RSTUDENT =         -2.203242
DFFITS =           -0.931027

   COEF     ESTIMATE          STER            TSTAT          PROB>|T|

A1_LIU       66.558527        6.364618        10.457584        0
A2_LIU       -0.339386        0.104076        -3.260937        0.003199
A3_LIU       -0.035274        0.003355       -10.512281        0
```

6.1.5 Utilities Raw Materials Inputs

The share of raw materials inputs in total output (QRIUV/QGIUV) is modelled as a function of the demand for electricity (EN7FC_T), the capital stock (KIU) and the real price of raw materials (PQRIU/PQGIU). The capital stock is included to deal with the excess capacity installed in the 1980s. Where the sole producer of electricity, the ESB, was a monopolist, the high capital stock that had to be remunerated through an increased level of profits, reduced the share of other factors in total output.

```
   19 :  QRIUV/QGIUV =
   A1_QRIU+A2_QRIU*LOG(EN7FC_T)+A3_QRIU*LOG(KIU)+A4_QRIU*LOG(PQRIU/PQGIU)

NOB = 28    NOVAR = 4  NCOEF = 4
RANGE: 1972A to 1999A
RSQ =               0.784516        CRSQ =              0.757581
F(3/24) =          29.12573         PROB>F =            0
SER =               0.018068        SSR =               0.007835
DW(0) =             1.689654        COND =            235.123623
MAX:HAT =           0.241729        RSTUDENT =          2.352186
DFFITS =            0.887987

   COEF     ESTIMATE          STER            TSTAT          PROB>|T|

A1_QRIU       1.367412        0.156279         8.749787        0
A2_QRIU       0.23235         0.031828         7.300153        0
A3_QRIU      -0.322333        0.040559        -7.947312        0
A4_QRIU      -0.06829         0.038365        -1.779997        0.087743
```

6.2 Household Consumption

Changes to the determination of household consumption in the HERMES model are geared towards disaggregating consumption into energy and non-energy components. We estimate three separate equations for the consumption of electricity (CELEC), other energy (COEN) and petrol (CPET), based on households' consumption of electricity (EN7C_T), household's consumption of other energy (ENC_T-EN7C_T) and the transport sector's consumption of oil (EN4ST_T) respectively. These simple equations serve as a link between the engineering data in TOEs and the economic volume consumption data in the HERMES model.

The estimation results for these three equations are given below. All three links are significant with plausible coefficients.

```
   20 :  LOG(CELEC) = A1_CELEC+A2_CELEC*LOG(EN7C_T)

NOB = 25    NOVAR = 3  NCOEF = 3
RANGE: 1975A to 2000A
RSQ =              0.974039        CRSQ =            0.971679
F(1/0) =         412.720274        PROB>F =          0
SER =              0.035609        SSR =             0.027896
DW(0) =            1.67327         COND =           54.210368
MAX:HAT =          0.205567        RSTUDENT =       -4.728511
DFFITS =          -1.116455

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_CELEC        0.333272        0.6908          0.482445        0.634256
A2_CELEC        0.973425        0.11526         8.445452        0
AR1.20          0.726608        0.147834        4.915026        0

   21 :  LOG(COEN) = A1_COEN+A2_COEN*LOG(ENC_T-EN7C_T)

NOB = 21    NOVAR = 3  NCOEF = 3
RANGE: 1979A to 2000A
RSQ =              0.892287        CRSQ =            0.880319
F(1/0) =          74.555448        PROB>F =          0
SER =              0.059139        SSR =             0.062954
DW(0) =            1.788832        COND =           41.113497
MAX:HAT =          0.341417        RSTUDENT =       -2.353088
DFFITS =          -0.968099

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_COEN       -0.152621        2.19246        -0.069612        0.94527
A2_COEN        0.878139        0.29037         3.024205        0.007291
AR1.21         0.882157        0.077584       11.370333        0

   22 :  LOG(CPET) = A1_CPET+A2_CPET*LOG(EN4ST_T)

NOB = 25    NOVAR = 3  NCOEF = 3
RANGE: 1975A to 2000A
RSQ =              0.97403         CRSQ =            0.971669
F(1/0) =         412.560428        PROB>F =          0
SER =              0.037695        SSR =             0.031261
DW(0) =            1.896481        COND =           45.043001
MAX:HAT =          0.222442        RSTUDENT =       -3.518848
DFFITS =           1.160025

   COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_CPET        0.533039        0.534495        0.997274        0.329475
A2_CPET        0.784203        0.069018       11.362298        0
AR1.22         0.689164        0.14977         4.601488        0
```

Total volume consumption of energy in the model is then given by:

```
CEN            =       CELEC+COEN+CPET
```

Similarly the price deflators PCELEC, PCOEN and PCPET are linked to PEN7C_T PENCOEN[20] AND PCPET using three simple equations. The estimation results are shown below.

[20] PENCOEN is derived as a log-linear index of non-electricity energy prices to consumers.

```
23 :  LOG(PCELEC) = A1_PCELEC+A2_PCELEC*LOG(PEN7C_T)

NOB = 25    NOVAR = 3  NCOEF = 3
RANGE: 1975A to 2000A
RSQ =              0.990669        CRSQ =             0.98982
F(1/0) =        1167.827836        PROB>F =           0
SER =              0.040994        SSR =              0.036971
DW(0) =            2.481934        COND =            33.979783
MAX:HAT =          0.338902        RSTUDENT =         3.999757
DFFITS =           1.066547

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PCELEC       -5.871499        0.389328      -15.081109        0
A2_PCELEC        0.830985        0.055794       14.89378         0
AR1.23           0.649773        0.163539        3.973205        0

   24 :  LOG(PCOEN) = A1_PCOEN+A2_PCOEN*LOG(PENCOEN)

NOB = 20    NOVAR = 2  NCOEF = 2
RANGE: 1980A to 1999A
RSQ =              0.931436        CRSQ =             0.927627
F(1/18) =        244.527634        PROB>F =           0
SER =              0.035574        SSR =              0.022779
DW(0) =            2.13592         COND =             2.178253
MAX:HAT =          0.401687        RSTUDENT =         3.723099
DFFITS =           1.875475

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_PCOEN        0.01004         0.010489        0.957105        0.351194
A2_PCOEN        0.537057        0.034344       15.637379        0


   25 :  LOG(PCPET) = A1_PCPET+A2_PCPET*LOG(PEN41U_T)

NOB = 25    NOVAR = 3  NCOEF = 3
RANGE: 1975A to 2000A
RSQ =              0.994257        CRSQ =             0.993735
F(1/0) =        1904.30402         PROB>F =           0
SER =              0.03409         SSR =              0.025567
DW(0) =            2.473434        COND =            33.66201
MAX:HAT =          0.374442        RSTUDENT =         3.556571
DFFITS =           0.95634

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_PCPET       -6.832077        0.365974      -18.668211        0
A2_PCPET        1.007442        0.054075       18.630537        0
AR1.25          0.693061        0.173329        3.998535        0
```

Total consumption of energy at current prices (CENV) and a price deflator for consumption of energy (PCEN) are then derived as follows:

```
CELECV         =      CELEC*PCELEC,
COENV          =      COEN*PCOEN,
CPETV          =      CPET*PCPET,
CENV           =      CELECV+COENV+CPETV,
PCEN           =      CENV/CEN,
```

6.3 Deflator for Energy Inputs in Manufacturing Sector

The price of energy inputs into the manufacturing sector (PQEIMT) is modelled as a function of the price of energy to the industrial sector (PENI)[21].

```
PENCOEN=exp((EN1C_T*log(PEN1C_T)+EN4C_T*log(PEN422C_T)+EN6C_T*log(PEN6C_T)+
               EN8C_T*log(PEN81C_T))/(EN1C_T+EN4C_T+EN6C_T+EN8C_T)
```

[21] PENI is a log-linear index of energy prices in the industrial sector.

```
PENI           =      exp((EN1I_T*log(PEN1I_T)+EN42I_T*log(PEN422I_T)+EN43I_T*log(PEN43I_T)+
                      EN6I_T*log(PEN6I_T)+EN7I_T*log(PEN7I_T))/
```

```
   31 :  LOG(PQEIMT) =
   A1_PQEIMT+A2_PQEIMT*LOG(PENI)+(1-A2_PQEIMT)*LOG(PQEIMT(-1))

NOB = 27    NOVAR = 3  NCOEF = 3
RANGE: 1972A to 1999A
RSQ =              0.909063        CRSQ =            0.901485
F(1/0) =         119.959709        PROB>F =          0
SER =              0.052679        SSR =             0.066603
DW(0) =            1.820213        COND =            1.217842
MAX:HAT =          0.567241        RSTUDENT =       -3.02118
DFFITS =          -0.629023

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PQEIMT        0.027233        0.025406        1.07188         0.294435
A2_PQEIMT        0.740686        0.058375       12.688383        0
AR1.31           0.601406        0.121044        4.968503        0
```

6.4 Individual Energy Prices

6.4.1 Price of Electricity

The anchor electricity price used in the model is the wholesale price of electricity PEN71_T. This is defined as a weighted average of the shares of employment, energy and raw materials inputs in total output in the utilities sector, weighted by the input prices[22].

```
PEN71_T        =      EXP((YWIU(-1)/QGIUV(-1))*log(WIU)+(QEIUV(-1)/QGIUV(-))*log(PQEIU)
                      +(QRIUV(-1)/QGIUV(-1))*LOG(PQRIU))
```

This in turn drives the electricity price in the industrial sector (PEN7I_T) and in the household sector (PEN7C_T). The long-run coefficient on the anchor energy price is greater than one in the industrial sector but less than one in the household sector, where the wage rate is also found to have a significant effect on electricity prices.

```
   29 :  LOG(PEN7I_T) = A1_PEN7I+A2_PEN7I*LOG(PEN71_T)+A4_PEN7I*LOG(PEN7I_T(-1))

NOB = 40    NOVAR = 3  NCOEF = 3
RANGE: 1960A to 1999A
RSQ =              0.998696        CRSQ =            0.998626
F(2/37) =      14173.871579        PROB>F =          0
SER =              0.039306        SSR =             0.057165
DW(0) =            1.661486        COND =           89.253556
MAX:HAT =          0.218958        RSTUDENT =       -2.636556
DFFITS =          -1.18295

    COEF     ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN7I       -0.612328        0.052019      -11.771228        0
A2_PEN7I        0.78482         0.041948       18.709329        0
A4_PEN7I        0.290706        0.037483        7.755729        0

   30 :  LOG(PEN7C_T) =
   A1_PEN7C+A2_PEN7C*LOG(PEN71_T)+A3_PEN7C*LOG(WIU)+A4_PEN7C*LOG(PEN7C_T(-1))

NOB = 24    NOVAR = 4  NCOEF = 4
RANGE: 1976A to 1999A
RSQ =              0.994739        CRSQ =            0.99395
F(3/20) =       1260.599396        PROB>F =          0
SER =              0.03798         SSR =             0.02885
DW(0) =            1.837574        COND =          130.857028
MAX:HAT =          0.355603        RSTUDENT =       -2.512871
DFFITS =          -1.459959
```

```
                              (EN1I_T+EN42I_T+EN43I_T+EN6I_T+EN7I_T))/A1_PENI,
```

[22] PQEIU is the log-linear weighted index of individual fuel prices to the electricity generation sector.

```
PQEIU   =       exp((EN1E_T*log(PEN1E_T)+EN4E_T*log(PEN43E_T)+EN6E_T*log(PEN6E_T)+
                EN8E_T*log(PEN8E_T))/(EN1E_T+EN4E_T+EN6E_T+EN8E_T))/A1_PQEIU
```

COEF	ESTIMATE	STER	TSTAT	PROB>|T|
A1_PEN7C	-0.065894	0.202057	-0.326114	0.747726
A2_PEN7C	0.511914	0.054017	9.476815	0
A3_PEN7C	0.188845	0.047906	3.942	0.000806
A4_PEN7C	0.443581	0.059978	7.39577	0

6.4.2 Price of Coal

The anchor price of coal PEN1_T is set exogenously as the price to the electricity generation sector before tax, where PEN1E_T is the after-tax price of coal to the electricity generation sector:

```
PEN1E_T        =       PEN1_T+RGTECA*A1_CARB+RGTEE,
```

RGTECA is the tax in euro per tonne of carbon dioxide and RGTEE is the tax on energy in euro per TOE. Ate present both taxes are zero. The price of coal in the household (PEN1C_T) and industrial sector (PEN1I_T) is modelled as a function of the exogenous anchor price of coal (PEN1_T) and the non-agricultural wage rate. The wage rate has a much stronger effect in the household sector, where the price of coal is much higher than in the industrial sector.

32 : LOG(PEN1C_T) = A1_PEN1C+A2_PEN1C*LOG(PEN1_T)+A3_PEN1C*LOG(WNA)

```
NOB = 27    NOVAR = 4  NCOEF = 4
RANGE: 1972A to 1999A
RSQ =              0.987223        CRSQ =            0.985556
F(2/0) =         592.348424        PROB>F =          0
SER =              0.071401        SSR =             0.117256
DW(0) =            2.185659        COND =           10.881233
MAX:HAT =          0.384051        RSTUDENT =        2.850669
DFFITS =          -1.610954
```

COEF	ESTIMATE	STER	TSTAT	PROB>|T|
A1_PEN1C	3.308368	0.23298	14.200231	0
A2_PEN1C	0.120808	0.041277	2.926784	0.007584
A3_PEN1C	0.614735	0.080048	7.679592	0
AR1.32	0.71013	0.11129	6.380901	0

33 : LOG(PEN1I_T) = A1_PEN1I+A2_PEN1I*LOG(PEN1_T)+A3_PEN1I*LOG(WNA)

```
NOB = 15    NOVAR = 4  NCOEF = 4
RANGE: 1984A to 1999A
RSQ =              0.903785        CRSQ =            0.877545
F(2/0) =          34.442435        PROB>F =          0
SER =              0.032685        SSR =             0.011751
DW(0) =            2.349499        COND =           62.722546
MAX:HAT =          0.927315        RSTUDENT =        2.182682
DFFITS =           7.796206
```

COEF	ESTIMATE	STER	TSTAT	PROB>|T|
A1_PEN1I	2.242382	0.369195	6.073704	0
A2_PEN1I	0.329552	0.04159	7.923885	0
A3_PEN1I	0.265166	0.079317	3.343123	0.006557
AR1.33	0.355795	0.069265	5.136754	0

6.4.3 Price of Oil

The anchor price of oil in the model is the price of energy imports PM3. All other oil prices are modelled as a simple function of this anchor price, except the equation for the price of unleaded petrol PEN41U_T which also includes the rate of excise tax on petrol REXPET.

There are seven different oil price equations, these model the price of unleaded petrol (PEN41U_T), fuel oil to industry (PEN422I_T), gas oil to households (PEN422C_T), diesel oil to industry (PEN43I_T), diesel oil to the electricity generation sector (PEN43E_T), LPG to the consumer (PEN45C_T) and kerosene to the consumer (PEN46C_T). The estimation results are shown below.

```
   34 :  LOG(PEN41U_T) = A1_PEN41U+A2_PEN41U*LOG(PM3)+A3_PEN41U*LOG(REXPET)

NOB = 31    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =              0.998546       CRSQ =             0.998442
F(2/28) =       9614.683924       PROB>F =           0
SER =              0.032023       SSR =              0.028713
DW(0) =            1.531083       COND =             4.101575
MAX:HAT =          0.229596       RSTUDENT =         3.368429
DFFITS =           0.815469

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN41U        6.817332        0.008743      779.72312         0
A2_PEN41U        0.297308        0.011621       25.5829          0
A3_PEN41U        0.754692        0.012179       61.966629        0

   35 :  LOG(PEN422I_T) = A1_PEN422I+A2_PEN422I*LOG(PM3)

NOB = 30    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =              0.994329       CRSQ =             0.993909
F(1/0) =        2367.110482       PROB>F =           0
SER =              0.067519       SSR =              0.123089
DW(0) =            2.224611       COND =             1.338201
MAX:HAT =          0.495823       RSTUDENT =         2.975216
DFFITS =           0.773389

     COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN422I        5.68743         0.166653       34.127288        0
A2_PEN422I        0.837123        0.049388       16.949934        0
AR1.35            0.924259        0.022298       41.450212        0

   36 :  LOG(PEN422C_T) = A1_PEN422C+A2_PEN422C*LOG(PM3)

NOB = 30    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =              0.992611       CRSQ =             0.992064
F(1/0) =        1813.55832        PROB>F =           0
SER =              0.087003       SSR =              0.204376
DW(0) =            2.734715       COND =             1.354295
MAX:HAT =          0.520351       RSTUDENT =        -1.976849
DFFITS =           1.261011

     COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN422C        6.398591        0.332364       19.251765        0
A2_PEN422C        0.724273        0.062106       11.661911        0
AR1.36            0.950894        0.013649       69.666639        0

   37 :  LOG(PEN43I_T) = A1_PEN43I+A2_PEN43I*LOG(PM3)

NOB = 30    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =              0.976285       CRSQ =             0.974529
F(1/0) =         555.768891       PROB>F =           0
SER =              0.13683        SSR =              0.505505
DW(0) =            2.38158        COND =             1.197119
MAX:HAT =          0.262576       RSTUDENT =         4.805266
DFFITS =           0.934155

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN43I        4.904494        0.110586       44.350088        0
A2_PEN43I        0.903182        0.099181        9.106402        0
AR1.37           0.774568        0.083443        9.282622        0

   43 :  LOG(PEN43E_T) = A1_PEN43E+A2_PEN43E*LOG(PM3)

NOB = 31    NOVAR = 2  NCOEF = 2
RANGE: 1970A to 2000A
```

```
RSQ =               0.974867        CRSQ =              0.974001
F(1/29) =        1124.882586        PROB>F =            0
SER =               0.131346        SSR =               0.500299
DW(0) =             1.228894        COND =              1.222024
MAX:HAT =           0.225692        RSTUDENT =         -3.14625
DFFITS =           -0.742222

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN43E        4.322534        0.024066      179.610381        0
A2_PEN43E        0.965983        0.028802       33.539269        0

 41 :  LOG(PEN45C_T) = A1_PEN45C+A2_PEN45C*LOG(PM3)

NOB = 30    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =               0.978356        CRSQ =              0.976753
F(1/0) =          610.227431        PROB>F =            0
SER =               0.114735        SSR =               0.355432
DW(0) =             1.567561        COND =              1.346743
MAX:HAT =           0.509113        RSTUDENT =          2.712107
DFFITS =            0.942853

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN45C        6.794051        0.344793       19.704741        0
A2_PEN45C        0.147931        0.082969        1.782973        0.085838
AR1.41           0.937677        0.018861       49.714305        0

   42 :  LOG(PEN46C_T) = A1_PEN46C+A2_PEN46C*LOG(PM3)

NOB = 30    NOVAR = 3  NCOEF = 3
RANGE: 1970A to 2000A
RSQ =               0.977251        CRSQ =              0.975566
F(1/0) =          579.939608        PROB>F =            0
SER =               0.128176        SSR =               0.443587
DW(0) =             1.852965        COND =              1.335259
MAX:HAT =           0.491138        RSTUDENT =         -4.36676
DFFITS =           -4.29004

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN46C        5.909978        0.299091       19.759816        0
A2_PEN46C        0.31286         0.094068        3.325905        0.002548
AR1.42           0.919933        0.02683        34.287582        0
```

6.4.4 *Price of Peat*

The anchor price of peat is the price of peat to the electricity generation sector before energy and carbon taxes PEN8_T:

```
PEN8E_T           =      PEN8_T+RGTECA*A8E_CARB+RGTEE,
```

The price of peat to the consumer (PEN81C_T) is modelled as a function of the anchor price and the non-agricultural wage rate. The equation is not very well-specified, the coefficient on the anchor price is not significant and is low.

```
   38 :  LOG(PEN81C_T) = A1_PEN81C+A2_PEN81C*LOG(PEN8_T)+A3_PEN81C*LOG(WNA)

NOB = 16    NOVAR = 3  NCOEF = 3
RANGE: 1985A to 2000A
RSQ =               0.548123        CRSQ =              0.478604
F(2/13) =           7.88445         PROB>F =            0.005723
SER =               0.077167        SSR =               0.077413
DW(0) =             1.984667        COND =            164.810178
MAX:HAT =           0.369917        RSTUDENT =          1.910706
DFFITS =            0.981504

    COEF      ESTIMATE          STER           TSTAT          PROB>|T|

A1_PEN81C        2.266423        1.4049          1.613228        0.130695
```

A2_PEN81C	0.358052	0.244268	1.465815	0.166465
A3_PEN81C	0.42646	0.112615	3.786901	0.002263

6.4.5 Price of Gas

The anchor price of gas is the price of gas to the electricity generation sector before energy and carbon taxes PEN6_T:

```
PEN6E_T              =      PEN6_T+RGTECA*A6_CARB+RGTEE,
```

It proved very difficult to estimate price equations for gas since gas prices have been administered over long contracts until recent years, and have been subject to infrequent discrete changes. This was especially difficult for the price of gas to industry (PEN6I) where the coefficient on the anchor price A2_PEN6I was imposed in estimation at a value of 0.5. The results of estimating the price of gas to consumers PEN6C_T and to industry PEN6I_T are shown below.

39 : LOG(PEN6C_T) = A1_PEN6C+A2_PEN6C*LOG(PEN6_T)

NOB = 16   NOVAR = 2 NCOEF = 2
RANGE: 1985A to 2000A

RSQ =	0.460494	CRSQ =	0.421958
F(1/14) =	11.949649	PROB>F =	0.003852
SER =	0.031588	SSR =	0.013969
DW(0) =	1.912876	COND =	63.772712
MAX:HAT =	0.300839	RSTUDENT =	2.198326
DFFITS =	1.155795		

COEF	ESTIMATE	STER	TSTAT	PROB>|T|
A1_PEN6C	5.180537	0.251868	20.568482	0
A2_PEN6C	0.188281	0.054466	3.456826	0.003852

40 : LOG(PEN6I_T) = A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*Time

NOB = 16   NOVAR = 2 NCOEF = 2
RANGE: 1985A to 2000A

RSQ =	0.515158	CRSQ =	0.480526
F(1/14) =	14.875364	PROB>F =	0.001744
SER =	0.168833	SSR =	0.399065
DW(0) =	0.76442	COND =	864.469031
MAX:HAT =	0.227941	RSTUDENT =	-1.696378
DFFITS =	-0.8629		

COEF	ESTIMATE	STER	TSTAT	PROB>|T|
A1_PEN6I	73.629432	18.243902	4.035838	0.001227
A3_PEN6I	-0.035314	0.009156	-3.856859	0.001744

6.5 Energy and Carbon Taxes

All of the individual fuel price equations are adjusted to allow for the effects of a carbon tax (RGTECA) and an energy tax (RGTEE) per TOE. In the case of a carbon tax, the relevant fuel price is adjusted for the CO_2 emission rate for that particular fuel. So, for example, the price of gas to industry is determined by the following equation:

```
PEN6I_T =exp(A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*Time)+RGTECA*A6_CARB+RGTEE
```

The estimate for the price of gas is adjusted to add on a carbon tax rate per TOE of CO_2 emitted (RGTECA*A6_CARB) and an energy tax per TOE (RGTEE).

The total tax revenue for the energy tax can be simply calculated using total primary requirement of energy in TOEs (ENTD_T) as the base:

```
GTEE          =       RGTEE*ENTD_T,
```

while the total tax revenue for the carbon tax can be calculated using total carbon dioxide emissions (CO_2) as the base. This includes a switch option so that emissions from kerosene used in the transport sector (A46_CARB*EN46ST_T) can be omitted from the tax (Z_PEN46C) as emissions from international air travel are currently not covered by Kyoto restrictions on emissions.

```
GTECA         =       ((CO2-A46_CARB*EN46ST_T*(1-Z_PEN46C))*RGTECA)/1000,
```

7 HOW DOES THE MODEL PERFORM WITHIN SAMPLE?

Table 1 shows the root mean squared percentage error (RMSPE) for key behavioural variables in the energy model estimated within sample. The overall RMSPE for total demand for energy ENFC_T at 2.6 per cent is reasonable as is the RMSPE for total carbon dioxide emissions CO_2 at 2.2 per cent. The errors for individual sector's demand are higher, particularly for the commercial and public sector. As mentioned above, data for this sector are derived residually so it is to be expected that the error would be largest here.

The RMSP errors for individual fuels are very high for coal and peat, but since these fuels are declining in importance over time this is not too worrying. The error for gas is worryingly high. The explanation is that gas was only introduced on a widespread basis in the mid-1980s so that the model has not been able to estimate stable economic relationships for this fuel and this will have to be watched out of sample. The demand for electricity has the lowest error, which is reassuring as this feeds through to the electricity generation sector.

Table 1 Within Sample Performance of the Energy Model

Demand by Sector	Total	Household	Commercial and Public	Industry	Transport	Agriculture
Variable:	ENFC_T	ENC_T	ENS_T	ENI_T	ENST_T	ENA_T
Root Mean Squared % Error	2.6	4.6	6.5	5.0	3.3	4.5
Demand by Fuel	Coal	Oil	Gas	Electricity	Peat	CO2 Emissions
	EN1FC_T	EN4FC_T	EN6FC_T	EN7FC_T	EN8FC_T	CO2
Root Mean Squared % Error	17.5	3.3	8.5	2.7	11.7	2.2

8 THE PRICE OF ENERGY AND CARBON EMISSIONS

The model presented here can simulate the direct effects of policies that raise the price of emitting carbon dioxide from burning fossil fuels. However, until it is integrated into the HERMES macro-economic model, it can not be used to estimate the full economic impact of policies aimed at reducing emissions of greenhouse gases. It can show how prices of energy would change and how the energy sector would react to such change but it leaves out many of the indirect effects of such policies.

There are a range of crucial economic channels that require a full macro-economic model to take them into account:

- The income effects on households of higher energy prices.
- The effects of higher energy prices and resulting lower profitability on the business sector.
- The effects of using the increased government revenue to reduce other taxes or increase expenditure.

As it stands what the model can do is to look at the effects of higher prices on the demand for different forms of energy, on the fuel mix used in the economy, and on the extent to which higher energy prices would cause households and businesses to economise on fuel use. It is these latter effects that we examine in this Section. The income effects for households and for businesses, which the energy model does not take into account, would be at least partly offset by the effects of recycling the government revenue as lower taxes.

One major international study (Coherence, 1999), suggests an international trading regime (restricted to Annex B countries) would result in a price of 17.7€ per tonne of carbon dioxide by the end of the decade. In this Section we examine the effects of a tax on carbon dioxide emissions of €10 a tonne, roughly half this estimated price for carbon dioxide. The effect would be similar under a regime of tradable emissions permits where the market price for permits was €10 per tonne of carbon dioxide.

This tax would have a significant effect on the price of energy. Table 1 shows the long-run impact on the price of different types of energy for the different sectors of the economy. The percentage change in price is highest for the electricity generating sector because there is a very small margin there over and above the import price of the energy. In the household sector distribution costs and existing taxes are already high so that the percentage change in price is much lower. This is also true for transport where taxes already account for a large part of the final price.

Table 2: Change in Energy Prices from Tax of € a tonne of CO_2, 2001
%

	Coal	Oil	Gas	Electricity	Peat	All Energy
Households	10.3	5.9	4.8	5.1	19.4	7.2
Industrial	38.1	7.9	11.8	5.8		16.8
Commercial						5.6
Transport		2.9				
Electricity	55.1	30.4	15.4		45.8	33.1

The effect of the induced price rise on the demand for energy in the different sectors is shown in Table 3. The percentage change in the demand for electricity, a fall of around 1.5%, is fairly similar for all sectors reflecting the similarity of the estimated price elasticities. For non-electrical energy, the fall in demand for the household the commercial and public sectors are very similar at just under 2%. The fall in demand in the transport sector is smaller. However, in the long run if the world price of fuel rose, induced technical progress could see greater efficiency gains.

For the industrial sector the model suggests a much bigger response in the long run than for the other sectors. However, this fall would take between five and ten years to take place – it is a long run phenomenon. In addition, it would only be likely to happen if the rise in prices of energy occurred throughout Europe, and possibly throughout the OECD area. The sensitivity to once off price increases is derived from the experience of the 1970s and the early 1980s where industry in all countries faced a huge rise in costs. The result was major research to economise on energy. Implementing the fruits of this research in new plant took many years and the same would be true today for a major increase in prices.

However, if the rise in prices only occurred in Ireland there would be a much smaller response. Instead of carrying out the necessary research it would be cheaper for energy intensive firms to move elsewhere. This highlights the importance of implementing a programme of measures to tackle global warming on an EU-wide basis.

Table 3: Change in Energy Demand from Tax of €10 a tonne of CO_2, 2001
%

Sector	Electricity	All Energy
Households	-1.5	-1.9
Industrial	-1.6	-14.0
Commercial	-1.5	-1.8
Transport	-1.5	-0.5
Electricity Generation		-1.6
Final Consumption	-1.6	-4.1
Primary Energy		-3.4

In the medium term, this decline in energy use would result in a reduction in carbon dioxide emissions of between 3% and 4%. This does not allow for induced changes in fuel mix within the electricity sector.

Finally, the results of this partial analysis would suggest that government tax revenue would have been over €400 million higher in 2001 than was actually the case. It would require the integration of this energy model into the full HERMES macro-economic model to analyse the impact of using this additional revenue to cut taxes (or to increase expenditure).

9 CONCLUSION

In this paper we have developed a model of the energy sector in Ireland that takes account of the sensitivity of decision making to changes in prices. The model is disaggregated into six sectors and it handles the demand for the main fuel types. The prices of the different types of energy are also modelled as a function of import prices, domestic costs and taxes. The model allows for the simulation of the effects of new taxes for carbon emissions. The effects of a rise in the price of carbon emissions, through the introduction of a regime of tradable emissions permits can also be handled within this framework.

Across the sectors there is evidence that the demand for energy is rising less rapidly than the growth in economic activity. In fact, the sensitivity of energy demand with respect to income is falling over time. While electricity demand is more responsive to rising incomes than is the demand for other forms of energy, it too is displaying a gradually declining elasticity of demand.

The model finds a relatively low but significant elasticity of demand for energy. For electricity the price elasticity is very similar across the sectors, between –0.2 and –0.3 (see Table 4x). In the case of other forms of energy the elasticity is slightly higher. In the case of industry the higher measured elasticity would not be applicable to the case of a rise in prices confined only to Ireland. Even if there was an EU-wide rise in prices for environmental reasons, the response would be lower than where the change in regime applies to all OECD countries. This is because of the potential importance of higher prices in stimulating world-wide research on increasing energy efficiency. Similar arguments apply to the transport sector. There investment in fuel efficiency is driven by world-wide regulations rather than the regulatory regime in any one country.

Table 4: Estimated Long-Run Price and Income Elasticities in the Key Behavioural Equations modelling the Demand for Energy

		Long-Run Price Elasticity	Long-Run Income Elasticity	Long-Run "Max Price" Elasticity	Standard Error of Equation
Electricity Demand:					
Household	EN7C	-0.21	1.2 (2000)		2.7
Commercial and Public	EN7S	-0.28	0.82 (1999)		2.6
Industry	EN7I_T	-0.29	0.28 (1999)		3.4
Agriculture	EN7A_T	-1.5			4.3
Aggregate Energy Demand:					
Household	ENCW	-0.26	0.41		5.8
Commercial and Public	ENS-EN7S	-0.34	0.65 (2000)		15.9
Industry	ENI_T		0.57 (2000)	-1.29	5.8
Agriculture	ENA_T	-0.71			3.7
Demand for Individual Fuels:					
Industry – Coal	EN1I_T	-1.24			20.9
Transport – Oil	EN49ST	-0.19	1.18	-0.44	4.6
Transport – Kerosene	EN46ST_T	-0.36			6.6

The model as currently structured probably underestimates the potential for energy substitution. The relatively recent advent of natural gas availability, and the resulting changes in the technical characteristics of energy markets, has made it impossible to estimate a fully satisfactory model of fuel substitution. In the case of electricity it is necessary to use a different model to understand the possibilities for fuel substitution. As a result, when examining the potential consequences of measures raising the cost of emitting carbon dioxide, the model will, if anything, tend to underestimate the possibilities of fuel substitution, and hence the desirable environmental impact of such measures. It will also tend to overestimate the direct negative economic consequences while also overestimating the potential revenue for the government from any such measures.

As it stands the model suggests that a price of €10 per tonne of carbon dioxide would see significant changes in behaviour in the energy sector. Once the economy had time to adjust, and even before the effects of changes in the electricity sector fuel mix are taken into account, carbon dioxide emissions would fall by between 3% and 4%. Some recent modelling of the EU economy suggests that under a tradable emissions regime, by the end of the decade, the price of carbon dioxide emissions would be almost double this level. The likely reduction in emissions would, as a consequence, be almost double that shown in the calculations in this paper.

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11 APPENDIX 1: NOTATION

The notation used relates to the macro-economic modelling structure. Where quantities of energy are involved the prefix EN is used. This is succeeded by a single digit that describes the type of energy. The following letters describe the sector or use to which the energy is put. The units used are indicated by another segment such as _T for tonnes of oil equivalent. The price variables relating to the different types of energy begin with the prefix PEN followed by a number to indicate the type of energy.

A.1. - Key to Mnemonics:

A = Agriculture
C = Domestic Consumption
E = Electricity Production
FC = Final Consumption
G = Gas Production
I = Industry
M = Imports
QD = Domestic Production
R= Refineries use of Crude Oil
S = Services – Commercial and Public
ST = Transport

TD = Total Primary Energy Use
X = Exports

1 = Coal
3 = Crude Oil
4 = Oil
41 = Petrol
42 = Diesel
43 = Fuel Oil
45 = LPG
46 = Kerosene
48 = Oil excluding LPG
49 = Oil excluding LPG and Kerosene
6 = Gas
7 = Electricity
8 = Turf
9 = Renewables – excluding Hydro

12 APPENDIX 2: MODEL LISTING

There are different time trends for each equation. These variables begin with the Mnemonic "ZT_". This is done to increase the flexibility of the model when used in simulation. When using the model for forecasting it allows the rate of technical progress, proxied by time, to be varied in each equation.

```
/* Energy demand in the residential sector                                        */
LOG(ENCW_T)     =       ENCW_C1+ENCW_C2*LOG(YRPERD)+ENCW_C3*LOG(PENC_MOD/PC)+
                        ENCW_C4*LOG(ENCW_T(-1))+log(ENCW_T_FIX),
EN4C_T          =       (ENCW_T-
(EN1C_T*A1_ENCW_T+EN6C_T*A6_ENCW_T+EN8C_T*A8_ENCW_T))/A4_ENCW_T,
ENC_T           =       EN1C_T+EN4C_T+EN6C_T+EN7C_T+EN8C_T+EN9C_T,
LOG(EN7C_T)     =       IF Z_EN7C == ONE THEN
                        EN7C_C5+EN7C_C6/YRPERD+EN7C_C7*LOG(PEN7C_T/PC)+EN7C_C8*LOG(EN7C_T(-1))
                        +LOG(EN7C1_T_FIX)
                        ELSE
                        EN7C_C1+EN7C_C2/HSTOCK1+EN7C_C3*LOG(PEN7C_T/PC)+
                        EN7C_C4*LOG(EN7C_T(-1))+LOG(EN7C2_T_FIX),
LOG(EN6C_T/(ENC_T-EN7C_T))=   EN6C_C1+EN6C_C2*ZT_EN6C+LOG(EN6C_T_FIX),
LOG(EN8C_T/(ENC_T-EN7C_T))=   EN8C_C1+EN8C_C2*ZT_EN8C+AR_EN8C*EN8C_R(-1)+LOG(EN8C_T_FIX),
LOG(EN1C_T/(ENC_T-EN7C_T))=   EN1C_C1+EN1C_C2*ZT_EN1C+AR_EN1C*EN1C_R(-1)+LOG(EN1C_T_FIX),
LOG(EN45C_T/EN4C_T)=    EN45C_C1+EN45C_C2*ZT_EN45C+LOG(EN45C_T_FIX),
EN48C_T         =       EN4C_T-EN45C_T,

/* Energy demand in the commercial and public sectors                                     */
LOG(ENS_T-EN7S_T)=      ENS_C1+ENS_C2/(OSM+OSNHE+OSNP)+ENS_C3*LOG(PENS_MOD/PC)+
                        AR_ENS*ENS_R(-1)+LOG(ENS_T_FIX),
LOG(EN7S_T)     =       EN7S_C1+EN7S_C2/(OSM+OSN)+EN7S_C3*LOG(PEN71_T/PC)+
                        EN7S_C4*LOG(EN7S_T(-1))+LOG(EN7S1_T_FIX),
EN6SCH_T        =       EN6CH_T*ENCHS*EN6SCH_T_FIX,
LOG(EN6S_T/EN4S_T)=     IF Z_EN6S == ONE THEN
                        EN6S_C1+EN6S_C3*LOG(PEN6C_T/PEN422C_T)
                        +EN6S_C4*LOG(EN6S_T(-1)/EN4S_T(-1))+LOG(EN6S1_T_FIX)
                        ELSE
                        log(((ENS_T-EN7S_T)*EN6SSH*EN6S2_T_FIX)/EN4S_T),
EN6SNH_T        =       EN6S_T-EN6SCH_T,
/* The demand for oil is a residual                                               */
EN4S_T          =       ENS_T-EN7S_T-EN6S_T-EN1S_T-EN8S_T-EN9S_T,
EN48S_T         =       EN4S_T-EN45S_T,

/* Energy demand in the industrial sector                                         */
LOG(EN1I_T)     =       EN1I_C1+EN1I_C2*LOG(PEN1I_T/PQGIMT)+EN1I_C3*ZT_EN1I+AR_EN1I*EN1I_R(-1)
```

```
                              +LOG(EN1I_T_FIX),
LOG(ENI_T)      =       ENI_C1+ENI_C2/OI+ENI_C3*LOG(QNIMT/QGIMT)
                        +ENI_C4*LOG(PQEIMTR_MAX)+ENI_C5*LOG(ENI_T(-1))+LOG(ENI_T_FIX),
LOG(EN7I_T)     =       EN7I_C1+EN7I_C2/OI+EN7I_C3*LOG(PEN71_T/PQGIMT)+
                        EN7I_C4*LOG(EN7I_T(-1))+LOG(EN7I1_T_FIX),
EN6ICH_T        =       EN6CH_T*ENCHI*EN6ICH_T_FIX,
EN6INH_T        =       (ENI_T-EN7I_T)*EN6ISH-EN6ICH_T+EN6INH_T_FIX,
EN6I_T          =       EN6ICH_T+EN6INH_T,
LOG(EN45I_T/EN4I_T)=    EN45I_C1+EN45I_C2*ZT_EN45I+AR_EN45I*EN45I_R(-1)+LOG(EN45I_T_FIX),
EN48I_T         =       ENI_T-EN1I_T-EN6I_T-EN7I_T-EN8I_T-EN9I_T-EN45I_T,
EN4I_T          =       EN45I_T+EN48I_T,

/* Energy demand in the transport sector                                          */
LOG(EN49ST_T)   =       EN4ST_C1+EN4ST_C2*LOG(SCARS)
                        +EN4ST_C3*LOG(PEN41U_T/(PEN41U_T_UK*REX_UK))
                        +EN4ST_C4*LOG(PEN41UR_MAX)+LOG(EN4ST_T_FIX),
LOG(EN46ST_T)   =       EN46ST_C1+EN46ST_C2*LOG(EN46ST_T(-1))+EN46ST_C3*LOG(PEN46C_T/PC)
                        +LOG(EN46ST_T_FIX),
EN4ST_T         =       EN49ST_T+EN45ST_T+EN46ST_T,
ENST_T          =       EN4ST_T+EN7ST_T,

/* Energy demand in the agricultural sector                                       */
LOG(ENA_T/QMA)  =       ENA_C1+ENA_C2*LOG(PQEIMT/PQMA)+LOG(ENA_T_FIX),
LOG(EN7A_T)     =       EN7A_C1+EN7A_C2*LOG(PEN7C_T/PC)+LOG(EN7A_T_FIX),
EN4A_T          =       ENA_T-EN7A_T-EN9A_T,

/* Final Consumption of energy by fuel type                                       */
EN1FC_T         =       EN1C_T+EN1S_T+EN1I_T,
EN4FC_T         =       EN4C_T+EN4S_T+EN4I_T+EN4ST_T+EN4A_T,
EN6FC_T         =       EN6C_T+EN6S_T+EN6I_T,
EN7FC_T         =       EN7C_T+EN7S_T+EN7I_T+EN7ST_T+EN7A_T,
EN8FC_T         =       EN8C_T+EN8S_T+EN8I_T,
EN9FC_T         =       EN9C_T+EN9S_T+EN9I_T+EN9A_T,
ENFC_T          =       EN1FC_T+EN4FC_T+EN6FC_T+EN7FC_T+EN8FC_T+EN9FC_T,

/* Total primary energy requirement by fuel type by sector                        */
EN1CTD_T        =       EN1C_T,
EN4CTD_T        =       EN4C_T*(1+EN4TRLOS_T/EN4FC_T),
EN6CTD_T        =       EN6C_T*(1+EN6TRLOS_T/EN6FC_T),
EN7CTD_T        =       EN7C_T*(1+EN7TRLOS_T/EN7FC_T),
EN8CTD_T        =       EN8C_T*(1+EN8TRLOS_T/EN8FC_T),
EN9CTD_T        =       EN9C_T,
ENCTD_T         =       EN1CTD_T+EN4CTD_T+EN6CTD_T+EN7CTD_T+EN8CTD_T+EN9CTD_T,
EN1STD_T        =       EN1S_T,
EN4STD_T        =       EN4S_T*(1+EN4TRLOS_T/EN4FC_T),
EN6STD_T        =       EN6S_T*(1+EN6TRLOS_T/EN6FC_T),
EN8STD_T        =       EN8S_T*(1+EN8TRLOS_T/EN8FC_T),
EN7STD_T        =       EN7S_T*(1+EN7TRLOS_T/EN7FC_T),
EN9STD_T        =       EN9S_T,
ENSTD_T         =       EN1STD_T+EN4STD_T+EN6STD_T+EN7STD_T+EN8STD_T+EN9STD_T,
EN1ITD_T        =       EN1I_T,
EN4ITD_T        =       EN4I_T*(1+EN4TRLOS_T/EN4FC_T),
EN6ITD_T        =       EN6I_T*(1+EN6TRLOS_T/EN6FC_T),
EN8ITD_T        =       EN8I_T*(1+EN8TRLOS_T/EN8FC_T),
EN7ITD_T        =       EN7I_T*(1+EN7TRLOS_T/EN7FC_T),
EN9ITD_T        =       EN9I_T,
ENITD_T         =       EN1ITD_T+EN4ITD_T+EN6ITD_T+EN7ITD_T+EN8ITD_T+EN9ITD_T,
EN4STTD_T       =       EN4ST_T*(1+EN4TRLOS_T/EN4FC_T),
EN7STTD_T       =       EN7ST_T*(1+EN7TRLOS_T/EN7FC_T),
ENSTTD_T        =       EN4STTD_T+EN7STTD_T,
EN4ATD_T        =       EN4A_T*(1+EN4TRLOS_T/EN4FC_T),
EN7ATD_T        =       EN7A_T*(1+EN7TRLOS_T/EN7FC_T),
EN9ATD_T        =       EN9A_T,
ENATD_T         =       EN4ATD_T+EN7ATD_T+EN9ATD_T,
EN1TD_T         =       EN1CTD_T+EN1STD_T+EN1ITD_T+EN1E_T+EN1G_T,
EN4TD_T         =       EN4CTD_T+EN4STD_T+EN4ITD_T+EN4STTD_T+EN4ATD_T+EN4E_T+EN4G_T,
EN6TD_T         =       EN6CTD_T+EN6STD_T+EN6ITD_T+EN6E_T+EN6G_T,
EN8TD_T         =       EN8CTD_T+EN8STD_T+EN8ITD_T+EN8E_T,
EN9TD_T         =       EN9CTD_T+EN9STD_T+EN9ITD_T+EN9ATD_T+EN9E_T+EN9G_T,
EN7TD_T         =       EN7QD_T,
/* Gas used as feedstock EN6IMCHF_T is included in Total Primary Energy Requirement       */
ENTD_T          =       EN1TD_T+EN4TD_T+EN6TD_T+EN8TD_T+EN9TD_T+EN6IMCHF_T+EN7TD_T,
ENQD_T          =       EN1QD_T+EN6QD_T+EN7QD_T+EN8QD_T+EN9QD_T,
M3              =       ENM_T*M3_DIS*M3_FIX,
ENM_T           =       ENX_T+ENTD_T-ENQD_T-ENBA_T+ENM_T_FIX,
```

```
/* Electricity production by fuel type: driven by demand EN7FC_T                   */
EN7G1_T        =       EN1E_T*ENGEFF1*EN7G1_T_FIX,
EN7G42_T       =       EN42E_T*ENGEFF42*EN7G42_T_FIX,
EN7G43_T       =       EN43E_T*ENGEFF43*EN7G43_T_FIX,
EN7G4_T        =       EN7G42_T+EN7G43_T,
EN7GCH6_T      =       EN6CH_T*(1-ENCHS-ENCHI)*ENGEFF6C*EN7GCH6_T_FIX,
EN7G8_T        =       EN8E_T*ENGEFF8*EN7G8_T_FIX,
EN7G9_T        =       IF Z_EN7G9 == ONE THEN
                       EN9E_T*ENGEFF9*EN7G91_T_FIX
                       ELSE
                       EN7GENES_T*ENRENSH*EN7G92_T_FIX,
EN7GNH6_T      =       EN7GENES_T-(EN7G1_T+EN7G8_T+EN7G4_T+EN7GCH6_T+EN7TD_T+EN7G9_T),
EN7G6_T        =       EN7GCH6_T+EN7GNH6_T,
EN6E_T         =       (EN6CH_T*(1-ENCHS-ENCHI)+(EN7GNH6_T/ENGEFF6N))*EN6E_T_FIX,
EN4E_T         =       EN42E_T+EN43E_T,
ENE_T          =       EN1E_T+EN4E_T+EN6E_T+EN7QD_T+EN8E_T+EN9E_T,
EN7CONL_T      =       ENE_T-EN7GEN_T,
EN7GENAD_T     =       EN7GENES_T-EN7GEN_T,
EN7GENES_T     =       EN7GEN_T/EN7GENAD_FIX,
EN7GEN_T       =       EN7AVAIL_T-EN7M_T+EN7X_T,
EN7AVAIL_T     =       EN7GSO_T+EN7OUSE_T,
EN7OUSE_T      =       EN7GSO_T*EN7OUSE_FIX,
EN7GSO_T       =       EN7FC_T/(1-EN7TRL_FIX),
EN7TRL_T       =       EN7GSO_T-EN7FC_T,
EN7TRLOS_T     =       EN1E_T+EN4E_T+EN6E_T+EN8E_T+EN9E_T+EN7QD_T+EN7M_T-EN7X_T-EN7FC_T,

/*     Carbon Dioxide Emissions                                                            */
A7_CARB        =       (EN1E_T*A1_CARB+EN4E_T*A4E_CARB+EN6E_T*A6_CARB+EN8E_T*A8E_CARB)
                       /EN7FC_T,
CO2LOS         =       EN4TRLOS_T*A4E_CARB+EN6TRLOS_T*A6_CARB+EN8TRLOS_T*A8E_CARB,
CO2C           =       EN1C_T*A1_CARB+EN48C_T*A49_CARB+EN45C_T*A45_CARB+EN6C_T*A6_CARB
                       +EN7C_T*A7_CARB+EN8C_T*A8_CARB,
CO2S           =       EN1S_T*A1_CARB+EN48S_T*A49_CARB+EN45S_T*A45_CARB+EN6S_T*A6_CARB
                       +EN7S_T*A7_CARB+EN8S_T*A8_CARB,
CO2I           =       EN1I_T*A1_CARB+EN48I_T*A49_CARB+EN45I_T*A45_CARB+EN6I_T*A6_CARB
                       +EN7I_T*A7_CARB+EN8I_T*A8_CARB,
CO2ST          =       EN49ST_T*A49_CARB+EN45ST_T*A45_CARB+EN46ST_T*A46_CARB
                       +EN7ST_T*A7_CARB,
CO2A           =       EN4A_T*A49_CARB+EN7A_T*A7_CARB,
CO2IMCHF       =       ENIMCHF_T*A6IMCHF_CARB,
CO21           =       EN1E_T*A1_CARB+EN1C_T*A1_CARB+EN1S_T*A1_CARB+EN1I_T*A1_CARB,
CO245          =       EN45C_T*A45_CARB+EN45S_T*A45_CARB+EN45I_T*A45_CARB
                       +EN45ST_T*A45_CARB,
CO246          =       EN46ST_T*A46_CARB,
CO24           =       EN4E_T*A4E_CARB+EN4TRLOS_T*A4E_CARB
                       +EN48C_T*A49_CARB+EN45C_T*A45_CARB+EN48S_T*A49_CARB
                       +EN45S_T*A45_CARB++EN48I_T*A49_CARB+EN45I_T*A45_CARB
                       +EN49ST_T*A49_CARB+EN45ST_T*A45_CARB+EN46ST_T*A46_CARB
                       +EN4A_T*A49_CARB,
CO249          =       CO24-CO245-CO246,
CO26           =       EN6E_T*A6_CARB+EN6TRLOS_T*A6_CARB+EN6C_T*A6_CARB+EN6S_T*A6_CARB
                       +EN6I_T*A6_CARB,
CO27           =       EN7C_T*A7_CARB+EN7S_T*A7_CARB+EN7I_T*A7_CARB+EN7ST_T*A7_CARB
                       +EN7A_T*A7_CARB,
CO28           =       EN8E_T*A8E_CARB+EN8TRLOS_T*A8E_CARB+EN8C_T*A8_CARB+EN8S_T*A8_CARB
                       +EN8I_T*A8_CARB,
CO2            =       CO2LOS+CO2C+CO2S+CO2I+CO2A+CO2ST+CO2IMCHF,
CO2ADJ         =       CO2-A46_CARB*EN46ST_T;

/*     Household Consumption                                                     */
log(CELEC)     =       A1_CELEC+A2_CELEC*log(EN7C_T)+AR_CELEC*CELEC_R(-1,
log(COEN)      =       A1_COEN+A2_COEN*log(ENC_T-EN7C_T)+AR_COEN*COEN_R(-1),
log(CPET)      =       A1_CPET+A2_CPET*log(EN4ST_T)+AR_CPET*CPET_R(-1),
CEN            =       CELEC+COEN+CPET,
PENCOEN        =       exp((EN1C_T*log(PEN1C_T)+EN4C_T*log(PEN422C_T)+EN6C_T*log(PEN6C_T)+
                       EN8C_T*log(PEN81C_T))/(EN1C_T+EN4C_T+EN6C_T+EN8C_T))/A1_PENCOEN,
log(PCELEC)    =       A1_PCELEC+A2_PCELEC*log(PEN7C_T)+AR_PCELEC*PCELEC_R(-1),
log(PCOEN)     =       A1_PCOEN+A2_PCOEN*log(PENCOEN),
log(PCPET)     =       A1_PCPET+A2_PCPET*log(PEN41U_T)+AR_PCPET*PCPET_R(-1),
CELECV         =       CELEC*PCELEC,
COENV          =       COEN*PCOEN,
CPETV          =       CPET*PCPET,
CENV           =       CELECV+COENV+CPETV,
PCEN           =       CENV/CEN,

/*     Energy Prices                                                             */
PENC_MOD       =       exp((EN1C_T*log(PEN1C_T)+EN4C_T*log(PEN422C_T)+
```

```
                           EN6C_T*log(PEN6C_T)+EN8C_T*LOG(PEN81C_T))/
                           (EN1C_T+EN4C_T+EN6C_T+EN8C_T))/A1_PENC_MOD*PENC_MOD_FIX,
PENS_MOD        =          exp((EN4S_T*log(PEN422C_T)+EN6S_T*log(PEN6C_T))/(EN4S_T+EN6S_T))/
                           A1_PENS_MOD*PENS_FIX,
PENI            =          exp((EN1I_T*log(PEN1I_T)+EN42I_T*log(PEN422I_T)+EN43I_T*log(PEN43I_T)+
                           EN6I_T*log(PEN6I_T)+EN7I_T*log(PEN7I_T))/
                           (EN1I_T+EN42I_T+EN43I_T+EN6I_T+EN7I_T))/A1_PENI*PENI_FIX,
log(PQEIMT)     =          A1_PQEIMT+A2_PQEIMT*log(PENI)+(1-A2_PQEIMT)*log(PQEIMT(-1))+
                           AR_PQEIMT*PQEIMT_R(-1)+LOG(PQEIMT_FIX),
PQEIU           =          exp((EN1E_T*log(PEN1E_T)+EN4E_T*log(PEN43E_T)+EN6E_T*log(PEN6E_T)+
                           EN8E_T*log(PEN8E_T))/(EN1E_T+EN4E_T+EN6E_T+EN8E_T))/A1_PQEIU*PQEIU_FIX,
PEN71_T         =          EXP((YWIU(-1)/QGIUV(-1))*log(WIU)+(QEIUV(-1)/QGIUV(-1))*log(PQEIU)
                           +(QRIUV(-1)/QGIUV(-1))*LOG(PQRIU))*PEN71_FIX,
PEN7I_T         =          exp(A1_PEN7I+A2_PEN7I*log(PEN71_T)+A4_PEN7I*log(PEN7I_T(-1)))
                           +PEN7I_FIX,
PEN7C_T         =          exp(A1_PEN7C+A2_PEN7C*log(PEN71_T)+A3_PEN7C*log(WIU)+
                           A4_PEN7C*log(PEN7C_T(-1)))+PEN7C_FIX,
PEN1E_T         =          PEN1_T+RGTECA*A1_CARB+RGTEE,
PEN6E_T         =          PEN6_T+RGTECA*A6_CARB+RGTEE,
PEN8E_T         =          PEN8_T+RGTECA*A8E_CARB+RGTEE,
PEN1C_T         =          exp(A1_PEN1C+A2_PEN1C*LOG(PEN1_T)+A3_PEN1C*LOG(WNA)
                           +AR_PEN1C*PEN1C_R(-1))+RGTECA*A1_CARB+RGTEE+PEN1C_FIX,
PEN1I_T         =          exp(A1_PEN1I+A2_PEN1I*LOG(PEN1_T)+A3_PEN1I*LOG(WNA)
                           +AR_PEN1I*PEN1I_R(-1))+RGTECA*A1_CARB+RGTEE+PEN1I_FIX,
PEN41U_T        =          exp(A1_PEN41U+A2_PEN41U*log(PM3)+A3_PEN41U*log(REXPET))
                           +RGTECA*A49_CARB+RGTEE+PEN41U_FIX,
PEN422I_T       =          exp(A1_PEN422I+A2_PEN422I*log(PM3)+AR_PEN422I*PEN422I_R(-1))
                           +RGTECA*A49_CARB+RGTEE+PEN422I_FIX,
PEN422C_T       =          exp(A1_PEN422C+A2_PEN422C*log(PM3)+AR_PEN422C*PEN422C_R(-1))
                           +RGTECA*A49_CARB+RGTEE+PEN422C_FIX,
PEN43I_T        =          exp(A1_PEN43I+A2_PEN43I*log(PM3)+AR_PEN43I*PEN43I_R(-1))
                           +RGTECA*A49_CARB+RGTEE+PEN43I_FIX,
PEN43E_T        =          exp(A1_PEN43E+A2_PEN43E*log(PM3))+RGTECA*A4E_CARB+RGTEE+PEN43E_FIX,
PEN45C_T        =          exp(A1_PEN45C+A2_PEN45C*log(PM3)+AR_PEN45C*PEN45C_R(-1))+
                           RGTECA*A45_CARB+RGTEE+PEN45C_FIX,
PEN46C_T        =          exp(A1_PEN46C+A2_PEN46C*log(PM3)+AR_PEN46C*PEN46C_R(-1))+
                           RGTECA*A46_CARB*Z_PEN46C+RGTEE+PEN46C_FIX,
PEN81C_T        =          exp(A1_PEN81C+A2_PEN81C*log(PEN8_T)+A3_PEN81C*log(WNA))
                           +RGTECA*A8_CARB+RGTEE+PEN81C_FIX,
PEN6C_T         =          exp(A1_PEN6C+A2_PEN6C*LOG(PEN6_T))+RGTECA*A6_CARB+RGTEE+PEN6C_FIX,
PEN6I_T         =          exp(A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*ZT_PEN6I)+RGTECA*A6_CARB+
                           RGTEE+PEN6I_FIX,
PEN6IMCHF_T     =          exp(A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*ZT_PEN6I)+RGTECA*A6_CARB+
                           RGTEE+PEN6IMCHF_FIX,
PQEIMTR         =          PQEIMT/PQGIMT,
PQEIMTR_MAX     =          if PQEIMTR>PQEIMTR_MAX(-1) then PQEIMTR else PQEIMTR_MAX(-1),
PEN41UR         =          PEN41U_T/PC,
PEN41UR_MAX     =          if PEN41UR>PEN41UR_MAX(-1) then PEN41UR else PEN41UR_MAX(-1),

/*      Energy and Carbon Taxes                                                 */
GTEE            =          RGTEE*ENTD_T,
GTECA           =          ((CO2-A46_CARB*EN46ST_T*(1-Z_PEN46C))*RGTECA)/1000,
```