Working Paper No. 396

July 2011

The HERMES model of the Irish Energy Sector

Hugh Hennessy and John FitzGerald

Corresponding Author: john fitzgerald@esri.ie

The HERMES model of the Irish Energy Sector

1. Introduction

In Ireland, the energy sector has undergone significant change in the last forty years. In this period, there has been a significant increase in the demand for energy. This increase has been driven by economic and demographic factors. Although the current deep recession has quelled the upward trend in the demand for energy, a future economic recovery will bring these issues back into focus. This paper documents a model of the Irish energy sector which relates energy demand to real economic variables. As part of the HERMES macro-economic model this model of the energy sector has, for a number of years, been used to forecast energy demand. However, the energy model itself can be considered in isolation from the MERMES macro-economic model and this paper gives details of its specification.

Because of the capital intensity and long life of the capital assets in the investment sector, a good understanding of how future energy demand will behave is of considerable importance. However, as with all other forecasts, energy demand forecasts are subject to considerable margins of error and wise policy and investment decisions will take this into account. The impact of inaccurate energy demand forecasting was evident in Ireland throughout the 1980s. As discussed in FitzGerald et al., 2002, decisions made in the 1970s led to excess spare capacity in the electricity sector throughout the 1980s. This placed an addition price burden on Irish consumers and had a negative impact on Ireland's competitiveness.

Because energy use accounts for a high share of greenhouse gas emissions it is particularly important to understand the forces driving energy demand. Such forecasts are crucial in understanding what drives greenhouse gas emissions in Ireland. In turn, such an understanding is important if effective policies are to be developed and implemented to reverse the trend growth in such emissions. Since each fuel has a different emission impact, it is important that energy forecasts be disaggregated by fuel type. This model considers the different types of fuels and analyses how changes in economic activity and changes in relative prices affect their consumption in Ireland. This information is important in analysing the potential impact of policy measures such as carbon taxes. This model has been used for this purpose in a number of studies including Conefrey *et al.,* 2009.

Over the last 30 years, there has been substantial research into forecasting energy demand in Ireland. Research into the drivers of household energy demand in Ireland was undertaken (Scott, 1980; Scott and Conniffe, 1990; Scott, 1991; Conniffe, 1993, 2000b). These papers concluded that the consumption of household energy is significantly affected by household size and income. FitzGerald (2000) constructed energy demand forecasts out to 2015 using a simpler model than the one presented in this report. This report is an update of FitzGerald et al. (2002) which constructed an energy forecasting model based on historical time series data. Adjustments and changes have been made to the modelling process. These will be noted and explained where appropriate throughout the report.

Data for the model are taken from the ESRI Databank (Bergin et al., 2009). This is a database of economic variables in Ireland from 1960 to 2006. It also includes variables on energy demand by fuel and energy prices. Since 1990, these energy demand figures are consistent with the official Energy Balances (SEAI, 2010). Once energy demand is known, the model attributes various emission coefficients to energy use. This gives us estimates of carbon dioxide (CO_2) emissions.

The structure of the report is as follows. Section 2 gives a brief overview of the methodology used to develop the energy demand model. A detailed description of the estimation equations[1] is undertaken in Section 3. Section 4 briefly describes IDEM, an electricity dispatch model, and its relationship with this energy demand model. It also discusses the engineering relationships which are used in the electricity generation module. Section 5 models the carbon dioxide (CO_2) levels based on the estimated energy demand and emission coefficients. Section 6 discusses the relationship between the energy demand sub-model and the main HERMES macroeconomic model. Section 7 looks at the performance of the model within sample. Section 8 concludes.

2. Methodology

This version of the energy model consists of four separate modules. The first module is a structural macro econometric model that estimates the demand for different fuels in the five different sectors of the economy. These sectors are chosen because they are already estimated in the large macroeconomic model HERMES. These estimates drive the results obtained in the next two modules. The second module models the electricity generation sector based on exogenous engineering relationships, along with energy demand forecast derived previously. Due to the demand side variability of power generation, the model is linked to an electricity generation optimum dispatch model, IDEM. The third module applies emission coefficients to the energy production and consumption estimates to explain the associated carbon dioxide emissions. The fourth module links the energy sub-model with the HERMES model. Prices of different fuels are also computed here.

In the next section, there is a detailed description of the estimated equations and the related regression results. In this section, we will provide a brief overview of the general methodological framework. We will also address some of the problems associated with this and previous research associated with forecasting energy demand in Ireland.

This energy model treats five different sectors of the economy; household, commercial and public, industry, transport and agriculture. For each sector the demand for energy is first divided into demand for electricity and the demand for other energy sources. The electricity demand is estimated for all sectors using long-run equilibrium and short-run error-correction models. In this approach it is assumed that there is a long run relationship between energy demand and a range of economic variables. However, in any one period

[1] A full list of estimation equations is included in Appendix 3. This is preceded by details of the notation used in the databank in Appendix 1 and entire model listing in Appendix 2.

actual energy demand may deviate from this long run relationship because of unexpected changes in the economic variables and because it takes time to adjust actual energy demand to this long run value (especially where investment is needed.) The short run equation then models the process whereby actual energy demand adjusts towards its long-term equilibrium value.

The demand for “other energy’ is modelled directly also using long-run equilibrium and short-run error-correction models. From these equations for “other energy” the demand for each individual fuel is computed by separate equations. This gives us values for the demand for each fuel type in each sector. This can be aggregated in a number of ways. The total energy consumption in a particular sector can be calculated or the entire demand for a certain fuel in the entire energy system can be derived.

The error correction models are only estimated for the main energy equations. A long-run equilibrium value is estimated using co-integrating regression methods. An error correction model is then estimated for each of these equations. The results of these equations tell us the speed at which each variable adjusts to its long-run equilibrium value. It is not necessary to estimate these error correction models for each fuel type in each sector. Estimating them for the main equations is sufficient.[2]

In our model we follow the two step Engel-Granger (EG) procedure for cointegration modelling[3]. The first stage of this method is to model the long-run relationship in levels. It is necessary to assume that this is a true long-run relationship to proceed with the Engel-Granger method. The residuals from this first-stage regression should then be tested for stationarity. If they are stationary, a cointegrating relationship exists and one can proceed to the second stage. The second stage is to estimate dynamic short-run relationships in differences in the endogenous variables. The short-run regression includes the lagged residuals from the first step as the error correction term. The results of these short-run equations tell us the speed at which each variable adjusts to its long-run equilibrium value. This procedure is different to the one used in FitzGerald et al. (2002) where only one equation was used with a lagged dependent variable being used to capture long-run dynamics. The change in specification means that the model will eventually converge to a long-run equilibrium after specific shocks, something that was not guaranteed with the previous specification.

There are some data limitations when estimating energy demand in Ireland, which have hampered previous research in the area. In particular it is desirable to have a long run of data going back before the 1970s oil crises. Historical energy price data is taken from the study by Scott, FitzGerald and Curtis (2001). Although these data have some deficiencies, they do allow for a more robust estimation of price elasticities by sector overtime. As will be discussed later, data problems exist in the estimation of the commercial and public sector.

[2] These equations are listed in Appendix 3. The abbreviation “DEL” signifies a change in a variable - an error-correction equation.

[3] This procedure was originally introduced in Engle (1987). It has been in many time-series based studied since its first use.

Another problem with the dataset is the timing of the introduction of gas in Ireland. As this only happened in the mid-1980s, sample size may impact on the robustness of the estimation results.

The forecasts for electricity demand derived from this energy model are then fed into a separate model of the electricity sector the IDEM model[4]. The IDEM model (Diffney et al., 2009) is an optimal dispatch model which computes the cheapest way to produce electricity for each half-hour period of a given year. Annual growth estimates of electricity demand for each year from the energy model are applied to the entire electricity demand profile in a particular year. The IDEM model is a static model which computes the cost of producing electricity in each year separately.

Section 6 describes how the energy sub-model is linked to the HERMES macroeconomic model. These links occur within the utilities sector in HERMES and the household consumption sector where energy and non-energy consumption are separate. The other set of links is the determination of a set of energy prices for different fuels. This links the prices faced by the manufacturing sector and the prices used in the energy model. This becomes important to achieve model consistency. For example, oil price scenarios must be the same facing the energy demand side as well the manufacturing side to achieve model consistency. The HERMES energy model is part of the entire HERMES model. It is estimated simultaneously and an equilibrium point is achieved. At present, the energy model is largely post-recursive so that shocks to this sector only impact mildly on the wider economy.

3. Sectoral demand for Energy

In each case discussed below the full equation estimation is given in appendix 3. The model listing is given in Appendix 2.

[4] See FitzGerald et al. (2008) and Diffney et al. (2009) for a more complete description of the IDEM model

3.1 Household demand for energy

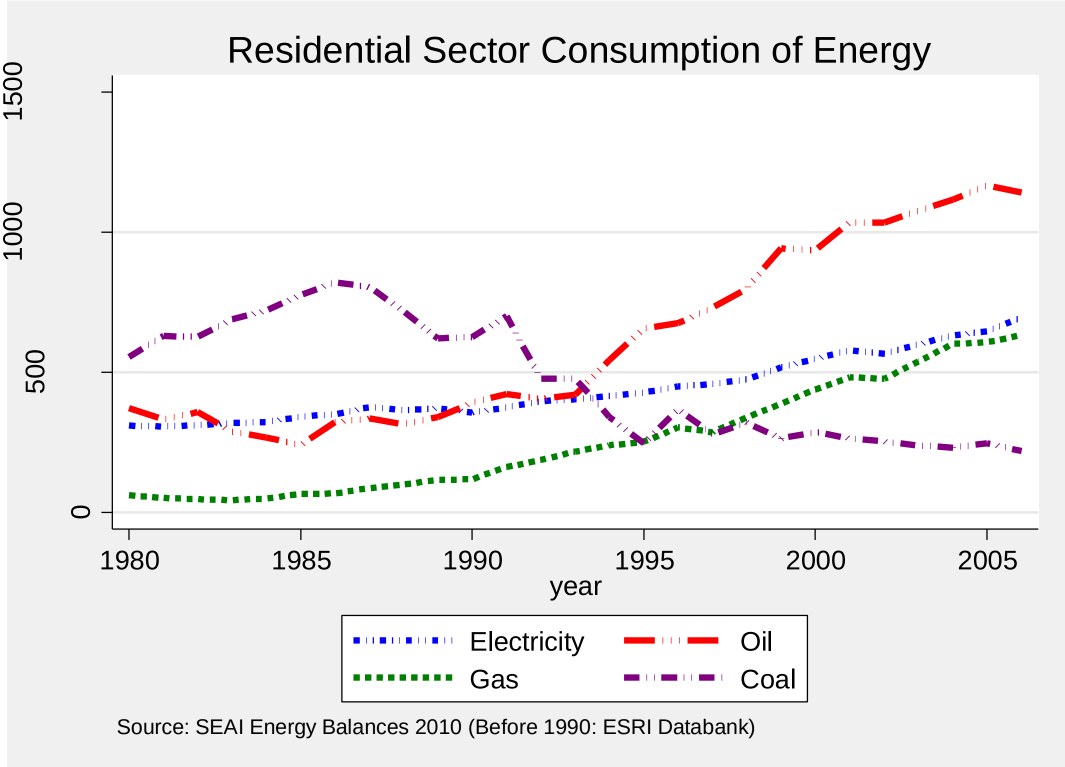

Figure 1: Residential Sector Consumption of Energy

Demand for energy in the residential sector accounts for about 23% of total energy consumption in Ireland. The energy consumption in this sector has also grown significantly over the last 40 years. This is due to increasing population levels along with improving economic conditions. However, the energy share of the residential sector has declined across the time period. The demand for electricity has grown steadily. The fuel mix of this electricity generation has changed a lot to accommodate this increase. The fuel mix of the rest of residential energy consumption has changed markedly over the last two decades (See Figure 1). The introduction of natural gas into domestic households from the mid-1980s has led to this fuel experiencing a steady upward demand trend. This largely replaces coal and peat.

3.1.1 Household demand for electricity

Household electricity is modelled using two different equations. It follows the overall simple model that demand in period t is affected by output elasticities, price elasticities and time elasticities. Here the output is proxied by the inverse of the housing stock (HSTOCK1). This reciprocal relationship allows the elasticity with respect to the number of households to fall overtime[5]. This is the specification normally used in the model. The other specification uses

[5] See Dargay (1992) for a discussion of this type of functional form in energy demand modelling

the reciprocal of real disposable income (YRPERD). The modelling period for this estimation is 1970-2005

*LOG(EN7C_T_STAR) =EN7C_C1+EN7C_C2/HSTOCK1+EN7C_C3*LOG(PEN7C_T/PC)+EN7C_C4*ZT_EN7C* *(647a)*

*LOG(EN7C_T_STAR) = EN7C_C8+EN7C_C9/YRPERD+EN7C_C10*ZT_EN7C* *(647b)*

Where:

EN7C_T_STAR	=	Equilibrium consumption of electricity by households in kTOE.
HSTOCK1	=	Number of households, (thousands)
PEN7C_T	=	Price of electricity for households Euro per kTOE.
PC	=	Price deflator for personal consumption
ZT_EN7C	=	Time trend
YRPERD	=	Real personal disposable income.

The coefficients are numbered from EN7C_C1 to EN7C_C10.

In the long-run, the price elasticity is -0.31. This captures improvements in efficiency which will only impact on the long-run effect. Overall, these results are slightly higher compared to the ones obtained in FitzGerald et al., 2002 which estimated slightly lower price elasticities for the demand for electricity.

The long-run elasticity with respect to the output variable (housing stock in this specification) has consistently fallen over the estimated time period. This long-run elasticity falls from 2.5 in the mid 1980s to 1.5 in 2006. The estimation also reveals a statistically significant negative time trend implying a trend fall in household electricity consumption each year of nearly 2%. This equation is well specified and produces a standard error of 2.7 per cent.

The important coefficient on the error correction model[6] is the error correction term. This is the difference in the lagged residuals of the long-run relationship. This determines the speed at which the short-run values reach the long-run equilibrium. In this instance, there is a statistically significant negative relationship which means that the short-run value can adjust to its long-run value.

The alternative specification (647b) uses disposable income as the output variable. This equation has a larger standard error. The price variable proved not to be significant and was dropped in the final specification. The long-run elasticity with respect to disposable income falls from around 0.8 in the early 1980s to 0.3 by 2005. In the model, the specification using the housing stock is chosen due to its superior statistical performance.

3.1.2 Household demand for energy other than electricity

This category of energy is modelled with a different specification to that for electricity. All variables are in log form. Again, there are two alternative equations used to explain residential use of fuel energy. Disposable income (YRPERD) is the output variable that drives

[6] The equation and the regressions for all the error correction models are displayed in appendix 2

energy demand in both equations. However, a different price variable is specified in each case. The price variable (PENC_MOD) is derived as a log-linear price index of individual fuel prices and fuel shares for the fuels coal, gas, oil and peat. The other price variable that is tested is the maximum recorded price in to date (PENCR_MAX). This essentially tests for evidence of efficiency improvements using an irreversible price effects variable[7].

*LOG(ENCW_T_STAR) = ENCW_C7+ENCW_C8*LOG(YRPERD)+ENCW_C9*LOG(PENCR_MAX(-1))+ENCW_C10*ZT_ENCW* *(645a)*

*LOG(ENCW_T_STAR)=ENCW_C1+ENCW_C2*LOG(YRPERD)+ENCW_C3*LOG(PENC_MOD/PC)+ENCW_C4*ZT_ENCW)* *(645b)*

Where:

ENCW_T_STAR	=	Equilibrium household consumption of non-electrical energy, kTOE.
PENCR_MAX	=	Maximum relative price of this category of energy achieved in the past.
PENC_MOD	=	Price of non-electrical energy for households.
PC	=	Price deflator for personal consumption
ZT_ENCW	=	Time trend
YRPERD	=	Real personal disposable income.

The coefficients are numbered from ENCW_C1 to ENCW_C10.

Energy demand is modelled over the estimation period 1970-2005. The first equation is the default equation.

In the default equation, 645a, the demand for energy is a function of real personal disposable income and of relative prices and time. The standard of error of the equation is 5.8%. Both the income and price effects are significant. This is contrast to FitzGerald et al., 2002 which found an insignificant price effect. The long-run income elasticity with respect to disposable income is 0.38. The long-run price elasticity is high at -0.73. The price term is the maximum price for energy previously attained relative to the current price for consumption. The logic of this specification is that when prices rise permanently (here defined as reaching a temporary peak) this sends a signal to households and developers of household appliances that investment in energy efficiency is likely to be profitable. However, once the investment is made the energy efficiency improvement does not disappear, even if prices temporarily fall back. The time trend proved of +1% a year was just significant in the estimation. The error-correction term proved statistically significant which means that energy demand adjusts to its long-run equilibrium.

We also model the demand for other energy using a standard relative price specification (645b). In this case the income elasticity is 0.75 and the relative price term has a coefficient of -0.35. The time trend is not significant. The standard error of this equation is significantly higher than for the default equation.

[7] See Haas and Schipper (1998) for an example into this type of method

In the first equation (645a) the standard of error of the equation is high (7.4%). However, both the income and price effects are significant. This is contrast to FitzGerald et al., 2002 which found an insignificant price effect. The long-run income elasticity with respect to disposable income is 0.75

The long-run price elasticity is -0.35. This is a plausible result as energy demand is generally considered to be price inelastic. When prices rise permanently (here defined as reaching a temporary peak) this sends a signal to households and developers of household appliances that investment in energy efficiency is likely to be profitable. However, once the investment is made it does not disappear even if prices temporarily fall back. The time trend proved insignificant in the estimation. The error-correction term proved statistically significant which means that energy demand adjusts to its long-run equilibrium.

3.1.3 Household fuel mix

As discussed above, there have been significant developments in the fuel mix of energy consumption in the last two decades. Because of major structural changes over the estimation period it is not easy to model the income and price elasticity of demand for individual fuels in a consistent manner. This prevents from constructing robust time-series equations which would allow us to examine substitution effects between fuels.

Consequently, the demand for individual fuel types is modelled using a simple specification where the share of three individual fuels as functions of time. In practise in forecasting it may be necessary to override these simple formulations. The rationale for this approach is that coal and peat are decreasing overtime. Gas is modelled slightly differently using a non-linear equation which assumes saturation in the gas share at 30%[8]. The demand for renewables (EN9C_T) is treated as exogenous at present. Renewables form only a very small fraction (0.005) of residential energy consumption, although this may increase in the future.

EN6C_T/(ENC_T-EN7C_T) = 0.3/(1+EXP(EN6C_C1+EN6C_C2(ZT_EN6C-1970)* (649)

*LOG(EN8C_T/(ENC_T-EN7C_T)) = EN8C_C1+EN8C_C2*ZT_EN8C* (650)

LOG(EN1C_T/(ENC_T-EN7C_T)) = IF (TYEAR < 1988) THEN (EN1C_C1+
*EN1C_C2*ZT_EN1C) ELSE (EN1C_C3+EN1C_C4*ZT_EN1C)* (651)

Where:

EN6C_T	=	Consumption of Gas in the residential sector, kTOE
EN7C_T	=	Consumption of electricity in residential sector, kTOE
ENC_T	=	Total household energy consumption, kTOE
EN8C_T	=	Consumption of peat in the Household sector, kTOE
EN1C_T	=	Consumption of coal in the Household sector, kTOE
ZT_EN6C	=	Time trend

The time trend for the demand for coal is negative and statistically negative. This is also apparent with the demand for peat. This is as expected and is predicted to continue in the

[8] The current share of gas is around 20%.

future. The non-linear functional form is used to explain the share of gas in energy consumption to take account of the increasing share of gas. However, this increase is slowing down and is closing in on its long-run optimum value.

The demand for oil is then computed as the resulting residual

$$EN4C\_T = (ENCW\_T-(EN1C\_T*A1\_ENCW\_T+EN6C\_T*A6\_ENCW\_T+EN8C\_T*A8\_ENCW\_T))/A4\_ENCW\_T \quad (653)$$

Where:

EN4C_T = Household oil consumption, kTOE.

We can calculate total household demand for energy (ENC_T) as follows:

$$ENC\_T = EN1C\_T+EN4C\_T+EN6C\_T+EN7C\_T+EN8C\_T+EN9C\_T \quad (654)$$

Where:

ENC_T = Total household energy consumption

3.2 Commercial and public sector demand for energy

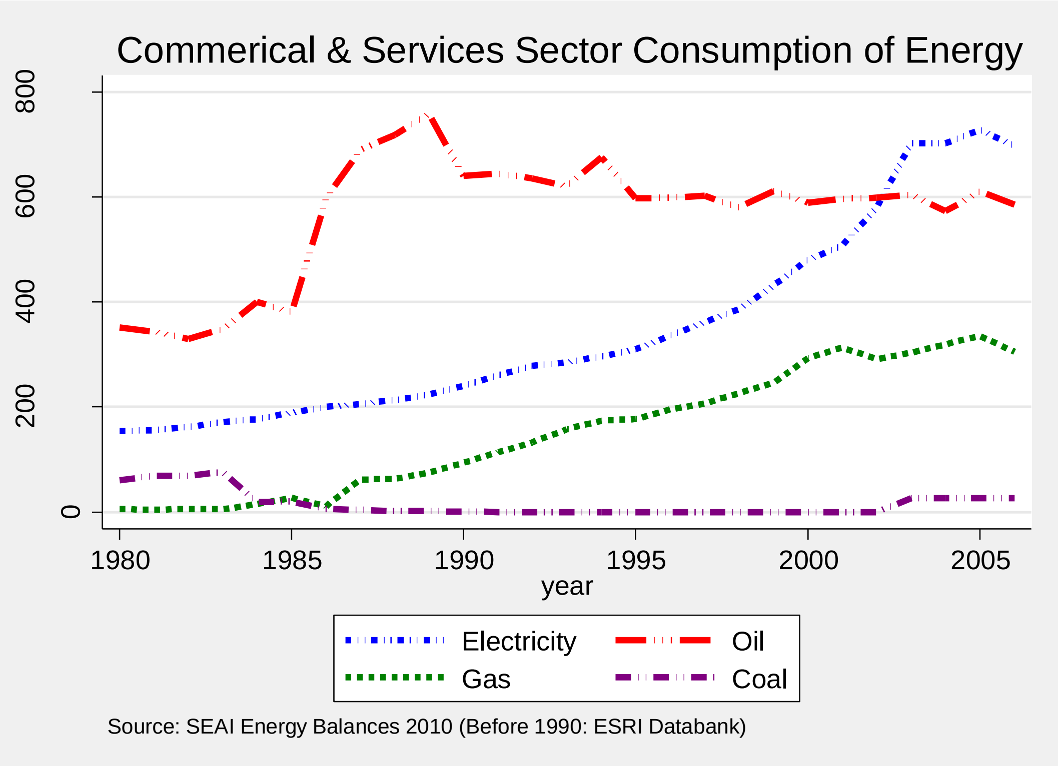

Figure 2: Commercial & Services Sector Consumption of Energy

In the commercial and public sector, energy demand is almost entirely made up of oil, gas and electricity (Figure 2). Since gas came on-stream, it has gradually replaced much of the oil used for central heating purposes. However, historical energy use data in the commercial and public services is residually determined. This may create errors in the data which may also be present in the estimation process.

As with the residential sector, we directly estimate the demand for electricity and for other energy as two separate equations. We then compute the energy demand for each fuel within the non-electrical energy aggregate. These equations again explain energy use in terms of an output or activity variable, relative prices and time effects, where appropriate. We use same type of econometric procedure as for the residential sector.

3.2.1 Commercial and public demand for electricity

*LOG (EN7S_T_STAR) = EN7S_C1+EN7S_C2/ (OSM+OSNHE+OSNP) +EN7S_C3*LOG (PEN71_T/PC)* *(658)*

Where:

EN7S_T_STAR	=	Equilibrium consumption of electricity by commercial sector in kTOE.
OSM	=	Value Added, market services
OSNHE	=	Value Added, non-market services
OSNP	=	Value Added, public administration and defence
PEN71_T	=	Price of electricity for industry Euro per kTOE.
PC	=	Price deflator for personal consumption

The coefficients are numbered from EN7S_C1 to EN7S_C3.

Demand for electricity is modelled as a function of GDP arising in the market and non-market sectors (OSM+OSHNE+OSNP) and the price of electricity to industrial consumers (PEN71_T) relative to a personal expenditure deflator (PC). The modelling period for this estimation was 1974-2006. The standard error on this equation is quite high at 9 per cent. The output elasticity for this equation, driven by the volume of output in the commercial and public sector, is declining overtime. We compute that this value was 1.9 in 1980 and had fallen to 0.7 in 2005. The long-run price elasticity is -0.15 which suggests that firms in this sector have limited options to substitute away from electricity.

The error correction coefficient was significant suggesting an attainable long-run equilibrium.

3.2.2 Commercial and public demand for energy other than electricity

The demand for non-electricity energy is modelled as a declining function of economic activity in the sector (OSM+OSHNE+OSNP). As in the residential sector, a reciprocal for output is used so that the output elasticity declines overtime. The coefficient on relative prices proved insignificant. The equation was estimated on data from 1970-2006. The standard error on the equation is very high at 19 per cent. The implied elasticity of demand with respect to economic activity in the sector is estimated to have fallen from 1.8 in 1980 to 0.4 in 2006. The coefficient on the error-correction term is significant.

LOG(ENSR_T_STAR) = ENS_C1+ENS_C2/(OSM+OSNHE+OSNP) *(656)*

Where:

ENSR_T_STAR = Equilibrium demand for non-electrical energy in the services sector
OSM = Value Added, market services
OSNHE = Value Added, non-market services
OSNP = Value Added, public administration and defence

3.2.3 Commercial and public sector inter-fuel mix

$$LOG(EN6S\_T/ENSR\_T) = EN6S\_C1+EN6S\_C2*LOG(PEN6C\_T/PEN422C\_T)+ EN6S\_C3/ZT\_EN6S \quad (660)$$

Where:
EN6S_T = Demand for gas in the services sector
ENSR_T = Demand for non-electrical energy in the services sector
PEN422C_T = Price of light fuel oil to households, in TOEs
PEN6C_T = Price of natural gas in Euro per TOE
ZT_EN6S = Time Trend

We model the demand for gas relative to other energy as a function of the price of gas (PEN6C_T) relative to the price of light oil (PEN422C_T) and the inverse of time. Since gas is a comparatively newer fuel, we estimate the share using a shorter time series. The time period used is 1992-2006. Using the relative price of gas against oil allows us to examine the cross-price elasticities. We estimated that the long-run cross-price elasticity is -0.33. This is high and may be related to the shorter time series used in estimation.

We make a distinction in the demand for gas between heat generated as part of CHP (Combined Heat and Power Plant) generation and the demand for non-CHP gas. ENCHS is the proportion that accounts for the total CHP generation in the commercial and public sector. The two equations below show the breakdown of the gas consumption in this sector.

$$EN6SCH\_T = EN6CH\_T*ENCHS \quad (662)$$

$$EN6SNH\_T = EN6S\_T-EN6SCH\_T \quad (663)$$

Where:

EN6SCH_T = Gas consumed from CHP plants - attributed to the commercial sector
EN6CH_T = Total gas consumed from CHP plants, in kTOE
ENCHS = Proportion of total CHP generation in commercial sector
EN6SNH_T = commercial sector consumption of gas, excluding gas used in CHP, in kTOE

As mentioned previously, the demand for other fuels like coal, peat and renewable is negligible, thus these are assumed to be exogenous. The demand for oil in the commercial and public sectors is computed as the residual as follows:

$$EN4S\_T = ENS\_T-EN7S\_T-EN6S\_T-EN1S\_T-EN8S\_T-EN9S\_T \quad (664)$$

Where:

EN4S_T	=	Demand for oil in commercial sector, in kTOE
ENS_T	=	Demand for energy in commercial sector, in kTOE
EN7S_T	=	Demand for electricity in commercial sector, in kTOE
EN6S_T	=	Demand for gas in commercial sector, in kTOE
EN1S_T	=	Demand for coal in commercial sector, in kTOE
EN8S_T	=	Demand for peat in commercial sector, in kTOE
EN9S_T	=	Demand for renewables in commercial sector, in kTOE

Finally, the demand for non-LPG oil (EN48S_T) is residually determined given that the demand for LPG is treated as exogenous

3.3 Industrial Energy Demand

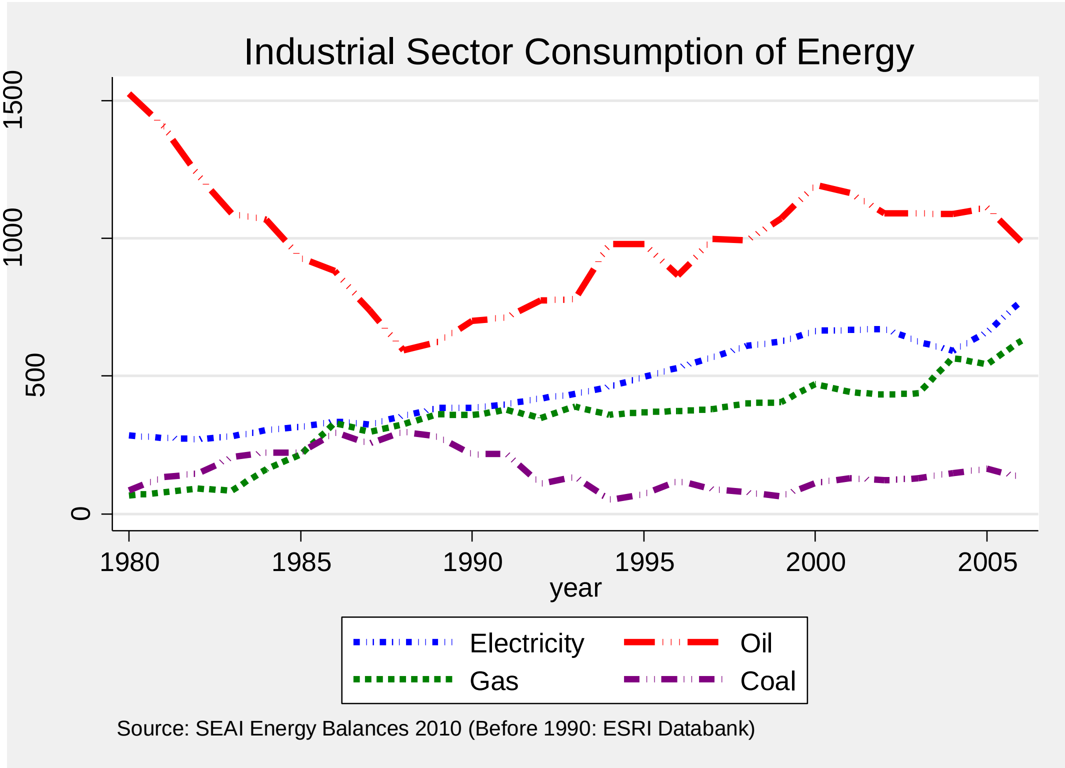

Figure 3: Industrial Sector Consumption of Energy

The industrial sector has undergone a major restructuring since the start of the 1980s. The use of oil relative to economic output, in particular, has dropped significantly. Other fuels have experienced an upward trend. This is all in the context of a significant increase in industrial output in this time period.

We model this sector in a similar way to previous ones. We estimate the demand for electricity and other energy separately. We then use these estimates to drive the levels of the other fuels in the sector using share equations. As previously, the demand for oil is determined as a residual.

3.3.1 Industrial sector demand for coal

Before the 1990s, the demand for coal in the industrial sector remained quite stable. However, since the early 1990s this demand has fallen considerably. The share of coal in the industrial sector has dropped from 19% in 1988 to 6% in 2006. For these reasons, we model the demand for coal using a structural break. We model the share of the demand for coal using a time trend and the relative price of coal to industry against the price of heavy oil to industry.

*LOG(EN1I_T/ENI_T) = IF (TYEAR < 1992) THEN (EN1I_C1+EN1I_C2*LOG(PEN1I_T/PEN43I_T)+EN1I_C3*ZT_EN1I) ELSE (EN1I_C4+ EN1I_C5*LOG(PEN1I_T/PEN43I_T)+EN1I_C6*ZT_EN1I)* (670)

Where:

EN1I_T	=	Demand for coal in industrial sector, in kTOE
ENI_T	=	Demand for energy in industrial sector, in kTOE
PEN1I_T	=	Price of coal for industry Euro per TOE.
PEN43I_T	=	Price of heavy oil for industry Euro per TOE.
ZT_EN1I	=	Time trend

The equation has a very high standard error at 28 per cent. Where the equation is estimated from 1992 onwards the results indicate a long-run price elasticity of -0.83 and a negative time trend. This would suggest that industry is moving away from coal.

3.3.2 Industrial sector demand for aggregate energy

The long-run value of the demand for non-electrical energy in the industrial sector is modelled as a declining function of the volume of GDP arising in industrial sector (OI) and the ratio of the volume of net (QNIMT) and gross (QGIMT) output in manufacturing industry. The latter variable picks up changes in the structure of the sector. The equation is estimated over the time period 1976-2005.

*LOG(ENIR_T_STAR) = ENI_C1+ENI_C2/OI+ENI_C3*LOG(QNIMT/QGIMT)* (666)

Where:

ENIR_T_STAR	=	Equilibrium demand for energy in industrial sector, in kTOE
OI	=	Value added, industrial sector
QNIMT	=	Net output, industry, manufacturing, total, constant prices
QGIMT	=	Gross output, industry, manufacturing, total

The coefficients are numbered from ENI_C1 to ENI_C3.

As shown in FitzGerald et al., 2002, the implied long-run elasticity on industrial GDP is falling sharply over time from 0.35 in 1980 to 0.06 in 2006. A maximum price variable proved insignificant in estimation and so was excluded from the final estimation. No error-correction procedure was conducted on this equation as the coefficients did not prove significant. Thus energy demand adjusts to its equilibrium level instantaneously in this sector.

3.3.3 Industrial sector demand for electricity

The demand for electricity in the industrial sector is driven by a relative price effect, an output effect and a time effect. A structural break is also used in the estimation process. A chow test suggests that this break is apparent in the mid 1980s. The equation is modelled using the reciprocal of the volume of GDP arising in the industrial sector, the price of electricity in the sector relative to a price deflator and a time trend.

LOG(EN7I_T_STAR) = IF(TYEAR<1985)THEN
*EN7I_C1+EN7I_C2*LOG(OI)+EN7I_C3*LOG(PEN7I_T/PQGIMT)+EN7I_C4*ZT_EN7I ELSE*
*(EN7I_C5+EN7I_C6*LOG(OI)+EN7I_C7*LOG(PEN7I_T/PQGIMT)+ EN7I_C8*ZT_EN7I) 658)*

EN7I_T_STAR	=	Equilibrium demand for electricity in industrial sector, in kTOE
OI	=	Value added, industrial sector
PEN7I_T	=	Price of electricity for industry Euro per TOE.
PQGIMT	=	Price deflator, gross output, industry, manufacturing
ZT_EN7I	=	Time trend

The coefficients are numbered from EN7I_C1 to EN7I_C8.

The equation for the period 1985-2006 is shows a reasonable fit with a standard error of 4 per cent. The long-run output elasticity is 0.51. The long-run price elasticity is -0.30. This is consistent with previous estimates observed in FitzGerald et al., 2002. The time trend is insignificant. The error-correction term is statistically significant so a long-run equilibrium is achievable. The output elasticity is higher than the output elasticity computed in the commercial sector. This is expected as many industrial firms may opt to move to self-generation if a long-run cost advantage exits.

3.3.4 Industrial sector fuel mix

As discussed previously, the use of coal played an important part in the industrial sector. This has declined in recent years. The shares of both peat and renewable are very small and are thus treated as exogenous. The demand for LPG is estimated using a simple time trend.

The demand for gas is estimated in a similar fashion to the commercial and public sector. It is split between CHP and non-CHP gas use. The share of total CHP generation in the industrial sector is given by the fraction ENCHI

*EN6ICH_T = EN6CH_T*ENCHI (673)*

Where:

EN6ICH_T	=	Gas consumed from CHP plants - attributed to the industrial sector
EN6CH_T	=	Total gas consumed from CHP plants, in kTOEs
ENCHI	=	Proportion of total CHP generation in industrial sector

We assume that the demand for non-CHP gas (EN6INH_T) rises in line with the demand for other energy in the industrial sector. However, this is subject to the availability of gas (EN6ISH).

*EN6INH_T = (ENI_T-EN7I_T)*EN6ISH-EN6ICH_T (674)*

Where:

EN6INH_T	=	Industry sector consumption of gas, excluding gas used in CHP
EN7I_T	=	Demand for electricity in industrial sector, in kTOEs
EN6ISH	=	Gas share of final consumption of energy in the industrial sector

The total demand for gas in the industrial sector is simply the sum of these two variables

EN6I_T = EN6ICH_T+EN6INH_T *(675)*

Finally, the demand for non-LPG oil (EN48I_T) in the industrial sector is left as a residual

EN48I_T = ENI_T-EN1I_T-EN6I_T-EN7I_T-EN8I_T-EN9I_T-EN45I_T *(676)*

EN4I_T = EN45I_T+EN48I_T *(677)*

Where:

EN4I_T	=	Demand for oil in industrial sector, in kTOE
ENI_T	=	Demand for energy in industrial sector, in kTOE
ENI7_T	=	Demand for electricity in industrial sector, in kTOE
ENI6_T	=	Demand for gas in industrial sector, in kTOE
EN1I_T	=	Demand for coal in industrial sector, in kTOE
EN8I_T	=	Demand for peat in industrial sector, in kTOE
EN9I_T	=	Demand for renewables in industrial sector, in kTOE

3.4 Transport energy demand

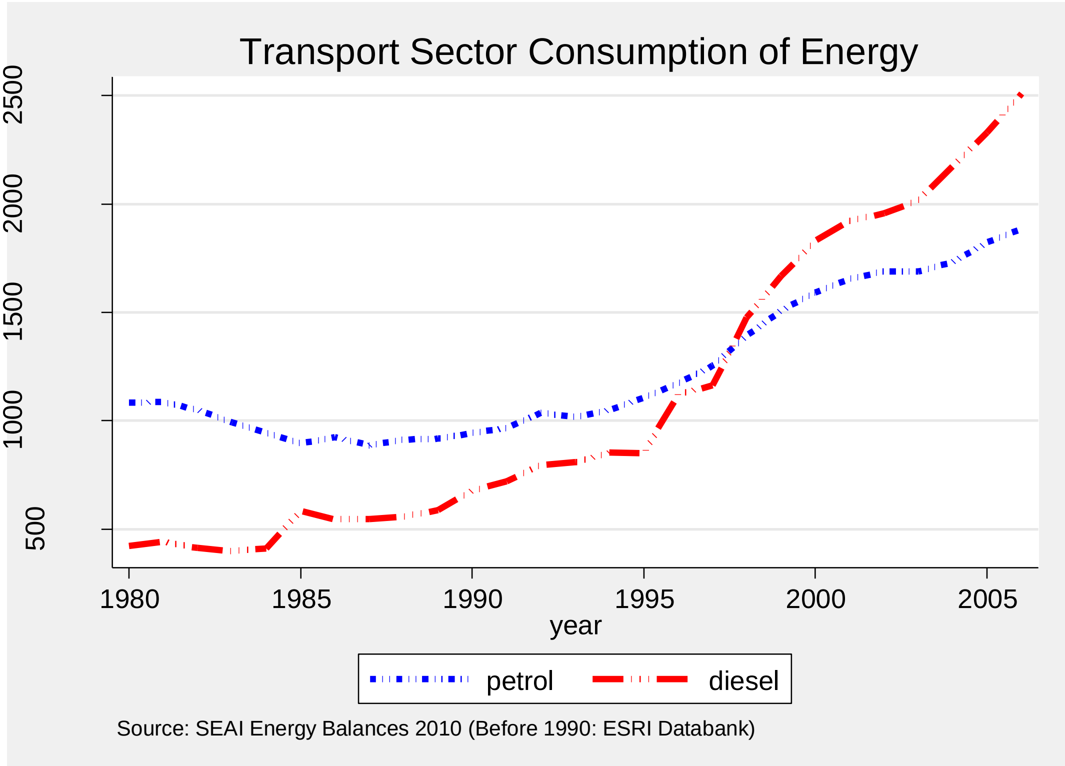

Figure 4: Transport Sector Consumption of Energy

As displayed in Figure 7, the demand for energy in transport is not only the largest demand of individual sectors but it is also the sector where demand is increasing the fastest. This is almost entirely made up of imported oil. Petrol and diesel are consumed for personal transport and freight purposes. The use of kerosene is predominantly confined to the airline sector.

We have directly estimated the demand for these three fuels using different methods. We also estimate the outputs that drive the demand for these fuels. The demand for petrol is driven by the stock of cars. The volume of freight drives the demand for diesel. The level of tourism is the main determinant of the demand for kerosene (for aviation). This is a significant improvement on Fitzgerald et al., 2002 where the transport sector demand for energy was confined in scope.

3.4.1 Transport sector demand for cars

We estimate the demand for private cars (SCARS) adapting a methodology initially developed by DKM (1998). These estimates of the car stock determine the demand for petrol. The demand for cars (SCARS) is estimated using a logistical function with a saturation rate on car ownership. This variable is driven by the ratio of disposable income (YRPERD) to the number of people in the age group 15-64. The age group 15-64 is a behavioural variable in the HERMES model

*DEL (1: LOG (0.8/ (SCARS/N1564)-1)) = A1_SCARS+A2_SCARS*DEL (1: YRPERD/N1564)   (683)*

Where:

SCARS	=	Stock of Cars, thousands
N1564	=	Number of people aged between 15 and 64
YRPERD	=	Real disposable income

The standard error of the equation is high at 5 per cent. As with error-correction procedures, the R-squared value is quite low at 0.22. The coefficient on the demand variable is low at -0.05. At the saturation point (0.8 in this equation), the increase in the car stock will be directly proportional to the increase in the population.

3.4.2 Transport sector demand for petrol

We model the demand for petrol (EN41ST_T) as a function of the stock of cars, the price of unleaded petrol relative to the UK price and a time trend. This time trend is intended to pick up any improvements in car stock efficiency. This equation is estimated from 1980-2005

*LOG(EN41ST_T) = A1_EN41ST+A2_EN41ST*LOG(SCARS)+A3_EN41ST*LOG(PEN41U_T/(PEN41U_T_UK*REX_UK))+A4_EN41ST*ZT_EN41ST   (681)*

Where:

EN41ST_T	=	Demand for petrol in the transport sector, kTOEs
PEN41U_T	=	Price of unleaded petrol in TOES
PEN41U_T_UK	=	Price of unleaded petrol in the UK in TOES

REX_UK	=	Exchange Rate (UK)

The coefficient on the car stock variable is positive and greater than 1 (1.27) which suggests that increasing the car stock will increase petrol consumption at a slightly greater rate. However, this coefficient is not significant. This is because newer cars are generally driven significantly more, even though they are more efficient. The coefficient on the Irish price relative to the UK price of petrol picks up the scope for fuel tourism. This coefficient is significant with a value of -0.15. There is a highly significant negative time trend of -2.3% a year which picks up the significant increase in energy efficiency of the vehicle stock over time.

3.4.3 Transport sector demand for diesel and other oil

To model the demand for diesel and other oil, we first need to estimate level of freight demand (TRANS_TK) in the economy. We model the demand for freight as a simple function of economic activity (GNP) and the ratio of the price of petrol to the consumption deflator.

*LOG(TRANS_TK) = A1_TRANS+A2_TRANS*LOG(GNP)+A3_TRANS*LOG(PEN41U_T/PC)* (679)

Where:

TRANS_TK	=	Goods transported by road in Ireland, million tonne kilometres
PEN41U_T	=	Price of unleaded petrol in TOES
GNP	=	Gross National Product, output basis, constant prices
PC	=	Price deflator

This equation has a standard error of 5 per cent. The elasticity with respect to GNP is high at 1.95. The price variable proved insignificant in the estimation.

This variable drives the demand for diesel (EN42ST_T) and other oil (EN43ST_T). The demand for diesel is then modelled as a function of the demand for freight and the ratio of the price of unleaded petrol in Ireland and its price in the UK. This will need to be adapted in the future due to increasing share of diesel cars in the car stock.

*LOG(EN42ST_T+EN43ST_T) = A1_EN42ST+A2_EN42ST*LOG(TRANS_TK)+*
*A3_EN42ST*LOG(PEN41U_T/(PEN41U_T_UK*REX_UK))* (680)

Where:

EN42ST_T	=	Demand for diesel in the transport sector, kTOEs
EN43ST_T	=	Demand for heavy oil in the transport sector, kTOEs
GNP	=	Gross National Product, output basis, constant prices
PC	=	Price deflator

The long-run elasticity of diesel demand with respect to freight is 0.63. This is plausible given the large increase in freight that was apparent since the mid-to-late 1990s. The price effect proves significant in the long-run equation. We estimate a long-run price elasticity of -0.61

3.4.4 Transport sector demand for kerosene

The demand for kerosene (EN46ST_T) is estimated as a function of tourism exports (XTO) and the price of kerosene offered to consumers. This kerosene price is used as there is no time series data available on what price the airlines pay for their fuel. The equation is modelled using a structural break. The elasticity with respect to tourism exports is very high at 2.6. This may need to be overridden when forecasting as the volume of air transport is likely to eventually reach an asymptote so that such an unbounded elasticity could exaggerate future energy use.

LOG(EN46ST_T) = IF (TYEAR < 1994) THEN
*(EN46ST_C1+EN46ST_C2*LOG(PEN46C_T/PC)+EN46ST_C3*LOG(XTO)) ELSE*
*(EN46ST_C4+EN46ST_C5*LOG(PEN46C_T/PC)+EN46ST_C6*LOG(XTO))* *(682)*

Where:

EN46ST_T	=	Demand for kerosene in the transport sector, kTOEs
PEN46C_T	=	Price of kerosene to consumers, in TOEs
XTO	=	Exports, tourism, constant prices
PC	=	Price deflator

The coefficients are numbered from EN46ST_C1 to EN46ST_C6.

There is a very small amount of LPG consumed in the transport sector. This is exogenously determined.

This allows us to compute the total oil consumed in transport as a simple sum of the previously constructed variables.

EN49ST_T = EN41ST_T+EN42ST_T+EN43ST_T *(678)*

EN4ST_T = EN49ST_T+EN45ST_T+EN46ST_T *(684)*

Where:

EN4ST_T	=	Demand for oil in transport sector, in kTOE
EN41ST_T	=	Demand for petrol in transport sector, in kTOE
EN42ST_T	=	Demand for diesel in transport sector, in kTOE
EN43ST_T	=	Demand for heavy oil in transport sector, in kTOE
EN46ST_T	=	Demand for kerosene in transport sector, in kTOE
EN7ST_T	=	Demand for electricity in transport sector, in kTOE
ENST_T	=	Demand for energy in transport sector, in kTOE

Finally, there is also a very small amount of electricity consumed in rail transport. The demand for electricity in transport (EN7ST_T) may increase in the future with the advent of electric vehicles.

ENST_T = EN4ST_T+EN7ST_T *(685)*

3.5 Agriculture energy demand

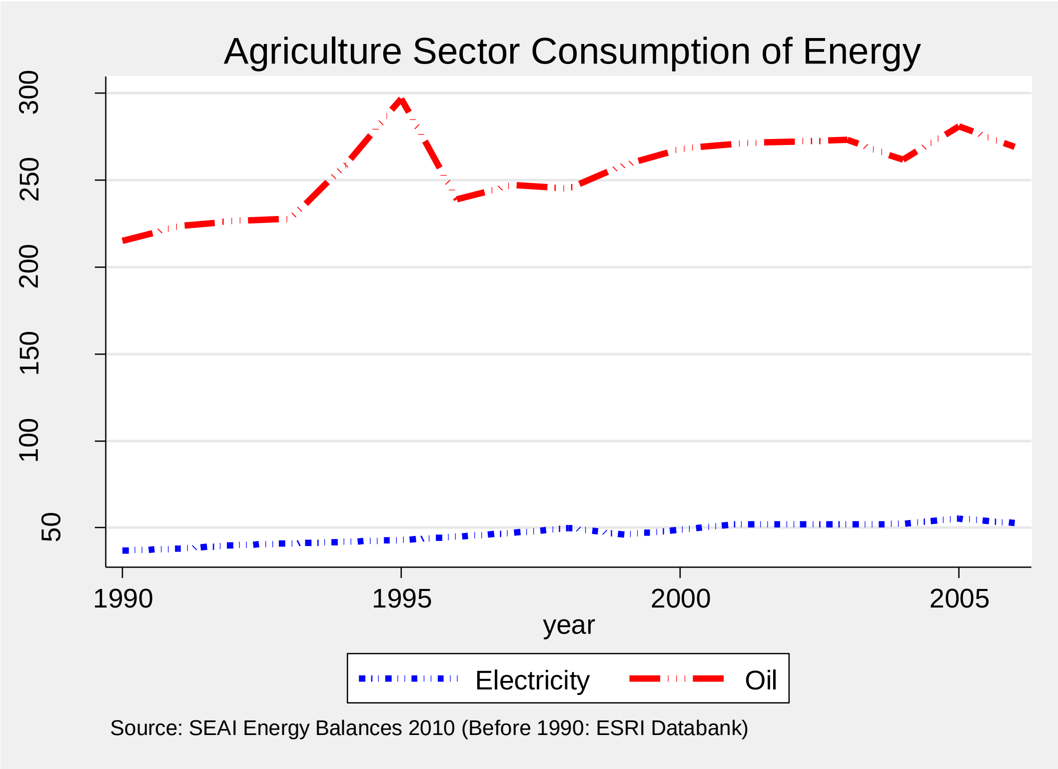

Figure 5: Agriculture Sector Demand for Eenrgy

As shown above, data for energy use in agriculture is only available from 1990. The demand for energy in the agriculture sector accounts for only a small fraction (2.5% in 2006) of total energy demanded. This figure has decreased over time and will probably decrease further in the future. As well as this, energy itself is forming a decreasing portion of agriculture inputs since the 1990s. The vast majority of agricultural energy demand is made up of electricity and oil (in this case, diesel).

This means that we only estimate two equations, namely the demand for oil and the demand for electricity. The demand for oil is computed residually.

3.5.1 Agriculture sector demand for energy

The demand for total energy in agriculture is modelled as a function of material agriculture inputs and a time trend

*LOG(ENA_T) = ENA_C1+ENA_C2*LOG(QMA)+ENA_C3*ZT_ENA* (686)

Where:

ENA_T	=	Demand for energy in agriculture sector, in kTOE
QMA	=	Material inputs, agriculture. constant prices

ZT_ENA = Time trend

The coefficients are numbered from ENA_C1 to ENA_C3.

We estimate a long-run elasticity with respect to agricultural inputs of 0.52. A significant positive time trend of +0.9% a year was observed.

3.5.2 Agricultural sector demand for electricity

The demand for electricity in agriculture is modelled with the same function as used for the demand for energy in agriculture. It must be noted that both estimations are conducted on a relatively short time period.

We estimate an insignificant long-run elasticity with respect to agricultural inputs of 0.26. This is significantly lower than the demand for energy in the agriculture sector. The main explanatory variable is a significant positive time trend of +2.2% a year.

*LOG(EN7A_T) = EN7A_C1+EN7A_C2*ZT_EN7A+EN7A_C3*LOG(QMA)* *(687)*

Where:

EN7A_T = Demand for electricity in agriculture sector, in kTOE
QMA = Material inputs, agriculture, constant prices
ZT_ENA = Time trend

We treat the demand for renewables in agriculture (EN9A_T) as being exogenously determined as it is very small. This leaves us with the demand for oil which is determined as a residual

EN4A_T = ENA_T-EN7A_T-EN9A_T *(688)*

Where:

EN4A_T = Demand for oil in agriculture sector, in kTOE

3.6 Identities to aggregate sectoral data

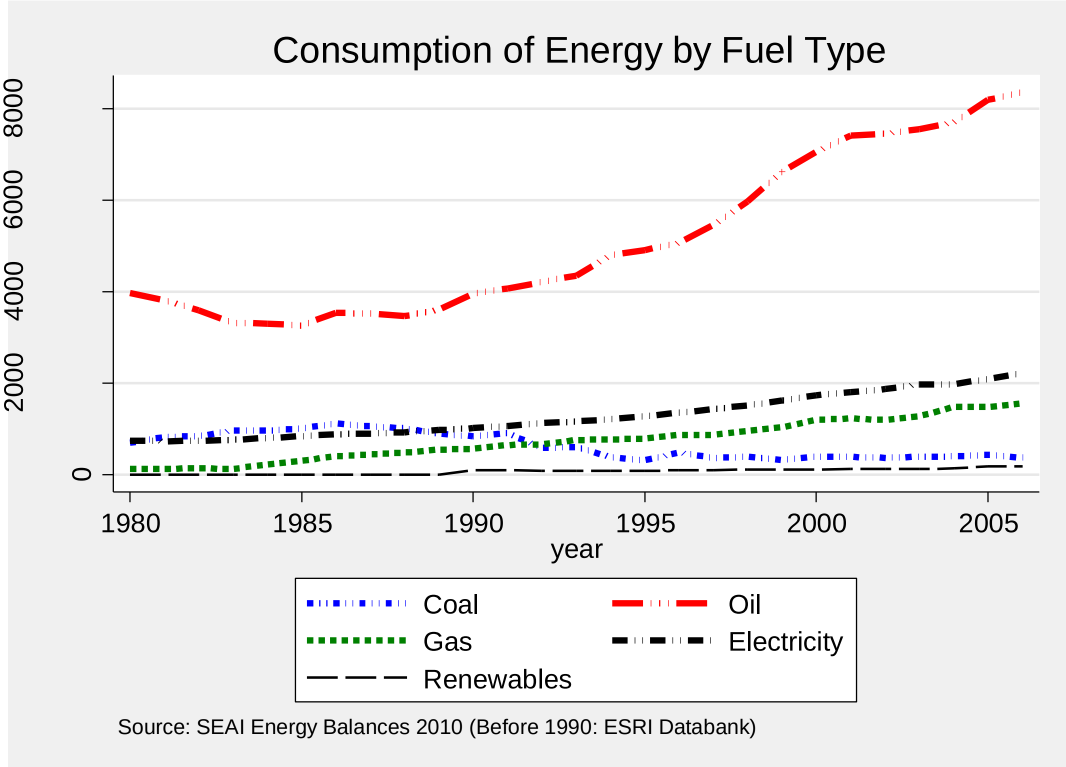

Figure 6: Total Consumption of Energy by fuel type

The demand for different fuels has been estimated across the different sectors. However, there are a few procedures that need to take place before the final energy demand figures are computed. Each is aggregated to total final consumption (Suffix FC relates to final consumption). The total final consumption of energy in the economy is given as follows:

ENFC_T = EN1FC_T+EN4FC_T+EN6FC_T+EN7FC_T+EN8FC_T+EN9FC_T *(695)*

Where:

EN4FC_T	=	Total final consumption of oil in kTOE
ENFC_T	=	Total final consumption of energy, in kTOE
EN6FC_T	=	Total final consumption of gas, in kTOE
EN7FC_T	=	Total final consumption of electricity, in kTOE
EN8FC_T	=	Total final consumption of peat, in kTOE
EN1FC_T	=	Total final consumption of coal, in kTOE
EN9FC_T	=	Total final consumption of renewables, in kTOE

The final demand for energy excludes the transmission losses that are apparent in energy. These losses differ by fuel type.

We also examine the level of export and more importantly imports of energy in the Irish energy system. We treat exports of energy (ENX_T) and stock changes (ENBA_T) as exogenous as they are currently very small[9]. This leaves us with only the imports of energy (ENM_T) to compute. This is derived as the residual between domestic production (ENQD_T) and total domestic energy requirement (ENTD_T)

$$ENM\_T = ENX\_T + ENTD\_T - ENQD\_T - ENBA\_T \quad (732)$$

Where:

ENM_T	=	Total imports of energy, in kTOE
ENX_T	=	Total exports of energy, in kTOE
ENTD_T	=	Total primary energy requirement, in kTOE
ENQD_T	=	Total production of energy, in kTOE
ENBA_T	=	Change in stocks of energy in kTOE

Lastly, imports of Oil (M3) are based on energy imports using an adjustment factor M3_DIS

$$M3 = ENM\_T * M3\_DIS \quad (733)$$

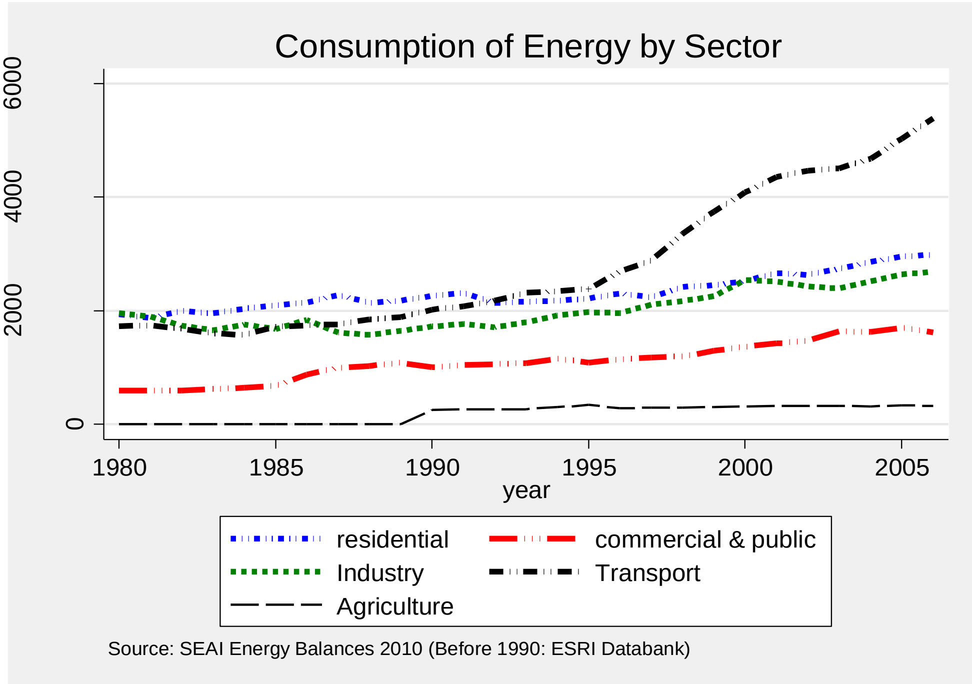

Figure 7: Consumption of Energy by Sector

4. Electricity Generation

The electricity generation sector covers all electricity generated, including electricity generated by renewables like wind. The output of the sector is driven by electricity demand (EN7FC_T). The estimation process to compute electricity demand was explained in the previous section.

[9] This might change in the future with the increasing levels of interconnection between Ireland and abroad.

Within the energy model there is a fully specified model of electricity generation. However in forecasting, the results from this sub-model are replaced with results derived from using the IDEM electricity generation model. This is because of the complexity of the electricity generating sector which is much better captured in the IDEM model which incorporates more information on the engineering characteristics of the sector. Some iteration may be needed to ensure that the results from the two models are fully consistent.

The model documented previously was estimated using annual data. However, annual data are not sufficient to capture the complexities of electricity generation. For this reason, electricity generation is explained by a separate model IDEM (Diffney et al., 2009).

Briefly, IDEM is an optimal dispatch model of the All-Island market[10]. Each generating station is ranked in the merit order according to its bid price (which is assumed to be its short run marginal cost). Then electricity demand is compared to the merit order and starting from the lowest cost, plants are switched on until the demand in each period is met. Once the merit order is defined and compared to demand, the system marginal price (SMP) is set to the bid price of the most expensive plant required to meet demand in every given period. This allows estimation of the costs and revenues for each plant over the year. This is comparable to how the electricity generation market operates in Ireland at present.

IDEM provides estimates of the generation cost of electricity that is needed to meet demand in all half-hour periods. This is based on operation of the cheapest plants as required. There is no transmission loss constraints imposed on this model. IDEM is valuable in analysing the reaction in the generation portfolio to changing prices and demand profiles. However all forecasts produced by the energy model are annual forecasts. IDEM produces estimates of the annual average price of electricity for each year out until 2025. These prices are then fed back into the HERMES energy model and the model is re-estimated. Such an iterative approach is possible because the HERMES energy model is largely post-recursive to the macro model.

Here we describe the electricity sector of the HERMES energy model, which, in forecasting, may be overridden by results from IDEM. We impose a number of engineering relationships to describe the losses in conversion, generation and transmission. This differs by fuel type so various parameters are used. These will be described in this section. We then compute the amount of energy consumed in generation (a suffix of G represents this). The portfolio of fuels used in electricity generation is generally more complete than in the other sectors. Coal, peat, renewables, gas and oil all make up differing amounts of this generation portfolio depending on aggregate demand and the time profile of this demand.

[10] The All-Island electricity market is made up of the Republic of Ireland and Northern Ireland. It came into existence on the 1st November 2007.

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* (735)

Where:

EN7G1_T	=	Estimated electricity generated from coal, TOE
EN1E_T	=	Energy sector consumption of Coal in TOE
ENGEFF1	=	Conversion factor for coal into electricity

Total gasoil and total fuel oil are constructed in the same way. Total oil based electricity generation is simply the sum of these two. The total peat consumed in electricity generation is also constructed this way.

*EN7G42_T = EN42E_T*ENGEFF42* (736)

*EN7G43_T = EN43E_T*ENGEFF43* (737)

EN7G4_T = EN7G42_T+EN7G43_T (738)

*EN7G8_T = EN8E_T*ENGEFF8* (739)

Where:

EN7G42_T	=	Estimated electricity generated from diesel, TOE
EN42E_T	=	Energy sector consumption of Coal in TOE
ENGEFF42	=	Conversion factor for coal into electricity
EN7G43_T	=	Estimated electricity generated from coal, TOE
EN43E_T	=	Energy sector consumption of Coal in TOE
ENGEFF43	=	Conversion factor for coal into electricity
EN7G4_T	=	Estimated electricity generated from oil, TOE
EN7G8_T	=	Estimated electricity generated from peat, TOE
EN8E_T	=	Energy sector consumption of peat in TOE
ENGEFF8	=	Conversion factor for peat into electricity

In FitzGerald et al. (2002) the future of renewables was modelled using both a policy switch variable reflecting the uncertainty towards renewables policy and using an efficiency of conversion parameter as used for other fuels. However, in the current model version with a more certain policy future, we simply apply efficiency of conversion factors (generally unity except for ENGEFF92 which is 0.35). Total electricity generated from renewables is then just the sum of the three variables.

*EN7G91_T = EN91E_T*ENGEFF91* (741)
*EN7G92_T = EN92E_T*ENGEFF92* (742)
*EN7G93_T = EN93E_T*ENGEFF93* (743)
EN7G9_T = EN7G91_T+EN7G92_T+EN7G93_T (744)

Where:

EN7G91_T	=	Estimated electricity generated from Hydro, in kTOE
EN91E_T	=	Energy sector production of Hydro, in kTOE

ENGEFF91	=	Conversion factor for Hydro into electricity
EN7G92_T	=	Estimated electricity generated from other renewables, in kTOE
EN92E_T	=	Energy sector production of other renewables, in kTOE
ENGEFF92	=	Conversion factor for other renewables into electricity
EN7G93_T	=	Estimated electricity generated from wind, in kTOE
EN93E_T	=	Energy sector production of wind, in kTOE
ENGEFF93	=	Conversion factor for wind into electricity

As discussed previously, gas is broken down into two components: CHP and non-CHP. Gas is the most important fuel in relation to the Irish electricity system. This leads into the rationale for the equations that follow. 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. We then apply a specific conversion factor as before.

EN7GCH6_T = EN6CH_T(1-ENCHS-ENCHI)*ENGEFF6C* *(739)*

Where:

EN7GCH6_T	=	Estimated electricity generated from gas in CHP plants, in kTOE
EN6CH_T	=	Total gas consumed from CHP plants, in kTOE
ENGEFF6C	=	Conversion factor for gas into electricity

Total electricity generated (EN7GENES_T) is the sum of the electricity generated from the all different fuels. Assuming that total electricity output is demand driven, and knowing that electricity from gas is needed to balance the system, the total output excluding CHP is computed residually.

EN7GNH6_T = EN7GENES_T-(EN7G1_T+EN7G8_T+EN7G4_T+EN7GCH6_T+EN7G9_T) *(745)*

EN7G6_T = EN7GCH6_T+EN7GNH6_T *(746)*

Where:

EN7GNH6_T	=	Estimated electricity generated from gas, excluding CHP plants, TOE
EN7GENES_T	=	Estimated electricity generated, in kTOE
EN7G1_T	=	Estimated electricity generated from coal, in kTOE
EN7G8_T	=	Estimated electricity generated from peat, in kTOE
EN7G4_T	=	Estimated electricity generated from oil, in kTOE
EN7GCH6_T	=	Estimated electricity generated from gas in CHP plants, in kTOE
EN7G9_T	=	Estimated electricity generated from renewables, in kTOE

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

EN6E_T = EN6CH_T(1-ENCHS-ENCHI) +EN7GNH6_T/ENGEFF6N* *(747)*

Where:

EN6E_T	=	Energy sector consumption of gas in TOE
EN7GNH6_T	=	Estimated electricity generated from gas, excluding CHP plants
ENGEFF6N	=	Conversion factor for non-CHP gas into electricity

Finally two aggregations are necessary to compute total energy used in electricity.

EN4E_T = EN42E_T+EN43E_T (748)
ENE_T = EN1E_T+EN4E_T+EN6E_T+EN8E_T+EN9E_T (749)

Where:

EN4E_T	=	Demand for oil in energy sector, in kTOE
EN41E_T	=	Demand for petrol in energy sector, in kTOE
EN42E_T	=	Demand for diesel in energy sector, in kTOE
EN43E_T	=	Demand for heavy oil in energy sector, in kTOE
EN46E_T	=	Demand for kerosene in energy sector, in kTOE
EN7E_T	=	Demand for electricity in energy sector, in kTOE
ENE_T	=	Demand for energy in energy sector, in kTOE

The conversion factors used above are not precise. No such precise numbers are publicly available post 1992. Because of this, we need to make an adjustment for the discrepancy between the total electricity generated in the model and the actual electricity generated.

EN7GENAD_T = EN7GENES_T-EN7GEN_T (751)
EN7GENES_T = EN7GEN_T/EN7GENAD_FIX (752)

Where:

EN7GENAD_T	=	Adjustment to bring estimated electricity generated to actual electricity generated
EN7GEN_T	=	Electricity generated
EN7GENES_T	=	Estimated electricity generated

Domestic electricity production (EN7GEN_T) is determined as the total available electricity less imports plus exports

EN7GEN_T = EN7AVAIL_T-EN7M_T+EN7X_T (753)

Where:

EN7GEN_T	=	Electricity generated, in kTOE
EN7AVAIL_T	=	Total electricity available, in kTOE
ENM_T	=	Total imports of energy, in kTOE
ENX_T	=	Total exports of energy, in kTOE

Finally, an important aspect of electricity generation is transmission losses. This is simply the difference between the electricity sent out by the generating plants (EN7GSO_T) and the total final consumption of electricity (EN7FC_T). We estimate that these losses vary between

3-14% depending on the fuel share portfolio of the power generating plants. These are set at 0.045 in the forecast period.

EN7GSO_T = EN7FC_T/(1-EN7TRL_FIX) (757)

EN7TRLOS_T = EN1E_T+EN4E_T+EN6E_T+EN8E_T+EN9E_T+EN7M_T-EN7X_T-EN7FC_T (759)

Where:

EN7GSO_T	=	Estimated electricity sent out from generating stations, in kTOE
EN7TRL_FIX	=	Adjustment to final consumption of electricity
EN7TRLOS_T	=	Energy lost in transformation into electricity, in kTOE

5. Carbon Dioxide Emissions

Once fuel consumption is determined, we simply apply fuel specific emission coefficients to the consumption of each total fuel type.

Fuel Type	**Hermes Mnemonic**	**Tonnes of CO2 per TOE**
Coal	A1 CARB	3.961
Oil - air transport: Kerosene	A46 CARB	2.980
Oil - Electricity	A4E CARB	3.182
Oil - other	A49 CARB	3.069
LPG	A45 CARB	2.667
Gas	A6 CARB	2.300
Gas - NET	A6IMCHF CARB	2.300
Peat - domestic	A8 CARB	4.140
Peat - electricity	A8E CARB	4.354

Table 1: Emission Coefficients by fuel type

The exception to this procedure is the emission coefficient for electricity. This is based on the emissions of the individual fuels that are used in power generation. This is projected to decline overtime as increasing levels of wind appear on the system. The model projects carbon dioxide emission by sector and by fuel type. These are aggregated together to establish total carbon dioxide emissions in Ireland for each year.

A7_CARB =
*(EN1E_T*A1_CARB+EN4E_T*A4E_CARB+EN6E_T*A6_CARB+EN8E_T*A8E_CARB)/EN7FC_T* (760)

CO2 = CO2LOS+CO2C+CO2S+CO2I+CO2A+CO2ST+CO2IMCHF (776)

Where:

A7_CARB	=	Power Generation Emission Factor
CO2LOS	=	Carbon Dioxide Emissions: Transmission Losses
CO2C	=	Carbon Dioxide Emissions in the Residential Sector
CO2S	=	Carbon Dioxide Emissions in the Services and Commercial Sector
CO2I	=	Carbon Dioxide Emissions in the Industrial Sector
CO2A	=	Carbon Dioxide Emissions in the Agriculture Sector
CO2ST	=	Carbon Dioxide Emissions in the Transport Sector
CO2IMCHF	=	Carbon Dioxide Emissions from Feedstock

The ISus model (Tol et al., 2009) has a more sophisticated approach to modelling carbon emissions. However, for the purpose of modelling the macro-economic impact of policies such as a carbon tax carbon emissions have been endogenised in HERMES as described above.

6. Links with the HERMES Macroeconomic Model

The Hermes Macroeconomic model is a large macro-econometric model of the Irish economy. It provides forecasts of economic output by sector out until 2025. The model was first developed in the late 1980s (Bradley et al., 1989). It has undergone significant iterations since then. [11] The energy model described previously is a sub-model within the main HERMES model. There are three sections where links have been established between the two. These links occur in the utilities sector, household consumption and the determination of energy prices.

6.1 Utilities Sector

The energy data derived previously is linked to economic variables which determine output and prices in the utilities sector.

6.1.1 Utilities Output

Utilities output in volume terms (QGIU) are driven by the demand for electricity (EN7FC_T).

$$LOG(QGIU) = A1\_QGIU+A2\_QGIU*LOG(EN7FC\_T) \qquad (104)$$

The long-run elasticity here is close to unity as might be expected in such a technical linking equation. The equation is well determined with an equation standard error of 3 per cent.

6.1.2 Utilities Output Prices

The price of utilities output (PQGIU) is estimated as a function of the price of electricity (PEN71_T). This price is based on the wholesale price index data for the price of electricity to industry.

[11] See Conefrey et al. (2010) for a brief history of the development of the model as well as Bergin, *et al.,* 2003.

$$LOG(PQGIU) = A1\_PQGIU+A2\_PQGIU*LOG(PEN71\_T) \quad (105)$$

This equation is less well determined with an equation standard error of 12.2 per cent. However, the estimated coefficient (A2_PQGIU) is almost unity as might be expected. This is different to Fitzgerald et al., 2002 which found a coefficient significantly different from unity.

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)

$$LOG(QEIU) = A1\_QEIU+A2\_QEIU*LOG(ENE\_T)+A3\_QEIU*LOG(KIU) \quad (106)$$

Where:

QEIU	=	Energy inputs used in the utilities sector
ENE_T	=	total energy used in electricity generation
KIU	=	capital stock in the utilities sector

The standard error on this equation is 7.9 per cent. The coefficient on total energy used in electricity generation is close to unity (0.91).

6.1.4 Utilities Raw Materials Inputs

The share of raw materials inputs in total manufacturing output in value (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).

$$QRIUV/QGIUV = A1\_QRIU+A2\_QRIU*LOG(EN7FC\_T)+A3\_QRIU*LOG(KIU)+A4\_QRIU*LOG(PQRIU/PQGIU) \quad (108)$$

Where:

QRIUV	=	Inputs, utilities
QGIUV	=	Gross output, industry, utilities, at current prices
EN7FC_T	=	Final Consumption of electricity, in kTOE
KIU	=	Capital stock in the utilities sector
PQRIU	=	Price of raw materials, utilities
PQGIU	=	Price deflator, gross output, industry, utilities

The equation is well determined with a standard error of 4.3 per cent and the results are in line with FitzGerald et al., 2002.

6.2 Household Consumption

Consumption in the HERMES model is disaggregated into the consumption of energy and non-energy components. This allows for a link with the energy model. We estimate separate equations for the consumption of electricity in volume at constant prices (CELEC), the volume of consumption of other energy (at constant prices) (COEN) and the consumption of oil in the transport sector at constant prices. These variables are driven by the demand for electricity (EN7FC_T), the demand for 'other energy (ENCW_T) and the transport sector's consumption of oil (EN4ST_T). These simple equations link the energy demand volumes in TOEs and the economic volume consumption data in the HERMES model.

*LOG(CELEC)= A1_CELEC+A2_CELEC*LOG(EN7C_T)* (323)
*LOG(COEN) = A1_COEN+A2_COEN*LOG(ENCW_T)* (324)
*LOG(CPET) = A1_CPET+A2_CPET*LOG(EN4ST_T)* (325)

Where:

CELEC	=	Electricity, personal consumption, constant prices
COEN	=	Non-electrical energy, personal consumption, constant prices
CPET	=	Petrol, personal consumption, constant prices
EN7C_T	=	Demand for electricity in the household sector, in kTOE
ENCW_T	=	Demand for non-electrical energy in the household sector, in kTOE
EN4ST_T	=	Demand for oil in the transport sector, in kTOE

The equations above are well determined with significant coefficients on all explanatory variables. However, the coefficients are lower than reported in FitzGerald et al., 2002.

A similar estimation process is used to link the national accounting price deflators PCELEC, PCOEN and PCPET to the energy prices in TOEs. These are directly linked to PEN7C_T, PENCOEN and PCPET using three basic equations.

*LOG(PCELEC) = A1_PCELEC+A2_PCELEC*LOG(PEN7C_T)* (326)
*LOG(PCOEN) = A1_PCOEN+A2_PCOEN*LOG(PENCOEN)* (327)
*LOG(PCPET) = A1_PCPET+A2_PCPET*LOG(PEN41U_T)* (328)

Where:

PCELEC	=	Deflator for CSO data personal consumption of electricity
PCOEN	=	Deflator for CSO data personal consumption of non-electrical energy
PCPET	=	Deflator for CSO data personal consumption of petrol
PEN7C_T	=	Price of electricity for households Euro per kTOE.
PENCOEN	=	Price of non-electrical energy for households Euro per kTOE
PEN41U_T	=	Price of unleaded petrol in TOES

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

*CELECV = CELEC*PCELEC* (333)
*COENV = COEN*PCOEN* (334)
*CPETV = CPET*PCPET* (335)
CENV = CELECV+COENV+CPETV (336)
PCEN = CENV/CEN (337)

Where:

CELECV	=	Electricity, personal consumption, current prices
COENV	=	Non-electrical energy, personal consumption, current prices
CPETV	=	Petrol, personal consumption, current prices
CENV	=	Personal consumption, energy

PCEN = Price Deflator for energy

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 available to the industrial sector (PENI). PENI is a log-linear index of prices for respective fuels in the industrial sector

*LOG(PQEIMT) = A1_PQEIMT+A2_PQEIMT*LOG(PENI)+(1-A2_PQEIMT)*LOG(PQEIMT(-1))* (781)

Where:

PQEIMT = Price deflator for energy inputs into the manufacturing sector
PENI = Price of energy to the industrial sector

6.4 Individual Energy Prices

The general modelling framework to compute energy prices revolves around identifying an anchor price for each fuel. From this anchor price, we are able to relate this price to the price that is faced by consumers and industry.

6.4.1 Price of Electricity

The anchor electricity price used in the model is the wholesale price of electricity PEN71_T. This wholesale price is constructed using a weighted index of individual fuel prices in the electricity generation sector

*PEN71_T=EXP(A1_PEN71+A2_PEN71*LOG(PEN43E_T)+A3_PEN71*LOG(PEN1E_T) +A4_PEN71*LOG(PEN8E_T)+A5_PEN71*LOG(PEN6E_T)* (780)

Where:

PEN71_T = Price of electricity for industrial users, Average price per TOE
PEN43E_T = Price of heavy fuel oil in electricity generation, in TOEs
PEN1E_T = Price of coal in electricity generation, in TOEs
PEN8E_T = Price of peat in electricity generation, in TOEs
PEN6E_T = Price of gas in electricity generation, in TOEs

The coefficients are numbered from A1_PEN71 to A5_PEN71.
This price determines the price used in the industrial sector (PEN7I_T) and in the residential sector (PEN7C_T). The long-run coefficient on the anchor price differs for the household and industrial sectors. For the household sector, the coefficient is less than one (0.78) and for the industrial sector it is greater than one (1.06).

6.4.2 Price of Coal

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

*PEN1E_T = PEN1_T+RGTECAT*A1_CARB+RGTEE* (797)

Where:

PEN1E_T	=	Price of coal in electricity generation, in TOEs
PEN1_T	=	Anchor price of coal
RGTEE	=	Rate of energy tax
RGTECAT	=	Rate of carbon tax
A1_CARB[12]	=	Emission coefficient for coal

This includes a tax on carbon dioxide emissions[13]. The price of coal in the household (PEN1C_T) and industrial (PEN1I_T) sectors is modelled as a function of the above anchor price of coal (PEN1_T) and the non-agricultural wage rate.

*PEN1C_T = EXP(A1_PEN1C+A2_PEN1C*LOG(PEN1_T)+A3_PEN1C*LOG(WNA)+
RGTECANT*A1_CARB+RGTEE* (782)

*PEN1I_T =
EXP(A1_PEN1I+A2_PEN1I*LOG(PEN1_T))+RGTECANT*A1_CARB+RGTEE* (783)

Where:

PEN1C_T	=	Price of coal for households, in TOEs
PEN1I_T	=	Price of coal for industry, in TOEs
WNA	=	Average earnings, Non-agriculture

6.4.3 Price of Oil

Since all the oil consumed in Ireland is imported, we use the price of energy imports (PM3) as the anchor price for oil in the model. All other oil prices are modelled as a simple function of this anchor price. The exception to this is the price of unleaded petrol (PEN41U_T) which is a function of the anchor price and also the rate of excise tax on petrol (REXPET). One change in the model described in FitzGerald et al. (2002) is that the price of LPG is no longer a function of the price of oil but rather the price of gas.

*PEN41U_T=
EXP(A1_PEN41U+A2_PEN41U*LOG(PM3)+A3_PEN41U*LOG(REXPET))
+RGTECANT*A49_CARB+RGTEE* (784)

*PEN422I_T=
EXP(A1_PEN422I+A2_PEN422I*LOG(PM3))+RGTECANT*A49_CARB+RGTEE* (785)

*PEN422C_T=
EXP(A1_PEN422C+A2_PEN422C*LOG(PM3))+RGTECANT*A49_CARB+RGTEE* (786)

*PEN43I_T=
EXP(A1_PEN43I+A2_PEN43I*LOG(PM3)+RGTECANT*A49_CARB+RGTEE* (787)

*PEN45C_T =
EXP(A1_PEN45C+A2_PEN45C*LOG(PEN6C_T))+ RGTECANT*A45_CARB+RGTEE* (791)

[12] A list of the emission coefficients used is included in Table1 in Section 5
[13] RGTECA is the tax in euro per tonne of carbon dioxide. RGTEE is the tax on energy in euro per TOE

*PEN46C_T = EXP(A1_PEN46C+A2_PEN46C*LOG(PM3))+RGTEE+ RGTECANT*A46_CARB*Z_PEN46C* *(792)*

*PEN43E_T = EXP(A1_PEN43E+A2_PEN43E*LOG(PM3))+RGTECAT* A4E_CARB+RGTEE* *(793)*

Where:

PEN41U_T	=	Price of unleaded petrol in TOES
PEN422I_T	=	Price of light fuel oil to industry, in TOES
PEN422C_T	=	Price of light fuel oil to households, in TOES
PEN43I_T	=	Price of heavy fuel oil to industry, in TOEs
PEN45C_T	=	Price of LPG to households, per TOEs
PEN46C_T	=	Price of kerosene to consumers, in TOEs
PEN43E_T	=	Price of heavy fuel oil in electricity generation, in TOEs
PEN6C_T	=	Price of natural gas in Euro per TOE
PM3	=	Deflator of imports, SITC 3 (energy)
A49_CARB[14]	=	Emission coefficient for coal
REXPET	=	Rate of excise on petrol

6.4.4 Price of Peat

The anchor price of peat is the price of peat to the electricity generation sector before taxes:

*PEN8E_T = PEN8_T+RGTECAT*A8E_CARB+RGTEE* *(799)*

Where:

PEN8E_T	=	Price of peat in electricity generation, in TOEs
PEN8_T	=	Anchor price of peat

We then model the price of peat to the consumer (PEN81C_T) as a function of the anchor price and the non-agricultural wage rate. This equation does not perform particularly well. There is no peat consumed in the industrial sector.

*PEN81C_T = EXP(A1_PEN81C+A2_PEN81C*LOG(PEN8_T)+A3_PEN81C*LOG(WNA)) +RGTECANT*A8_CARB+RGTEE* *(788)*

Where:

PEN81C_T	=	Price of turf briquettes, per TOE
PEN8_	T =	Anchor price of peat
WNA	=	Average earnings, Non-agriculture

6.4.4 Price of Gas

The anchor price of gas (PEN6_T) is the price of gas to the electricity generation sector before energy taxes are applied.

*PEN6E_T = PEN6_T+RGTECAT*A6_CARB+RGTEE* *(798)*

[14] A list of the emission coefficients used is included in Table1 in Section 5

Where:

PEN6E_T	=	Price of gas in electricity generation, in TOEs
PEN6_T	=	Anchor price of gas

We then estimated the price of gas faced by consumers (PEN6C_T) and the price faced by industry (PEN6I_T). We modelled the price of gas as a simple function of the anchor price. For industry, we added a time trend to the estimation.

*PEN6C_T = EXP(A1_PEN6C+A2_PEN6C*LOG(PEN6_T))+RGTECANT* A6_CARB+RGTEE* (789)

*PEN6I_T = EXP(A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*ZT_PEN6I+) +RGTECANT*A6_CARB+RGTEE* (790)

Where:

PEN6C_T	= Price of gas for households, in TOEs
PEN6I_T	= Price of gas for industry, in TOEs
ZT_PEN6I	= Time trend

These price equations are generally estimated accounting for the presence of autocorrelation. This is corrected using Cochrane-Orcutt estimation.

6.5 Energy and Carbon Taxes

As is evident from the equations described previously, the price equations allow for the imposition of an energy tax (RGTEE), a carbon tax (RGTECANT) or both. For the carbon tax, the relevant fuel is adjusted to take account of its CO_2 emission rate. For example, the estimate for the price of coal is adjusted to add on a carbon rate tax rate per TOE of CO_2 emitted (RGTECANT*A1_CARB) and an energy tax per TOE (RGTEE)

This allows us to calculate the level of tax revenue associated with the imposition of particular taxes on the consumption of energy[15]. This model was used to examine the impacts of a carbon tax in Ireland on various aspects of the economy (Conefrey et al. 2008). This paper found that a double dividend exists if the revenue generated from the introduction of a tax on carbon is recycled back into the economy to reduce labour taxes. This paper also found that a greater incidence of this tax will fall on capital rather than labour.

7. How does the model perform within sample?

We assess the performance of the energy model on a number of bases. We show in the first column of Table 2 the standard error for each equation in the model described above. Then

[15] The model includes a switch (Z_PEN46C) option as emissions from kerosene in the air travel sector are not currently covered under the Kyoto protocol

we show in the second column results where we simulated the model and calculated the root mean squared percentage errors (RMPSE) for the important behavioural variables estimated within sample. This involves simulating the whole HERMES model. This allows errors in one equation to feed through into another equation, where the model estimates of the right hand side variables replace the historical values. This normally produces higher errors than where equations are used with historical values of endogenous variables. Finally in columns 3 and 4 we show the same information for the model described in FitzGerald *et al.,* 2002. In the case of the 2002 model it was simulated merely as an energy model without full interaction with the HERMES macro-economic model, which might have been expected to produce a better performance.

Table 2: Energy Demand by sector: Standard Errors and Root Mean Squared Percentage Errors

	Estimated 2008: Sample 1970-2005		**Estimated 2002: Sample 1970-1999**	
	Single Equation	Macro-Model	Single Equation	Energy Model
Error	S.E.	RMSPE	S.E.	RMSPE
Agriculture				
Total	4.8	4.7	3.7	4.5
Electricity	3.1			
Households				
Total		7.9		4.6
Electricity	2.7	4.0	2.7	
Other Energy	5.8	5.9	5.8	
Industry				
Total		8.1	5.8	5.0
Electricity	5.4	4.9	3.5	
Other Energy	10.3	10.0		
Services				
Total		15.5		6.5
Electricity	9.0	5.2	2.6	
Other Energy	21.0	19.0	15.9	
Transport				
Total		6.5		3.3
Petrol	3.6	12.9		
Diesel	5.6	5.8		
Kerosene	15.9	11.7		
Total Final Demand		3.5		2.6
Total Electricity Demand		2.6		

Generally the fit of the equations for electricity demand is better than the equations for demand for other forms of energy. This may, to some extent, reflect better quality of data. However, it also reflects the fact that in many cases unusual factors, not captured in the model, affected non-electricity energy demand while leaving electricity demand unaffected (e.g. cross-border fuel tourism).

The model described in this paper generally has the same basic specification as the model from 2002. The difference between the results from the two versions of the model arises primarily from the additional data used in the estimation of the latest version.

In the case of energy demand in agriculture, with similar specification, the fit of the current version of the model shows some disimprovement compared to the 2002 version of the model. However, when simulated as a model the estimate within sample shows a rather similar error.

The results for the household sector are very similar in the latest model version to those in the 2002 version. The equation for electricity demand in the sector shows a relatively low (and unchanged) standard error. While the RMSPE is higher when the model is simulated as a system, the results are still reasonably satisfactory. The model forecast for non-electrical energy demand in the sector shows a significantly higher (but unchanged) error. However, it is still at an acceptable level.

For industry the model estimate of demand for electricity is higher than for the household sector (and higher than in the 2002 version). The error on the equation for demand for non-electrical energy in the industrial sector shows a much higher error. When the aggregate demand for energy in the industrial sector is modelled, the error in the current version of the model is significantly higher than in the 2002 version. This suggests that the equations for the demand for non-electrical energy may need to be re-examined when the model is re-estimated.

The services sector demand for energy shows large errors. The data for this sector tend to be residually determined, concentrating errors in the sector from the overall data set. Thus it is not surprising that this sector performs worst in the model. For the future this sector of the model and of the data should be re-examined.

In the transport sector, the equations determining both petrol and diesel have acceptable standard errors, showing a reasonable fit within sample. However, in the case of the demand for petrol the RMSPE is much higher when the model is simulated as a system rather than on a single equation basis. The equation for kerosene use (in aviation) is unsatisfactory. This sector of the economy has grown very rapidly in recent years. However, the equation specification suggested that this rapid growth could continue indefinitely. The specification needs to be revised to impose some kind of long run asymptote. This would produce more realistic forecasts out of sample.

While individual equations show significant errors within sample, as discussed above, a rather different picture appears when the estimate for total economy-wide energy demand and demand for electricity is estimated. In this case the errors are quite low. This shows that the error in forecasting individual components of energy demand tend to cancel out giving an acceptable overall forecast. Thus, in using the model to forecast energy demand, much more attention should be paid to the overall total for energy (and electricity demand), which show a reasonable fit, than to the individual components.

8. Conclusions:

In this paper, we have updated and re-examined the specification of an energy model first outlined in Fitzgerald et al., 2002. This model is disaggregated by six sectors and by the various fuel types that comprise these sectors. Energy forecasting plays an important role in current planning decisions. Spare capacity in the power generation sector can impose excess costs on customers and business alike. On the other hand, undersupply can lead to occasional blackouts which have huge negative economic consequences (Leahy and Tol, 2010). In the short-run there is little that can be done to decrease energy consumption (except a severe recession). However in the long-run, investment decisions can be made to improve efficiency which reduces consumption.

Table 3 summarises the key elasticities of energy demand which are derived from the latest version of the model.

At present, the energy model lacks a robust understanding of the various substitution patterns that exist in each sector. This leads to probable underestimation of energy substitution. Improvement of this aspect of the model is left to future research. This limitation arises from the limited data sample available for estimation. Future research using different approaches may well allow better estimates of these substitution elasticities to be derived.

Many aspects of future energy demand are outside the control of policy makers in Ireland. Major developments are most likely to occur outside of Ireland. As shown in the model, the negative price elasticity of demand allows some cope for the success of domestic policy responses which change relative prices. The Irish government introduced a carbon tax on fuel use in late 2009. The impact of this policy is not directly measurable as of yet. However, it provides a long-term signal of pricing based on carbon intensity.

Table 3: Elasticities of energy demand

		Long-Run Price Elasticity	Long-Run Income Elasticity	Standard Error of Equation
Electricity Demand:				
Household	**EN7C_T**	-0.32	0.30 (2006)	2.7
Commercial and Industry	**EN7S_T**	-0.15	0.65 (2006)	8.9
Industry	**EN7I_T**	-0.21	0.37	5.4
Aggregate Energy Demand:				
Household	**ENCW_T**	-0.35	0.75	7.4
Commercial and Industry	**ENSR_T**		0.40 (2006)	21
Industry	**ENIR_T**		0.10 (2006)	10.2
Demand for Individual Fuels:				
Industry	**EN1I_T**	-0.74		
Transport – Oil	**EN49ST_T**	-0.23	1.25	3.5
Transport – Kerosene	**EN46ST_T**		1.28	15.9

The price elasticities shown here do not take account of the effects of higher prices in incentivising new research. Such new research will produce technical changes increasing energy efficiency and reducing emissions. When incorporated into new investment, this technical change will eventually reduce energy demand. However, this process takes considerable time. For this reason the model described in this paper is suitable for medium term forecasting (maybe up to a decade ahead). However, in the long term energy demand will be affected by technological developments which such a model is not able to capture.

References

Bergin, A., Cullen, J., Duffy, D., FitzGerald, J., Kearney, I., & McCoy, D. 2003. "Forecasting Record of the Medium-Term Review 1986-2001", *Medium-Term Review*, Vol. 2003-2010, No. 9, Appendix 2.

Bergin, A., Cullen, J., Duffy, D., FitzGerald, J., Kearney, I., & McCoy, D. 2003. "The ESRI Medium-Term Economic Model", *Medium-Term Review*, Vol. 2003-2010, No. 9, Appendix 1.

Bergin, A., Conefrey, T., FitzGerald, J., & Kearney, I. 3-4-2009 "The Behaviour of the Irish Economy: Insights from the HERMES Macro-Economic Model."

Bradley, J., FitzGerald, J., Hurley, D., Sullivan, L., & Storey, A. 1989. "HERMES-IRELAND A Model of the Irish Economy: Structure and Performance", Books and Monographs published by the ESRI Dublin: ESRI.

Callan, T., Lyons, S., Scott, S., Tol, R. S. J., & Verde, S. 2009. "The distributional implications of a carbon tax in Ireland", *Energy Policy*, Vol. 37, No. 2, pp. 407-412.

Conefrey, T., FitzGerald, J., Malaguzzi Valeri, L., & Tol, R. S. J. 2008 "The Impact of a Carbon Tax on Economic Growth and Carbon Dioxide Emissions in Ireland."

Conniffe, D. & Scott, S. 1990. "Energy Elasticities: Responsiveness of Demands for Fuels to Income and Price Changes", General Research Series Dublin: ESRI.

Conniffe, D. 1993. "Energy Elasticity Estimates and the Stability of the Relationship with GDP", in J. FitzGerald & D. McCoy, eds. (eds.), Dublin: ESRI.

Conniffe, D. 2000. "The Free Electricity Allowance and the Engel Curve", *The Economic and Social Review*, Vol. Vol. 31, No. 2.

Dargay, J. & Gately, D. 1995. "The imperfect price reversibility of non-transport oil demand in the OECD", *Energy Economics*, Vol. 17, No. 1, pp. 59-71.

Devitt, C., Hennessy, H., Lyons, S., Murphy, L., & Tol, R. S. J. 2010. "The Energy and Environment Review 2010", ESRI Research Series Dublin: ESRI.

Devitt, C., Diffney, S., FitzGerald, J., Lyons, S., & Malaguzzi Valeri, L. 2009 "The Likely Economic Impact of Increasing Investment in Wind on the Island of Ireland" Working Paper 334, Dublin: Economic and Social Research Institute.

Diffney, S., FitzGerald, J., Lyons, S., & Malaguzzi Valeri, L. 2009. "Investment in Electricity Infrastructure in a Small Isolated Market: the Case of Ireland", *Oxford Review of Economic Policy*, Vol. Vol. 25, No. 3, December 2009, pp. 469-487.

Engle, R. F. & Granger, C. W. J. 1987. "Co-Integration and Error Correction: Representation, Estimation, and Testing", *Econometrica*, Vol. 55, No. 2, pp. 251-276.

FitzGerald, J. 2000. "Energy Demand to 2015."

FitzGerald, J., Bergin, A., Conefrey, T., Diffney, S., Duffy, D., Kearney, I., Lyons, S., Malaguzzi Valeri, L., Mayor, K., & Tol, R. S. J. 2008. "Medium-Term Review 2008-2015, No. 11", ESRI Forecasting Series Dublin: ESRI.

FitzGerald, J. D., Hore, J., & Kearney, I. 2002. "A Model for Forecasting Energy Demand and Greenhouse Gas Emissions in Ireland", Working Paper 146, Dublin: Economic and Social Research Institute.

Haas, R. & Schipper, L. 1998. "Residential energy demand in OECD-countries and the role of irreversible efficiency improvements", *Energy Economics* , Vol. 20, No. 4, pp. 421-442.

Hennessy, H. & Tol, R. S. J. 2010. "The Impact of Climate Policy on Private Car Ownership in Ireland", Working Paper 342, Dublin: Economic and Social Research Institute.

Lau, L. J. 1986. "Chapter 26 Functional forms in econometric model building", in Zvi Griliches and Michael, ed. (eds.), *Handbook of Econometrics*, Volume 3 edn, Elsevier pp. 1515-1566.

Leahy, E. & Tol, R. S. J. 2010 "An Estimate of the Value of Lost Load for Ireland." Working Paper 357, Dublin: Economic and Social Research Institute.

Lyons, S. & Tol, R. S. J., 2010 Ireland's Sustainable Development Model: EPA STRIVE Programme 2007–2013. STRIVE Report Series No.47.

Narayan, P. K. & Narayan, S. 2005. "Estimating income and price elasticities of imports for Fiji in a cointegration framework", *Economic Modelling*, Vol. 22, No. 3, pp. 423-438.

O'Doherty, J. and Tol, Richard S. J. 2007. "An Environmental Input-Output Model for Ireland", *Economic and Social Review*, Vol. 38, No. 2, pp. 157-190

Scott, S. 1980. "Energy Demand in Ireland: Projections and Policy Issues", Policy Research Series Dublin: ESRI.

Scott, S. 1991. "Domestic Electricity Demand", General Research Series Dublin: ESRI.

Scott, S., Curtis, J. A., Eakins, J., FitzGerald, J., & Hore, J. 23-2-2001Environmental Accounts: Time Series and Eco-Taxes.

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

APPENDIX 2: ENTIRE MODEL LISTING

Energy demand in residential sector

```
645:    LOG(ENCW_T_STAR) = IF (Z_ENCW == 1) THEN
        (ENCW_C7+ENCW_C8*LOG(
        YRPERD)+ENCW_C9*LOG(PENCR_MAX(-1))+ENCW_C10*ZT_ENCW+
        ENCW_STAR1_FIX) ELSE
        (ENCW_C1+ENCW_C2*LOG(YRPERD)+ENCW_C3*LOG(
        PENC_MOD/PC)+ENCW_C4*ZT_ENCW+ENCW_STAR_FIX)
646:    DEL(1: LOG(ENCW_T)) = IF (Z_ENCW == 1) THEN
        ENCW_A01*(LOG(ENCW_T
        (-1))-LOG(ENCW_T_STAR(-1)))+ENCW1_FIX) ELSE
        (ENCW_A00*(LOG(
        ENCW_T(-1))-LOG(ENCW_T_STAR(-1)))+ENCW_FIX)
647:    LOG(EN7C_T_STAR) = IF (Z_EN7C == 1) THEN
        (EN7C_C1+EN7C_C2/HSTOCK1
        +EN7C_C3*LOG(PEN7C_T/PC)+EN7C_C4*ZT_EN7C+EN7C_STAR_FIX)
        ELSE (
        EN7C_C8+EN7C_C9/YRPERD++EN7C_C10*ZT_EN7C+EN7C_STAR1_FIX)
648:    DEL(1: LOG(EN7C_T)) = IF (Z_EN7C == 1) THEN
        (EN7C_C11*DEL(1: LOG(
        PEN7C_T/PC))+EN7C_A00*(LOG(EN7C_T(-1))-LOG(EN7C_T_STAR(-
        1)))+
        EN7C_FIX) ELSE (EN7C_C12*DEL(1:
        LOG(PEN7C_T/PC))+EN7C_A01*(LOG(
        EN7C_T(-1))-LOG(EN7C_T_STAR(-1)))+EN7C1_FIX)
649:    EN6C_T/(ENC_T-EN7C_T) =
        0.3/(1+EXP(EN6C_C1+EN6C_C2*(ZT_EN6C-1970)
        ))+EN6C_FIX
650:    LOG(EN8C_T/(ENC_T-EN7C_T)) =
        EN8C_C1+EN8C_C2*ZT_EN8C+EN8C_FIX
651:    LOG(EN1C_T/(ENC_T-EN7C_T)) = IF (TYEAR < 1988) THEN
        (EN1C_C1+
        EN1C_C2*ZT_EN1C+EN1C_FIX) ELSE
        (EN1C_C3+EN1C_C4*ZT_EN1C+EN1C_FIX)
652:    LOG(EN45C_T/EN4C_T) = IF (TYEAR < 1995) THEN
        (EN45C_C1+EN45C_C2*
        ZT_EN45C+EN45C_FIX) ELSE
        (EN45C_C3+EN45C_C4*ZT_EN45C+EN45C_FIX)
653:    EN4C_T = (ENCW_T-
        (EN1C_T*A1_ENCW_T+EN6C_T*A6_ENCW_T+EN8C_T*
        A8_ENCW_T))/A4_ENCW_T
654:    ENC_T = EN1C_T+EN4C_T+EN6C_T+EN7C_T+EN8C_T+EN9C_T
655:    EN48C_T = EN4C_T-EN45C_T
```

Energy demand in the commercial and public sectors

```
656:    LOG(ENSR_T_STAR) =
        ENS_C1+ENS_C2/(OSM+OSNHE+OSNP)+ENSR_STAR_FIX
657:    DEL(1: LOG(ENSR_T)) = ENS_C5*DEL(1:
        LOG(PENS_MOD/PC))+ENS_A00*(
        LOG(ENSR_T(-1))-LOG(ENSR_T_STAR(-1)))+ENSR_FIX
658:    LOG(EN7S_T_STAR) =
        EN7S_C1+EN7S_C2/(OSM+OSNHE+OSNP)+EN7S_C3*LOG(
        PEN71_T/PC)+EN7S_STAR_FIX
```

```
659:        DEL(1: LOG(EN7S_T)) = EN7S_A00*(LOG(EN7S_T(-1))-
            LOG(EN7S_T_STAR(-
            1)))+EN7S_FIX
660:        LOG(EN6S_T/ENSR_T) =
            EN6S_C1+EN6S_C2*LOG(PEN6C_T/PEN422C_T)+
            EN6S_C3/ZT_EN6S+EN6S_FIX
661:        ENS_T = ENSR_T+EN7S_T
662:        EN6SCH_T = EN6CH_T*ENCHS*EN6SCH_T_FIX
663:        EN6SNH_T = EN6S_T-EN6SCH_T
664:        EN4S_T = ENS_T-EN7S_T-EN6S_T-EN1S_T-EN8S_T-EN9S_T
665:        EN48S_T = EN4S_T-EN45S_T
```

Energy demand in the industrial sector

```
666:        LOG(ENIR_T_STAR) =
            ENI_C1+ENI_C2/OI+ENI_C3*LOG(QNIMT/QGIMT)+
            ENIR_STAR_FIX
667:        ENIR_T/QMIMT = IF (TYEAR < 1980) THEN
            (A1_ENIR+A2_ENIR*ZT_ENIR)
            ELSE ((IF (TYEAR < 1991) THEN (A3_ENIR+A4_ENIR*ZT_ENIR)
            ELSE (
            A5_ENIR+A6_ENIR*ZT_ENIR))+ENIR_FIX)
668:        LOG(EN7I_T_STAR) = IF (TYEAR < 1985) THEN
            (EN7I_C1+EN7I_C2*LOG(OI
            )+EN7I_C3*LOG(PEN7I_T/PQGIMT)+EN7I_C4*ZT_EN7I+EN7I_STAR_FI
            X)
            ELSE (EN7I_C5+EN7I_C6*LOG(OI)+EN7I_C7*LOG(PEN7I_T/PQGIMT)+
            EN7I_C8*ZT_EN7I+EN7I_STAR_FIX)
669:        DEL(1: LOG(EN7I_T)) = IF (TYEAR < 1985) THEN
            (EN7I_C10*DEL(1: LOG
            (OI))+EN7I_C11*DEL(1:
            LOG(PEN7I_T/PQGIMT))+EN7I_A00*(LOG(EN7I_T(
            -1))-LOG(EN7I_T_STAR(-1)))+EN7I_FIX) ELSE (EN7I_C13*DEL(1:
            LOG(
            OI))+EN7I_C14*DEL(1:
            LOG(PEN7I_T/PQGIMT))+EN7I_A01*(LOG(EN7I_T(-
            1))-LOG(EN7I_T_STAR(-1)))+EN7I_FIX)
670:        LOG(EN1I_T/ENI_T) = IF (TYEAR < 1992) THEN
            (EN1I_C1+EN1I_C2*LOG(
            PEN1I_T/PEN43I_T)+EN1I_C3*ZT_EN1I+EN1I_FIX) ELSE (EN1I_C4+
            EN1I_C5*LOG(PEN1I_T/PEN43I_T)+EN1I_C6*ZT_EN1I+EN1I_FIX)
671:        LOG(EN45I_T/EN4I_T) = EN45I_C1+EN45I_C2*ZT_EN45I+EN45I_FIX
672:        ENI_T = ENIR_T+EN7I_T
673:        EN6ICH_T = EN6CH_T*ENCHI*EN6ICH_T_FIX
674:        EN6INH_T = (ENI_T-EN7I_T)*EN6ISH-EN6ICH_T+EN6INH_T_FIX
675:        EN6I_T = EN6ICH_T+EN6INH_T
676:        N48I_T = ENI_T-EN1I_T-EN6I_T-EN7I_T-EN8I_T-EN9I_T-EN45I_T
677:        EN4I_T = EN45I_T+EN48I_T
```

Energy demand in the transport sector

```
678:        EN49ST_T = EN41ST_T+EN42ST_T+EN43ST_T
679:        LOG(TRANS_TK) =
            A1_TRANS+A2_TRANS*LOG(GNP)+A3_TRANS*LOG(PEN41U_T/
            PC)+TRANS_FIX
680:        LOG(EN42ST_T+EN43ST_T) =
            A1_EN42ST+A2_EN42ST*LOG(TRANS_TK)+
            A3_EN42ST*LOG(PEN41U_T/(PEN41U_T_UK*REX_UK))+EN42ST_FIX
```

```
681:        LOG(EN41ST_T) =
            A1_EN41ST+A2_EN41ST*LOG(SCARS)+A3_EN41ST*LOG(
            PEN41U_T/(PEN41U_T_UK*REX_UK))+A4_EN41ST*ZT_EN41ST+EN41ST_
            FIX
682:        LOG(EN46ST_T) = IF (TYEAR < 1994) THEN
            (EN46ST_C1+EN46ST_C2*LOG(
            PEN46C_T/PC)+EN46ST_C3*LOG(XTO)+EN46ST_FIX) ELSE
            (EN46ST_C4+
            EN46ST_C5*LOG(PEN46C_T/PC)+EN46ST_C6*LOG(XTO)+EN46ST_FIX)
683:        DEL(1: LOG(0.8/(SCARS/N1564)-1)) =
            A1_SCARS+A2_SCARS*DEL(1:
            YRPERD/N1564)+SCARS_FIX
684:        EN4ST_T = EN49ST_T+EN45ST_T+EN46ST_T
685:        ENST_T = EN4ST_T+EN7ST_T
```

Energy demand in agriculture

```
686:        LOG(ENA_T) = ENA_C1+ENA_C2*LOG(QMA)+ENA_C3*ZT_ENA+ENA_FIX
687:        LOG(EN7A_T) =
            EN7A_C1+EN7A_C2*ZT_EN7A+EN7A_C3*LOG(QMA)+EN7A_FIX
688:        EN4A_T = ENA_T-EN7A_T-EN9A_T
```

Final consumption of energy by fuel type

```
689:        EN1FC_T = EN1C_T+EN1S_T+EN1I_T
690:        EN4FC_T = EN4C_T+EN4S_T+EN4I_T+EN4ST_T+EN4A_T
691:        EN6FC_T = EN6C_T+EN6S_T+EN6I_T
692:        EN7FC_T = EN7C_T+EN7S_T+EN7I_T+EN7ST_T+EN7A_T
693:        EN8FC_T = EN8C_T+EN8S_T+EN8I_T
694:        EN9FC_T = EN9C_T+EN9S_T+EN9I_T+EN9A_T
695:        ENFC_T = EN1FC_T+EN4FC_T+EN6FC_T+EN7FC_T+EN8FC_T+EN9FC_T
```

Total primary energy requirement by fuel type by sector

```
696:        EN1CTD_T = EN1C_T
697:        EN4CTD_T = EN4C_T*(1+EN4TRLOS_T/EN4FC_T)
698:        EN6CTD_T = EN6C_T*(1+EN6TRLOS_T/EN6FC_T)
699:        EN7CTD_T = EN7C_T*(1+EN7TRLOS_T/EN7FC_T)
700:        EN8CTD_T = EN8C_T*(1+EN8TRLOS_T/EN8FC_T)
701:        EN9CTD_T = EN9C_T
702:        ENCTD_T =
            EN1CTD_T+EN4CTD_T+EN6CTD_T+EN7CTD_T+EN8CTD_T+EN9CTD_T
703:        EN1STD_T = EN1S_T
704:        EN4STD_T = EN4S_T*(1+EN4TRLOS_T/EN4FC_T)
705:        EN6STD_T = EN6S_T*(1+EN6TRLOS_T/EN6FC_T)
706:        EN8STD_T = EN8S_T*(1+EN8TRLOS_T/EN8FC_T)
707:        EN7STD_T = EN7S_T*(1+EN7TRLOS_T/EN7FC_T)
708:        EN9STD_T = EN9S_T
709:        ENSTD_T =
            EN1STD_T+EN4STD_T+EN6STD_T+EN7STD_T+EN8STD_T+EN9STD_T
710:        EN1ITD_T = EN1I_T
711:        EN4ITD_T = EN4I_T*(1+EN4TRLOS_T/EN4FC_T)
712:        EN6ITD_T = EN6I_T*(1+EN6TRLOS_T/EN6FC_T)
713:        EN8ITD_T = EN8I_T*(1+EN8TRLOS_T/EN8FC_T)
714:        EN7ITD_T = EN7I_T*(1+EN7TRLOS_T/EN7FC_T)
715:        EN9ITD_T = EN9I_T
```

```
716:       ENITD_T =
           EN1ITD_T+EN4ITD_T+EN6ITD_T+EN7ITD_T+EN8ITD_T+EN9ITD_T
717:       EN4STTD_T = EN4ST_T*(1+EN4TRLOS_T/EN4FC_T)
718:       EN7STTD_T = EN7ST_T*(1+EN7TRLOS_T/EN7FC_T)
719:       ENSTTD_T = EN4STTD_T+EN7STTD_T
720:       EN4ATD_T = EN4A_T*(1+EN4TRLOS_T/EN4FC_T)
721:       EN7ATD_T = EN7A_T*(1+EN7TRLOS_T/EN7FC_T)
722:       EN9ATD_T = EN9A_T
723:       ENATD_T
           EN1TD_T =
           EN1CTD_T+EN1STD_T+EN1ITD_T+EN1E_T+EN1G_T+EN1TD_T_FIX
725:       EN4TD_T =
           EN4CTD_T+EN4STD_T+EN4ITD_T+EN4STTD_T+EN4ATD_T+EN4E_T+
           EN4G_T+EN4TD_T_FIX
726:       EN6TD_T = EN6CTD_T+EN6STD_T+EN6ITD_T+EN6E_T+EN6G_T
727:       EN8TD_T = EN8CTD_T+EN8STD_T+EN8ITD_T+EN8E_T
728:       N9TD_T = EN9CTD_T+EN9STD_T+EN9ITD_T+EN9ATD_T+EN9E_T+EN9G_T
729:       ENTD_T =
           EN1TD_T+EN4TD_T+EN6TD_T+EN8TD_T+EN9TD_T+EN6IMCHF_T
730:       EN9QD_T = EN9TD_T
731:       ENQD_T = EN1QD_T+EN6QD_T+EN8QD_T+EN9QD_T
732:       ENM_T = ENX_T+ENTD_T-ENQD_T-ENBA_T+ENM_T_FIX
733:       M3 = ENM_T*M3_DIS*M3_FIX
```

Electricity production by fuel type: driven by demand EN7FC_T

```
734:       EN9E_T = EN91E_T+EN92E_T+EN93E_T
735:       EN7G1_T = EN1E_T*ENGEFF1*EN7G1_T_FIX
736:       EN7G42_T = EN42E_T*ENGEFF42*EN7G42_T_FIX
737:       EN7G43_T = EN43E_T*ENGEFF43*EN7G43_T_FIX
738:       EN7G4_T = EN7G42_T+EN7G43_T
739:       EN7GCH6_T = EN6CH_T*(1-ENCHS-ENCHI)*ENGEFF6C*EN7GCH6_T_FIX
740:       EN7G8_T = EN8E_T*ENGEFF8*EN7G8_T_FIX
741:       EN7G91_T = EN91E_T*ENGEFF91*EN7G91_T_FIX
742:       EN7G92_T = EN92E_T*ENGEFF92*EN7G92_T_FIX
743:       EN7G93_T = EN93E_T*ENGEFF93*EN7G93_T_FIX
744:       EN7G9_T = EN7G91_T+EN7G92_T+EN7G93_T
745:       EN7GNH6_T = EN7GENES_T-
           (EN7G1_T+EN7G8_T+EN7G4_T+EN7GCH6_T+EN7G9_T)
746:       EN7G6_T = EN7GCH6_T+EN7GNH6_T
747:       EN6E_T = EN6CH_T*(1-ENCHS-
           ENCHI)+EN7GNH6_T/ENGEFF6N+EN6E_T_FIX
748:       EN4E_T = EN42E_T+EN43E_T
749:       ENE_T = EN1E_T+EN4E_T+EN6E_T+EN8E_T+EN9E_T
750:       EN7CONL_T = ENE_T-EN7GEN_T
751:       EN7GENAD_T = EN7GENES_T-EN7GEN_T
752:       EN7GENES_T = EN7GEN_T/EN7GENAD_FIX
753:       EN7GEN_T = EN7AVAIL_T-EN7M_T+EN7X_T
754:       EN7AVAIL_T = EN7GSO_T+EN7OUSE_T
755:       EN7OUSE_T = EN7GSO_T*EN7OUSE_FIX
756:       EN7GSO_T = EN7FC_T/(1-EN7TRL_FIX)
757:       EN7TRL_T = EN7GSO_T-EN7FC_T
758:       EN9TRLOS_T = EN9TD_T-EN9E_T-EN9FC_T
759:       EN7TRLOS_T = EN1E_T+EN4E_T+EN6E_T+EN8E_T+EN9E_T+EN7M_T-
           N7X_T-EN7FC_T
760:       A7_CARB =
           (EN1E_T*A1_CARB+EN4E_T*A4E_CARB+EN6E_T*A6_CARB+EN8E_T*
           A8E_CARB)/EN7FC_T
761:       CO2LOS =
           EN4TRLOS_T*A4E_CARB+EN6TRLOS_T*A6_CARB+EN8TRLOS_T*
```

```
            A8E_CARB
762:        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
763:        CO2S =
            EN1S_T*A1_CARB+EN48S_T*A49_CARB+EN45S_T*A45_CARB+EN6S_T*
            A 6_CARB+EN7S_T*A7_CARB+EN8S_T*A8_CARB
764:        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
765:        CO2ST =
            EN49ST_T*A49_CARB+EN45ST_T*A45_CARB+EN46ST_T*A46_CARB+
            EN7ST_T*A7_CARB
766:        CO2A = EN4A_T*A49_CARB+EN7A_T*A7_CARB
767:        CO2IMCHF = ENIMCHF_T*A6IMCHF_CARB
768:        CO21 =
            EN1E_T*A1_CARB+EN1C_T*A1_CARB+EN1S_T*A1_CARB+EN1I_T*
             A1_CARB
769:        CO245 =
            EN45C_T*A45_CARB+EN45S_T*A45_CARB+EN45I_T*A45_CARB+
            EN45ST_T*A45_CARB
770:        CO246 = EN46ST_T*A46_CARB
771:        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
772:        CO249 = CO24-CO245-CO246
773:        CO26 =
            EN6E_T*A6_CARB+EN6TRLOS_T*A6_CARB+EN6C_T*A6_CARB+EN6S_T*
            A6_CARB+EN6I_T*A6_CARB
774:        CO27 =
            EN7C_T*A7_CARB+EN7S_T*A7_CARB+EN7I_T*A7_CARB+EN7ST_T*
            A7_CARB+EN7A_T*A7_CARB
775:        CO28 =
            EN8E_T*A8E_CARB+EN8TRLOS_T*A8E_CARB+EN8C_T*A8_CARB+EN8S_T*
            A8_CARB+EN8I_T*A8_CARB
776:        CO2 = CO2LOS+CO2C+CO2S+CO2I+CO2A+CO2ST+CO2IMCHF
777:        CO2ADJ = CO2-A46_CARB*EN46ST_T
```

Energy Prices

```
778:        PEN7I_T = EXP(A1_PEN7I+A2_PEN7I*LOG(PEN71_T)+PEN7I_FIX)
779:        PEN7C_T = EXP(A1_PEN7C+A2_PEN7C*LOG(PEN71_T)+PEN7C_FIX)
780:        PEN71_T =
            EXP(A1_PEN71+A2_PEN71*LOG(PEN43E_T)+A3_PEN71*LOG(PEN1E_T)+
            A4_PEN71*LOG(PEN8E_T)+A5_PEN71*LOG(PEN6E_T)+PEN71_FIX)
781:        LOG(PQEIMT) = A1_PQEIMT+A2_PQEIMT*LOG(PENI)+(1-
            A2_PQEIMT)*LOG(
            PQEIMT(-1))+PQEIMT_FIX
782:        PEN1C_T =
            EXP(A1_PEN1C+A2_PEN1C*LOG(PEN1_T)+A3_PEN1C*LOG(WNA)+
            PEN1C_FIX)+RGTECANT*A1_CARB+RGTEE
783:        PEN1I_T =
            EXP(A1_PEN1I+A2_PEN1I*LOG(PEN1_T)+PEN1I_FIX)+RGTECANT*
            A1_CARB+RGTEE
784:        PEN41U_T =
            EXP(A1_PEN41U+A2_PEN41U*LOG(PM3)+A3_PEN41U*LOG(REXPET)
            +PEN41U_FIX)+RGTECANT*A49_CARB+RGTEE
```

```
785:        PEN422I_T =
            EXP(A1_PEN422I+A2_PEN422I*LOG(PM3)+PEN422I_FIX)+
            GTECANT*A49_CARB+RGTEE
786:        PEN422C_T =
            EXP(A1_PEN422C+A2_PEN422C*LOG(PM3)+PEN422C_FIX)+
            RGTECANT*A49_CARB+RGTEE
787:        PEN43I_T =
            EXP(A1_PEN43I+A2_PEN43I*LOG(PM3)+PEN43I_FIX)+RGTECANT*
            A49_CARB+RGTEE
788:        PEN81C_T =
            EXP(A1_PEN81C+A2_PEN81C*LOG(PEN8_T)+A3_PEN81C*LOG(WNA)
            +PEN81C_FIX)+RGTECANT*A8_CARB+RGTEE
789:        PEN6C_T =
            EXP(A1_PEN6C+A2_PEN6C*LOG(PEN6_T)+PEN6C_FIX)+RGTECANT*
            A6_CARB+RGTEE
790:        PEN6I_T =
            EXP(A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*ZT_PEN6I+
            PEN6I_FIX)+RGTECANT*A6_CARB+RGTEE
791:        PEN45C_T =
            EXP(A1_PEN45C+A2_PEN45C*LOG(PEN6C_T)+PEN45C_FIX)+
            RGTECANT*A45_CARB+RGTEE
792:        PEN46C_T =
            EXP(A1_PEN46C+A2_PEN46C*LOG(PM3)+PEN46C_FIX)+RGTEE+
            RGTECANT*A46_CARB*Z_PEN46C
793:        PEN43E_T =
            EXP(A1_PEN43E+A2_PEN43E*LOG(PM3)+PEN43E_FIX)+RGTECAT*
            A4E_CARB+RGTEE
794:        PENC_MOD = EXP((EN1C_T(-1)*LOG(PEN1C_T)+EN4C_T(-
            1)*LOG(PEN422C_T)
            +EN6C_T(-1)*LOG(PEN6C_T)+EN8C_T(-
            1)*LOG(PEN81C_T))/(EN1C_T(-1)+
            EN4C_T(-1)+EN6C_T(-1)+EN8C_T(-
            1)))/A1_PENC_MOD*PENC_MOD_FIX
795:        PENS_MOD = EXP((EN4S_T(-1)*LOG(PEN422C_T)+EN6S_T(-
            1)*LOG(PEN6C_T)
            )/(EN4S_T(-1)+EN6S_T(-1)))/A1_PENS_MOD*PENS_FIX
796:        PENI = EXP((EN1I_T(-1)*LOG(PEN1I_T)+EN42I_T(-
            1)*LOG(PEN422I_T)+
            EN43I_T(-1)*LOG(PEN43I_T)+EN6I_T(-1)*LOG(PEN6I_T)+EN7I_T(-
            1)*LOG
            (PEN7I_T))/(EN1I_T(-1)+EN42I_T(-1)+EN43I_T(-1)+EN6I_T(-
            1)+EN7I_T
            (-1)))/A1_PENI*PENI_FIX
797:        PEN1E_T = PEN1_T+RGTECAT*A1_CARB+RGTEE+PEN1E_FIX
798:        PEN6E_T = PEN6_T+RGTECAT*A6_CARB+RGTEE+PEN6E_FIX
799:        PEN8E_T = PEN8_T+RGTECAT*A8E_CARB+RGTEE+PEN8E_FIX
800:        PEN6IMCHF_T = PEN6I_T+PEN6IMCHF_FIX
801:        PQEIMTR = PQEIMT/PQGIMT
802:        PQEIMTR_MAX = IF (PQEIMTR > PQEIMTR_MAX(-1)) THEN PQEIMTR
            ELSE (PQEIMTR_MAX(-1))
803:        PEN41UR = PEN41U_T/PC
804:        PEN41UR_MAX = IF (PEN41UR > PEN41UR_MAX(-1)) THEN EN41UR
            ELSE (
            PEN41UR_MAX(-1))
```

3. Utilities

```
104:        LOG(QGIU) = A1_QGIU+A2_QGIU*LOG(EN7FC_T)+QGIU_FIX
105:        LOG(PQGIU) = A1_PQGIU+A2_PQGIU*LOG(PEN71_T)+PQGIU_FIX
106:        LOG(QEIU) =
            A1_QEIU+A2_QEIU*LOG(ENE_T)+A3_QEIU*LOG(KIU)+QEIU_FIX
```

```
107:        LOG(LIU/QGIU) =
            A1_LIU+A2_LIU*LOG(WIU/PQGIU)+A3_LIU*ZT_LIU+
            LIU_FIX
108:        QRIUV/QGIUV =
            A1_QRIU+A2_QRIU*LOG(EN7FC_T)+A3_QRIU*LOG(KIU)+
            A4_QRIU*LOG(PQRIU/PQGIU)+QRIUV_FIX
```

10. Household Consumption

```
323:        LOG(CELEC) = A1_CELEC+A2_CELEC*LOG(EN7C_T)+CELEC_FIX
324:        LOG(COEN) = A1_COEN+A2_COEN*LOG(ENCW_T)+COEN_FIX
325:        LOG(CPET) = A1_CPET+A2_CPET*LOG(EN4ST_T)+CPET_FIX
326:        LOG(PCELEC) = A1_PCELEC+A2_PCELEC*LOG(PEN7C_T)+PCELEC_FIX
327:        LOG(PCOEN) = A1_PCOEN+A2_PCOEN*LOG(PENCOEN)+PCOEN_FIX
328:        LOG(PCPET) = A1_PCPET+A2_PCPET*LOG(PEN41U_T)+PCPET_FIX
```

APPENDIX 3: REGRESSION OUTPUT

645a: LOG(ENCW_T_STAR)=				
ENCW_C7+ENCW_C8*LOG(YRPERD)+ENCW_C9*LOG(PENCR_MAX(-1))+ENCW_C10*ZT_ENCW				
	ESTIMATE	STER	TSTAT	P-VAL
ENCW_C7	-4.997020	6.924720	-0.721621	0.475936
ENCW_C8	0.376041	0.108402	3.468939	0.001557
ENCW_C9	-0.730415	0.135074	-5.407511	0.000007
ENCW_C10	0.009180	0.004225	2.172740	0.037564
R-squared	0.908000			
R-squared-adjusted	0.899433			
NOB	35			
SER	0.057560			
F	102.361200			

646a: DEL(1: LOG(ENCW_T)) = ENCW_A01*(LOG(ENCW_T(-1))-LOG(ENCW_T_STAR(-1)))				
	ESTIMATE	STER	TSTAT	P-VAL
ENCW_A01	-0.682332	0.166123	-4.107392	0.000238
R-squared	0.332000			
R-squared-adjusted	0.311981			
NOB	35			
SER	0.0532387			
F	16.87067			

645b: LOG(ENCW_T_STAR)=				
ENCW_C1+ENCW_C2*LOG(YRPERD)+ENCW_C3*LOG(PENC_MOD/PC)+ENCW_C4*ZT_ENCW				
	ESTIMATE	STER	TSTAT	P-VAL
ENCW_C1	19.165160	7.433843	2.578096	0.014743
ENCW_C2	0.753241	0.142765	5.276093	0.000009
ENCW_C3	-0.354393	0.126541	-2.800619	0.008579
ENCW_C4	-0.006862	0.004441	-1.545058	0.132166
R-squared	0.845000			
R-squared-adjusted	0.830990			
NOB	36			
SER	0.074324			
F	58.362850			

646a: DEL(1: LOG(ENCW_T)) = ENCW_A00*(LOG(ENCW_T(-1))-LOG(ENCW_T_STAR(-1)))				
	ESTIMATE	STER	TSTAT	P-VAL

ENCW_A00	-0.476928	0.135034	-3.531907	0.001210	
R-squared	0.268000				
R-squared-adjusted	0.246897				
NOB	35				
SER	0.055700				
F	12.474370				

EN7C_C1+EN7C_C2/HSTOCK1+EN7C_C3*LOG(PEN7C_T/PC)+EN7C_C4*ZT_EN7C					
	ESTIMATE	STER	TSTAT	P-VAL	
EN7C_C1	50.318790	11.142890	4.515776	0.000076	
EN7C_C2	-2815.118000	282.117400	-9.978535	0.000000	
EN7C_C3	-0.317322	0.052745	-6.016125	0.000001	
EN7C_C4	-0.019877	0.005315	-3.739946	0.000699	
R-squared	0.995000				
R-squared-adjusted	0.994140				
NOB	37				
SER	0.027156				
F	2036.753000				

647b: LOG(EN7C_T_STAR)=EN7C_C8+EN7C_C9/YRPERD+EN7C_C10*ZT_EN7C					
	ESTIMATE	STER	TSTAT	P-VAL	
EN7C_C8	-20.091290	2.936388	-6.842177	0.000000	
EN7C_C9	-23452.920000	1177.877000	-19.911180	0.000000	
EN7C_C10	0.013386	0.001462	9.159113	0.000000	
R-squared	0.995000				
R-squared-adjusted	0.994676				
NOB	47				
SER	0.042157				
F	4298.002000				

648: DEL(1: LOG(EN7C_T))=					
EN7C_C12*DEL(1: LOG(PEN7C_T/PC))+EN7C_A01*(LOG(EN7C_T(-1))-LOG(EN7C_T_STAR(-1)))					
	ESTIMATE	STER	TSTAT	P-VAL	
EN7C_C12	-0.173535	0.057346	-3.026107	0.004775	
EN7C_A01	-0.793828	0.135378	-5.863795	0.000001	
R-squared	0.592000				
R-squared-adjusted	0.566892				
NOB	35				
SER	0.028151				
F	23.905630				

650: LOG(EN8C_T/(ENC_T-EN7C_T)) = EN8C_C1+EN8C_C2*ZT_EN8C	

	ESTIMATE	STER	TSTAT	P-VAL
EN8C_C1	77.618640	39.073880	1.986459	0.053233
EN8C_C2	-0.039661	0.019570	-2.026562	0.048795
R-squared	0.085000			
R-squared-adjusted	0.064584			
NOB	46			
SER	0.125523			
F	4.106953			

651: LOG(EN1C_T/(ENC_T-EN7C_T)) = EN1C_C3+EN1C_C4*ZT_EN1C				
	ESTIMATE	STER	TSTAT	P-VAL
EN8C_C1	157.998300	11.717340	13.484140	0.000000
EN8C_C2	-0.079982	0.005867	-13.631450	0.000000
R-squared	0.916000			
R-squared-adjusted	0.911250			
NOB	19			
SER	0.140083			
F	185.816400			

652: LOG(EN45C_T/EN4C_T) = EN45C_C3+EN45C_C4*ZT_EN45C				
	ESTIMATE	STER	TSTAT	P-VAL
EN45C_C3	68.120460	11.436860	5.956222	0.000140
EN45C_C4	-0.035338	0.005717	-6.181141	0.000104
R-squared	0.793000			
R-squared-adjusted	0.771815			
NOB	12			
SER	0.068365			
F	38.206500			

656: LOG(ENSR_T_STAR) = ENS_C1+ENS_C2/(OSM+OSNHE+OSNP)				
	ESTIMATE	STER	TSTAT	P-VAL
ENS_C1	7.441814	0.072748	102.295400	0.000000
ENS_C2	-35651.430000	1887.682000	-18.886360	0.000000
R-squared	0.890000			
R-squared-adjusted	0.887695			
NOB	46			
SER	0.210081			
F	356.694600			

657: DEL(1: LOG(ENSR_T)) =				
ENS_C5*DEL(1: LOG(PENS_MOD/PC))+ENS_A00*(LOG(ENSR_T(-1))-LOG(ENSR_T_STAR(-1)))				

	ESTIMATE	STER	TSTAT	P-VAL	
ENS_C5	-0.267899	0.152868	-1.752482	0.088706	
ENS_A00	-0.264766	0.139476	-1.898287	0.066174	
R-squared	0.188000				
R-squared-adjusted	0.140182				
NOB	36				
SER	0.158270				
F	3.934666				

658: LOG(EN7S_T_STAR) =					
EN7S_C1+EN7S_C2/(OSM+OSNHE+OSNP)+EN7S_C3*LOG(PEN71_T/PC)					
	ESTIMATE	STER	TSTAT	P-VAL	
EN7S_C1	8.155792	0.620927	13.134860	0.000000	
EN7S_C2	-57579.070000	3109.531000	-18.516960	0.000000	
EN7S_C3	-0.153051	0.096749	-1.581937	0.124151	
R-squared	0.978000				
R-squared-adjusted	0.976047				
NOB	33				
SER	0.089596				
F	652.979500				

659: DEL(1: LOG(EN7S_T)) = EN7S_A00*(LOG(EN7S_T(-1))-LOG(EN7S_T_STAR(-1)))					
	ESTIMATE	STER	TSTAT	P-VAL	
EN7S_A00	-0.831614	0.185978	-4.471574	0.000097	
R-squared	0.392000				
R-squared-adjusted	0.372487				
NOB	32				
SER	0.048320				
F	19.994970				
660: LOG(EN6S_T/ENSR_T) =					

EN6S_C1+EN6S_C2*LOG(PEN6C_T/PEN422C_T)+EN6S_C3/ZT_EN6S					
	ESTIMATE	STER	TSTAT	P-VAL	
EN6S_C1	79.671620	14.100560	5.650244	0.000107	
lngaspricecs	-0.336134	0.201104	-1.671445	0.120486	
EN6S_C3	- 161855.800000	28186.710000	-5.742276	0.000093	
R-squared	0.902000				
R-squared-adjusted	0.885837				
NOB	15				
SER	0.079334				

F	55.315990			

666: LOG(ENIR_T_STAR) = ENI_C1+ENI_C2/OI+ENI_C3*LOG(QNIMT/QGIMT)				
	ESTIMATE	STER	TSTAT	P-VAL
ENI_C1	6.863342	0.208448	32.925970	0.000000
ENI_C2	-3479.016000	695.054100	-5.005388	0.000027
ENI_C3	-0.563261	0.191075	-2.947853	0.006388
R-squared	0.475000			
R-squared-adjusted	0.437123			
NOB	31			
SER	0.102632			
F	12.648800			

667: ENIR_T/QMIMT = (A5_ENIR+A6_ENIR*ZT_ENIR))IF (TYEAR < 1991				
	ESTIMATE	STER	TSTAT	P-VAL
A5_ENIR	6.867845	0.314488	21.838210	0.000000
A6_ENIR	-0.003420	0.000158	-21.617550	0.000000
R-squared	0.930000			
R-squared-adjusted	0.928332			
NOB	37			
SER	0.010274			
F	467.318300			

668: LOG(EN7I_T_STAR) = EN7I_C5+EN7I_C6*LOG(OI)+EN7I_C7*LOG(PEN7I_T/PQGIMT)+EN7I_C8*ZT_EN7I (IF (TYEAR > 1985))				
	ESTIMATE	STER	TSTAT	P-VAL
EN7I_C5	-17.104490	25.321040	-0.675505	0.507941
EN7I_C6	0.374185	0.160795	2.327088	0.031831
EN7I_C7	-0.206755	0.066016	-3.131903	0.005763
EN7I_C8	0.010480	0.013508	0.775826	0.447926
R-squared	0.967000			
R-squared-adjusted	0.961763			
NOB	22			
SER	0.054381			
F	177.066200			

669: DEL(1: LOG(EN7I_T)) = EN7I_C13*DEL(1: LOG(OI))+EN7I_C14*DEL(1: LOG(PEN7I_T/PQGIMT)) +EN7I_A01*(LOG(EN7I_T(-1))-LOG(EN7I_T_STAR(-1)))(IF (TYEAR > 1985))				
	ESTIMATE	STER	TSTAT	P-VAL

EN7I_C13	0.562945	0.105845	5.318580	0.000039
EN7I_C14	0.056776	0.084672	0.670538	0.510584
EN7I_A01	-0.716291	0.207175	-3.457418	0.002638
R-squared	0.669000			
R-squared-adjusted	0.616244			
NOB	22			
SER	0.041230			
F	12.776020			

670: LOG(EN1I_T/ENI_T) =				
EN1I_C4+ EN1I_C5*LOG(PEN1I_T/PEN43I_T)+EN1I_C6*ZT_EN1I (IF (TYEAR > 1992))				
	ESTIMATE	STER	TSTAT	P-VAL
EN1I_C4	87.737680	80.512640	1.089738	0.297229
EN1I_C5	-0.742658	0.491070	-1.512325	0.156332
EN1I_C6	-0.045751	0.040476	-1.130332	0.280423
R-squared	0.177000			
R-squared-adjusted	0.039354			
NOB	15			
SER	0.293876			
F	1.286766			

679: LOG(TRANS_TK) = A1_TRANS+A2_TRANS*LOG(GNP)+A3_TRANS*LOG(PEN41U_T/PC)				
	ESTIMATE	STER	TSTAT	P-VAL
A1_TRANS	-16.051590	2.410658	-6.658592	0.000011
A2_TRANS	1.749274	0.072793	24.030720	0.000000
A3_TRANS	0.733028	0.260037	2.818934	0.013661
R-squared	0.981000			
R-squared-adjusted	0.978301			
NOB	17			
SER	0.076747			
F	361.687000			

680: LOG(EN42ST_T+EN43ST_T) =				
A1_EN42ST+A2_EN42ST*LOG(TRANS_TK)+A3_EN42ST*LOG(PEN41U_T/(PEN41U_T_UK*REX_UK))				
	ESTIMATE	STER	TSTAT	P-VAL
A1_EN42ST	1.422286	0.404264	3.518209	0.003410
A2_EN42ST	0.647945	0.042729	15.163920	0.000000
A3_EN42ST	-0.586896	0.099725	-5.885149	0.000040
R-squared	0.987000			
R-squared-adjusted	0.984745			
NOB	17			
SER	0.055636			

F	517.407900			

681: LOG(EN41ST_T) =				
A1_EN41ST+A2_EN41ST*LOG(SCARS)+A3_EN41ST*LOG(PEN41U_T/(PEN41U_T_UK*REX_UK))				
A4_EN41ST*ZT_EN41ST				
	ESTIMATE	STER	TSTAT	P-VAL
A1_EN41ST	48.870450	5.102606	9.577546	0.000000
A2_EN41ST	1.248560	0.078141	15.978330	0.000000
A3_EN41ST	-0.225488	0.035654	-6.324383	0.000000
A4_EN41ST	-0.025250	0.002825	-8.938079	0.000000
R-squared	0.985000			
R-squared-adjusted	0.983464			
NOB	37			
SER	0.035579			
F	714.681500			

682:LOG(EN46ST_T) = EN46ST_C4+EN46ST_C5*LOG(PEN46C_T/PC)+EN46ST_C6*LOG(XTO)				
(IF (TYEAR > 1994))				
	ESTIMATE	STER	TSTAT	P-VAL
EN46ST_C4	-5.776222	2.964284	-1.948606	0.077301
EN46ST_C5	0.314434	0.313505	1.002964	0.337431
EN46ST_C6	1.280042	0.206968	6.184737	0.000069
R-squared	0.786000			
R-squared-adjusted	0.747523			
NOB	14			
SER	0.159154			
F	20.244920			

683:DEL(1: LOG(0.8/(SCARS/N1564)-1)) = A1_SCARS+A2_SCARS*DEL(1: YRPERD/N1564)				
	ESTIMATE	STER	TSTAT	P-VAL
A1_SCARS	-0.041896	0.009462	-4.427887	0.000062
A2_SCARS	-0.049836	0.013495	-3.692952	0.000609
R-squared	0.237000			
R-squared-adjusted	0.219264			
NOB	46			
SER	0.049643			
F	13.637890			

686: LOG(ENA_T) = ENA_C1+ENA_C2*LOG(QMA)+ENA_C3*ZT_ENA				
	ESTIMATE	STER	TSTAT	P-VAL
ENA_C1	-14.127710	6.352147	-2.224084	0.043107

ENA_C2	0.551289	0.234410	2.351814	0.033846
ENA_C3	0.007679	0.003874	1.982160	0.067443
R-squared	0.757000			
R-squared-adjusted	0.722798			
NOB	17			
SER	0.048475			
F	21.859840			

687: LOG(EN7A_T) = EN7A_C1+EN7A_C2*ZT_EN7A+EN7A_C3*LOG(QMA)				
	ESTIMATE	STER	TSTAT	P-VAL
EN7A_C1	-39.140830	4.108086	-9.527753	0.000000
EN7A_C2	0.020308	0.002505	8.105796	0.000001
EN7A_C3	0.294965	0.151599	1.945698	0.072051
R-squared	0.946000			
R-squared-adjusted	0.938363			
NOB	17			
SER	0.031350			
F	122.792300			

778: PEN7I_T = EXP(A1_PEN7I+A2_PEN7I*LOG(PEN71_T)				
	ESTIMATE	STER	TSTAT	P-VAL
A1_PEN7I	-0.561045	0.539882	-1.039199	0.306046
A2_PEN7I	1.068588	0.082698	12.921640	0.000000
R-squared	0.831000			
R-squared-adjusted	0.825844			
NOB	36			
SER	0.076619			
F	166.968700			

779: PEN7C_T = EXP(A1_PEN7C+A2_PEN7C*LOG(PEN71_T)				
	ESTIMATE	STER	TSTAT	P-VAL
A1_PEN7C	2.109113	0.745544	2.828959	0.007778
A2_PEN7C	0.788933	0.097387	8.100976	0.000000
R-squared	0.659000			
R-squared-adjusted	0.648685			
NOB	36			
SER	0.057016			
F	65.625820			

780: PEN71_T = EXP(A1_PEN71+A2_PEN71*LOG(PEN43E_T)+A3_PEN71*LOG(PEN1E_T)+				
A4_PEN71*LOG(PEN8E_T)+A5_PEN71*LOG(PEN6E_T)				

	ESTIMATE	STER	TSTAT	P-VAL
A1_PEN71	4.718765	0.718606	6.566554	0.000002
A2_PEN71	0.089905	0.056311	1.596586	0.125298
A3_PEN71	0.024173	0.045711	0.528835	0.602466
A4_PEN71	0.121487	0.152979	0.794141	0.435996
A5_PEN71	0.173461	0.065003	2.668507	0.014378
R-squared	0.575000			
R-squared-adjusted	0.494144			
NOB	26			
SER	0.053302			
F	7.105303			

781: LOG(PQEIMT) = A1_PQEIMT+A2_PQEIMT*LOG(PENI)+(1-A2_PQEIMT)*LOG(PQEIMT(-1))				
	ESTIMATE	STER	TSTAT	P-VAL
A1_PQEIMT	0.023534	0.013929	1.689593	0.100828
A2_PQEIMT	0.477127	0.049824	9.576209	0.000000
A3_PQEIMT	0.465281	0.047116	9.875207	0.000000
R-squared	0.993000			
R-squared-adjusted	0.992757			
NOB	35			
SER	0.057930			
F	2331.096000			

782: PEN1C_T = EXP(A1_PEN1C+A2_PEN1C*LOG(PEN1_T)+A3_PEN1C*LOG(WNA))+				
RGTECANT*A1_CARB+RGTEE				
	ESTIMATE	STER	TSTAT	P-VAL
A1_PEN1C	3.483774	0.216494	16.091820	0.000000
A2_PEN1C	0.105327	0.035756	2.945667	0.006067
A3_PEN1C	0.569030	0.067145	8.474692	0.000000
R-squared	0.761000			
R-squared-adjusted	0.745194			
NOB	34			
SER	0.064100			
F	49.255250			

783: PEN1I_T = EXP(A1_PEN1I+A2_PEN1I*LOG(PEN1_T))+RGTECANT*A1_CARB+RGTEE				
	ESTIMATE	STER	TSTAT	P-VAL
A1_PEN1I	3.946122	0.176443	22.364880	0.000000
A2_PEN1I	0.140529	0.039494	3.558259	0.001189
R-squared	0.283000			
R-squared-adjusted	0.261104			
NOB	34			

SER	0.072702				
F	12.661200				

784: PEN41U_T = EXP(A1_PEN41U+A2_PEN41U*LOG(PM3)+A3_PEN41U*LOG(REXPET))+					
RGTECANT*A49_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN41U	6.987405	0.009038	773.088700	0.000000	
A2_PEN41U	0.297026	0.016430	18.078160	0.000000	
A3_PEN41U	0.730866	0.015988	45.712420	0.000000	
R-squared	0.996000				
R-squared-adjusted	0.996162				
NOB	36				
SER	0.034884				
F	4543.357000				

785: PEN422I_T = EXP(A1_PEN422I+A2_PEN422I*LOG(PM3))+RGTECANT*A49_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN422I	6.236300	0.200469	31.108490	0.000000	
A2_PEN422I	0.803054	0.055327	14.514720	0.000000	
R-squared	0.861000				
R-squared-adjusted	0.856954				
NOB	36				
SER	0.076393				
F	210.677000				

786: PEN422C_T = EXP(A1_PEN422C+A2_PEN422C*LOG(PM3))+RGTECANT*A49_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN422C	6.106141	0.070284	86.878300	0.000000	
A2_PEN422C	1.202757	0.073596	16.342810	0.000000	
R-squared	0.884000				
R-squared-adjusted	0.880829				
NOB	37				
SER	0.353547				
F	267.087400				

787: PEN43I_T = EXP(A1_PEN43I+A2_PEN43I*LOG(PM3))+RGTECANT*A49_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN43I	5.445171	0.136520	39.885600	0.000000	
A2_PEN43I	0.858857	0.107524	7.987617	0.000000	
R-squared	0.652000				
R-squared-adjusted	0.642134				

NOB	36				
SER	0.145812				
F	63.802020				

788: PEN81C_T = EXP(A1_PEN81C+A2_PEN81C*LOG(PEN8_T)+A3_PEN81C*LOG(WNA))+					
RGTECANT*A8_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN81C	2.252930	0.119210	18.898870	0.000000	
A2_PEN81C	0.149241	0.046663	3.198301	0.003047	
A3_PEN81C	0.784422	0.040093	19.564880	0.000000	
R-squared	0.989000				
R-squared-adjusted	0.988613				
NOB	36				
SER	0.057066				
F	1520.387000				

789: PEN6C_T = EXP(A1_PEN6C+A2_PEN6C*LOG(PEN6_T))+RGTECANT*A6_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN6C	4.598473	0.545981	8.422413	0.000000	
A2_PEN6C	0.333185	0.109719	3.036697	0.005687	
R-squared	0.278000				
R-squared-adjusted	0.247476				
NOB	26				
SER	0.104598				
F	9.221526				

790: PEN6I_T = EXP(A1_PEN6I+A2_PEN6I*LOG(PEN6_T)+A3_PEN6I*ZT_PEN6I)+					
RGTECANT*A6_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN6I	11.584000	45.572560	0.254188	0.801609	
A2_PEN6I	0.273490	0.197352	1.385797	0.179100	
A3_PEN6I	-0.003674	0.023000	-0.159732	0.874487	
R-squared	0.083000				
R-squared-adjusted	0.003152				
NOB	26				
SER	0.165061				
F	1.039522				

791: PEN45C_T = EXP(A1_PEN45C+A2_PEN45C*LOG(PEN6C_T))+RGTECANT*A45_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN45C	4.980265	0.914426	5.446326	0.000005	

A2_PEN45C	0.296281	0.127593	2.322085	0.026352	
R-squared	0.137000				
R-squared-adjusted	0.111497				
NOB	36				
SER	0.100829				
F	5.392077				

792: PEN46C_T = EXP(A1_PEN46C+A2_PEN46C*LOG(PM3))+RGTEE+					
RGTECANT*A46_CARB*Z_PEN46C					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN46C	6.033240	0.051351	117.489800	0.000000	
A2_PEN46C	0.570721	0.102569	5.564249	0.000014	
R-squared	0.585000				
R-squared-adjusted	0.565717				
NOB	24				
SER	0.086920				
F	30.960870				

793: PEN43E_T = EXP(A1_PEN43E+A2_PEN43E*LOG(PM3))+RGTECAT*A4E_CARB+RGTEE					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PEN43E	5.015587	0.083216	60.272020	0.000000	
A2_PEN43E	0.930938	0.089766	10.370670	0.000000	
R-squared	0.760000				
R-squared-adjusted	0.752739				
NOB	36				
SER	0.136154				
F	107.550800				

104: LOG(QGIU) = A1_QGIU+A2_QGIU*LOG(EN7FC_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_QGIU	1.334726	0.247575	5.391191	0.000005	
A2_QGIU	0.932022	0.035246	26.443680	0.000000	
R-squared	0.954000				
R-squared-adjusted	0.952269				
NOB	36				
SER	0.031122				
F	699.268100				

105: LOG(PQGIU) = A1_PQGIU+A2_PQGIU*LOG(PEN71_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PQGIU	-7.330862	0.189390	-38.707700	0.000000	

A2_PQGIU	1.043366	0.030011	34.766110	0.000000	
R-squared	0.972000				
R-squared-adjusted	0.971054				
NOB	37				
SER	0.122719				
F	1208.683000				

106: LOG(QEIU) = A1_QEIU+A2_QEIU*LOG(ENE_T)+A3_QEIU*LOG(KIU)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_QEIU	-2.812532	0.594981	-4.727099	0.000047	
A2_QEIU	0.912052	0.147270	6.193066	0.000001	
A3_QEIU	0.188872	0.145680	1.296484	0.204377	
R-squared	0.899000				
R-squared-adjusted	0.892062				
NOB	34				
SER	0.079379				
F	137.366000				

107: LOG(LIU/QGIU) = A1_LIU+A2_LIU*LOG(WIU/PQGIU)+A3_LIU*ZT_LIU					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_LIU	72.931990	5.370849	13.579230	0.000000	
A2_LIU	-0.305618	0.088798	-3.441733	0.001588	
A3_LIU	-0.038729	0.002836	-13.657320	0.000000	
R-squared	0.966000				
R-squared-adjusted	0.963572				
NOB	36				
SER	0.057405				
F	463.904400				

108: QRIUV/QGIUV = A1_QRIU+A2_QRIU*LOG(EN7FC_T)+A3_QRIU*LOG(KIU)+					
A4_QRIU*LOG(PQRIU/PQGIU)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_QRIU	2.283510	0.371908	6.139985	0.000001	
A2_QRIU	0.173756	0.091578	1.897365	0.066835	
A3_QRIU	-0.353808	0.105044	-3.368192	0.001985	
A4_QRIU	-0.151368	0.077762	-1.946546	0.060413	
R-squared	0.637000				
R-squared-adjusted	0.602496				
NOB	36				
SER	0.043103				
F	18.683170				

323: LOG(CELEC) = A1_CELEC+A2_CELEC*LOG(EN7C_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_CELEC	0.597818	0.381177	1.568347	0.127649	
A2_CELEC	0.980421	0.062733	15.628490	0.000000	
R-squared	0.894000				
R-squared-adjusted	0.890210				
NOB	31				
SER	0.034401				
F	244.249600				

324: LOG(COEN) = A1_COEN+A2_COEN*LOG(ENCW_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_COEN	0.081067	1.463153	0.055406	0.956195	
A2_COEN	0.492360	0.107315	4.588002	0.000080	
R-squared	0.421000				
R-squared-adjusted	0.400597				
NOB	31				
SER	0.051009				
F	21.049760				

325: LOG(CPET) = A1_CPET+A2_CPET*LOG(EN4ST_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_CPET	2.542669	0.328512	7.739968	0.000000	
A2_CPET	0.567898	0.041718	13.612900	0.000000	
R-squared	0.865000				
R-squared-adjusted	0.860017				
NOB	31				
SER	0.041749				
F	185.310900				

326: LOG(PCELEC) = A1_PCELEC+A2_PCELEC*LOG(PEN7C_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PCELEC	-6.280276	0.467516	-13.433300	0.000000	
A2_PCELEC	0.847288	0.065431	12.949330	0.000000	
R-squared	0.853000				
R-squared-adjusted	0.847472				
NOB	31				
SER	0.040308				
F	167.685000				

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

	ESTIMATE	STER	TSTAT	P-VAL	
A1_PCOEN	0.002470	0.051700	0.047772	0.962226	
A2_PCOEN	0.592756	0.079322	7.472818	0.000000	
R-squared	0.658000				
R-squared-adjusted	0.646406				
NOB	31				
SER	0.045542				
F	55.843010				

328: LOG(PCPET) = A1_PCPET+A2_PCPET*LOG(PEN41U_T)					
	ESTIMATE	STER	TSTAT	P-VAL	
A1_PCPET	-7.242368	0.508522	-14.242000	0.000000	
A2_PCPET	1.010937	0.072679	13.909720	0.000000	
R-squared	0.870000				
R-squared-adjusted	0.865157				
NOB	31				
SER	0.036288				
F	193.480200				

Year	Number	Title/Author(s) ESRI Authors/Co-authors *Italicised*
2011		
	395	Do Domestic Firms Benefit from Foreign Presence and Competition in Irish Services Sectors? *Stefanie A. Haller*
	394	Transitions to Long-Term Unemployment Risk Among Young People: Evidence from Ireland *Elish Kelly, Seamus McGuinness* and *Philip J. O'Connell*
	393	Decomposing the Impacts of Overeducation and Overskilling on Earnings and Job Satisfaction: An Analysis Using REFLEX data Nuria Sánchez-Sáncheza and *Seamus McGuinness*
	392	Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response Megan Ceronsky, David Anthoff, Cameron Hepburn and *Richard S.J. Tol*
	391	Economic Costs of Ocean Acidification: A Look into the Impacts on Shellfish Production Daiju Narita, Katrin Rehdanz and *Richard S.J. Tol*
	390	Schelling's Conjecture on Climate and Development: A Test *David Anthoff; Richard S.J. Tol*
	389	The Role of Decision-Making Biases in Ireland's Banking Crisis *Pete Lunn*
	388	Greener Homes: An Ex-Post Estimate of the Cost of Carbon Dioxide Emission Reduction using Administrative Micro-Data from the Republic of Ireland *Eimear Leahy, Richard S.J. Tol*
	387	Credit Where Credit's Due: Accounting for Co-Authorship in Citation Counts *Richard S.J. Tol*

For earlier *Working Papers* see
http://www.esri.ie/publications/search_for_a_working_pape/search_results/index.xml