ESRI

Working Paper No. 424

February 2011

The ESRI Energy Model

Valeria Di Cosmo, Marie Hyland

Corresponding Author: valeria di cosmo@esri.ie

Note: The financial support from SEAI and EPRC is gratefully acknowledged.

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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 HERMES 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. An earlier version of 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 and Hennessy (2011) 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) and from the International Energy Association (IEA). The ESRI databank 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: household, industry, commercial and public, transport and agriculture. 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 create 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 estimation equations and the regression results of these equations. 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 module is separated into the five sectors considered before.

For all sectors we first of all test the data for non-stationarity using a unit root test. If the tests do not reject the null hypothesis of presence of a unit root in the endogenous and in

[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.

the exogenous variables we test for the presence of cointegrating relationships. If cointegrating relationships are not rejected by the data, we follow the two step Engel-Granger (EG) procedure for cointegration modelling[2]. 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 are then tested for stationarity. If they are stationary, a cointegrating relationship exists and we can proceed to the second stage. The second stage is to estimate dynamic short-run relationships. The short-run regression includes the lagged residuals from the first step as the error correction term. Because the variables used in the dynamic relationship are stationary, the t-statistics can now be interpreted without bias. The results of these short-run equations tell us the speed at which each variable adjusts to its long-run equilibrium value.

We estimate the long run relationship between endogenous and exogenous variables separately.

This procedure is consistent with the specification adopted by Hennessy and FitzGerald (2011) that tested the error correction model specification for the main energy equations. There are some data issues when estimating energy demand in Ireland. These limitations have hampered previous research in the area. Historical energy price data are taken from the study by Scott, Fitz Gerald and Curtis (2001). Although this is not perfect, it does 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. Another problem with the dataset is related to the timing of the introduction of gas in Ireland. As this only happened in the mid-1980s, the smaller sample size may impact the robustness of the estimates.

Energy forecasts from this sub-model are then fed in the power generation sector. This is modelled separately in the IDEM model[3]. 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 are applied to the entire electricity demand profile in 2007. This 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 modelled separately. 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 with the prices used in the energy model. This is 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 sub-model was traditionally an embedded part of the larger HERMES model. In the most recent version of the energy model presented here, the

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

3 See Fitz Gerald et al. (2008) and Diffney et al. (2009) for a more complete description of the IDEM model

energy sub-model is post-recursive to the HERMES macroeconomic model, so that shocks in the sector do not impact on the wider economy.

3. Sectoral demand for Energy

3.1 Household demand for energy

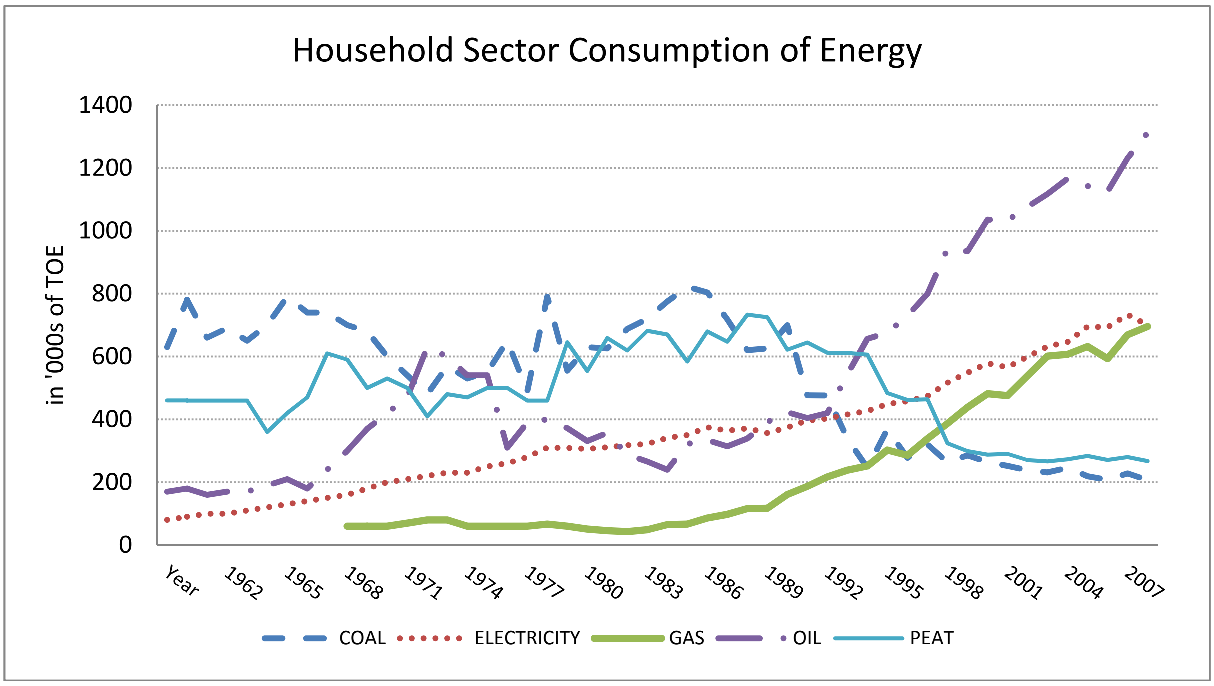

Figure 1: Household Sector Consumption of Energy

Demand for energy in the residential sector accounts for approximately 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 and the fuel mix used in electricity generation has changed a lot to accommodate this increase. The fuel mix of the rest of residential energy consumption has also changed markedly over the last two decades (See Figure 1). Natural gas was brought on-stream for domestic users in the mid-1980s and has since experienced a steady upward demand trend. This largely replaces coal and peat.

3.1.1 Household demand for electricity

Household electricity demand follows the simple model that demand in period t is affected by output and prices. Here the household demand for electricity (*EN7C_T)* is modelled using the inverse of the housing stock (HSTOCK). This reciprocal relationship allows the output elasticity to fall overtime[4]. A Chow test for structural stability revealed a structural break in 1976, therefore, the equation was estimated for period from 1976-2009.
We have firstly tested the stationarity of the series and the presence of cointegration. As the Dickey-Fuller test cannot reject the null hypothesis of non stationarity of the endogenous

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

variable and HSTOCK, but accepts the stationarity of the residuals, we estimated both an error correction model (ECM) and a long run regression.
In the ECM the coefficient of the lagged residuals is equal to -0.380 and is strongly significant; this confirms that the model will converge to its equilibrium value in the long run.[5]
We estimate the following:

$$\ln(EN7C_T) = C1_{EN7C} * \ln\left(\frac{1}{HSTOCK}\right) + C2_{EN7C} * \ln\left(\frac{PEN7C_T}{PC}\right) + C3_{EN7C}\text{trend} \quad (1)$$

Where:

$EN7C_T$	=	Consumption of electricity by households, in kTOE.
HSTOCK	=	Number of permanent dwellings, (thousands)
$PEN7C_T$	=	Price of electricity for households, in €/kTOE.
PC	=	Price deflator for personal consumption

The coefficients are numbered from EN7C_C1 to EN7C_C3.

600: ln(EN7C_T)=C1_EN7C*ln(1/HSTOCK)+C2_EN7C*ln((PEN7C_T)/PC)+C3_EN7C*trend				
	ESTIMATE	STER	TSTAT	P-VAL
invHstock	-0.8384	0.0212	-39.53	0.0000
LN_(PEN7C_T)/PC)	-0.0680	0.0236	-2.88	0.0070
trend	0.0162	0.0008	20.28	0.0000
R-squared	0.9908			
R-squared-adjusted	0.9898			
NOB	33.0000			
SER	0.0309			
F	1035.4200			

The price elasticity is equal to -0.06 and the time trend is positive and significant; the inclusion of the positive time trend in our specification implies the possibility of a technological change over time. Finally, the sign of the output coefficient (here represented by the inverse of the housing stock) has the expected sign and it is strongly significant.
We also estimated the model using the reciprocal of income an exogenous variable, but this specification had a higher standard error and resulted in an insignificant price variable.

3.1.2 Household demand for energy other than electricity

This type of energy (log_ENCR) is the sum of the demand for all forms of energy except electricity. It is modelled using the inverse of housing stock (HSTOCK), in logs, as the output variable driving energy demand. The price variable (PENC_MOD) is derived as a log-linear weighted price index of individual fuel prices and fuel shares for coal, gas, oil and peat, deflated by the consumer inflation index (PC). The number of the degree days was included in the analysis, but omitted from the final specification as it proved to be insignificant.
A Dickey-Fuller test performed on the endogenous variable does not reject the null hypothesis of a unit root. The same test indicates that the HSTOCK and the PENC_MOD variables are also non-stationary. Following the Engle-Granger procedure described earlier

[5] The results of the ECM are reported in the Appendix at the end of this report (res_HSTOCK(-1)).

we test the stationarity of the residuals and the DF test rejects the hypothesis of non stationarity; we then estimate both an ECM and a long run model to take account of the presence of cointegration.

The value of the lagged residual in the ECM model we estimate is -0.736 and it is strongly significant; this means that the model will converge to the long run equilibrium, which is characterized by the following regression:

$$\ln(ENCR) = C1_{ENCR} + C2_{ENCR} * \ln\left(\frac{1}{HSTOCK}\right) + C3_{ENCR} * \ln(PENC_{MOD}) \qquad (2)$$

Where:

$ENCR$	=	Consumption of non-electrical energy byhouseholds in kTOE.
$HSTOCK$	=	Number of permanent dwellings, (thousands)
$PENC\_MOD$	=	Price of non-electrical energy for households.

The coefficients are numbered from ENCR_C1 to ENCR_C3.

This equation is estimated over the period 1970-2008. The Durbin Watson alternative test for autcorrelation rejects the null hypothesis of the presence of autocorrelation in the residuals.[6] The elasticity of the inverse of housing stock is equal to -0.78 and the price elasticity is -0.15. As with the demand for electricity, we tried including the reciprocal of disposable income but this resulted in a model with a higher standard error, and in which prices were not significant.

601: ln(ENCR)=C1_ENCR+C2*ln(1/HSTOCK)+C3_ENCR*ln(PENC_MOD)				
	ESTIMATE	STER	TSTAT	P-VAL
LN_PENC_MOD	-0.1468	0.0666524	-2.20	0.034
HSTOCK	-0.7846	0.0602162	-13.03	0.000
_cons	2.8769	0.2656042	10.83	0.000
R-squared	0.9079			
R-squared-adjusted	0.9028			
NOB	39			
SER	0.0539			
F	177.47			

3.1.3 Household fuel mix

We have documented how we estimate the demand for energy and electricity; however, this tells us little about the consumption of energy by fuel type. As mentioned previously, there have been significant developments in the residential fuel mix in the last two decades. These changes have made using the approach described above problematic. This is because these changes have often been large discrete changes (like the introduction of gas in the

[6] The null hypothesis of absence of autocorrelation was accepted with a p-value equals to 0.1193.

1980s), which prevent us from constructing robust time-series equations which would allow us to examine substitution effects between fuels.

Consequently, these fuels are modelled using the share of the four individual fuels as functions of time and their own prices. The rationale for this is that coal and peat are decreasing over time, and therefore we expect that the trend variable will be statistically significant with a negative sign. The demand for oil was determined as a residual, and the demand for renewables (EN9C_T) is treated as exogenous at present. Renewables currently account for only a very small fraction (2%) of residential energy consumption, although this may increase in the future.

$$\ln\left(\frac{EN1C_T}{ENC_T - EN7C_T}\right) = C1_{EN1C} + C2_{EN1C} * trend \quad (3)$$

$$\ln\left(\frac{EN6C_T}{ENC_T - EN7C_T}\right) = C1_{EN6C} + C2_{EN6C} * \ln\left(\frac{PEN6C_T}{PENC_{MOD}}\right) + C3_{EN6C} * \ln(\text{YRPERD}) \quad (4)$$

$$\ln\left(\frac{EN8C_T}{ENC_T - EN7C_T}\right) = C1_{EN8C} + C2_{EN8C} * \text{trend} \quad (5)$$

Where:

$\frac{EN1C_T}{ENC_T - EN7C_T}$ = Demand for coal as a share of non-electric energy demand, in kTOE

$\frac{EN6C_T}{ENC_T - EN7C_T}$ = Demand for gas as a share of non-electric energy demand, in kTOE

$\frac{PEN6C_T}{PENC\_MOD}$ = Price of gas relative to the price of non-electric energy in €/ kTOE

$\frac{EN8C_T}{ENC_T - EN7C_T}$ = Demand for peat as a share of non-electric energy demand, in kTOE

$YRPERD$ = Real personal disposable income

The demand for coal was estimated using a Cochrane-Orcutt regression from 1980 in order to correct for autocorrelation in the residuals. As expected the time trend in the coal and peat equations is negative and statistically significant with a coefficient of -0.076 and -0.021 respectively. The elasticity of the gas equation with respect to income is 0.69, whereas the elasticity of this variable with respect to its price is equal to -0.316. This equation was estimated from 1995 to take into account the presence of structural break that occurred in that year.

The results from these estimations are presented in the following Tables:

602:ln((EN1C_T)/(ENC_T-EN7C_T))=C2_EN1C*ln((EN1C_(T-1))/(ENC_(T-1)-EN7C_(T-1)))+C3_EN1C*trend				
	ESTIMATE	STER	TSTAT	P-VAL
_cons	1.1528	0.2450	4.70	0.00
trend	-0.0767	0.0065	-11.75	0.00
R-squared	0.8416			
R-squared-adjusted	0.8355			
NOB	28.0000			
SER	0.1275			
F	138.1800			

603:ln((EN6C_T)/(ENC_T-EN7C_T))=C1_EN6C+C2_EN6C*ln(PEN6C_T/(PENC_MOD))+C3_EN6C*ln(YRPERD)				
	ESTIMATE	STER	TSTAT	P-VAL
LN_(PGAS/(PENC_MOD))	-0.3158	0.1660	-1.90	0.084
LN_(YRPERD)	0.6933	0.0841	8.24	0.000
_cons	-8.9675	0.9417	-9.52	0.000
R-squared	0.9356			
R-squared-adjusted	0.9455			
NOB	14.0000			
SER	0.0506			
F	95.4300			

605:ln((EN8C_T)/(ENC_T-EN7C_T))=C1_EN8C+C2_EN8C*ln((EN8C_(T-1))/(ENC_(T-1)-EN7C_(T-1)))+C3_EN8C*trend				
	ESTIMATE	STER	TSTAT	P-VAL
trend	-0.0219	0.0031	-7.00	0.000
_cons	-0.7603	0.0898	-8.47	0.000
R-squared	0.5102			
R-squared-adjusted	0.4998			
NOB	49.0000			
SER	0.3095			
F	48.9700			

Finally, the demand for oil is then computed as the resulting residual

$$EN4C\_T = ENCR\_T-(EN1C\_T+EN4C\_T+EN6C\_T+EN8C\_T+EN9C\_T) \quad (6)$$

And then the total demand of energy in the household sector is calculated as follows:

$$ENC\_T = ENCR\_T+EN7C\_T \quad (7)$$

3.2 Industrial Energy Demand

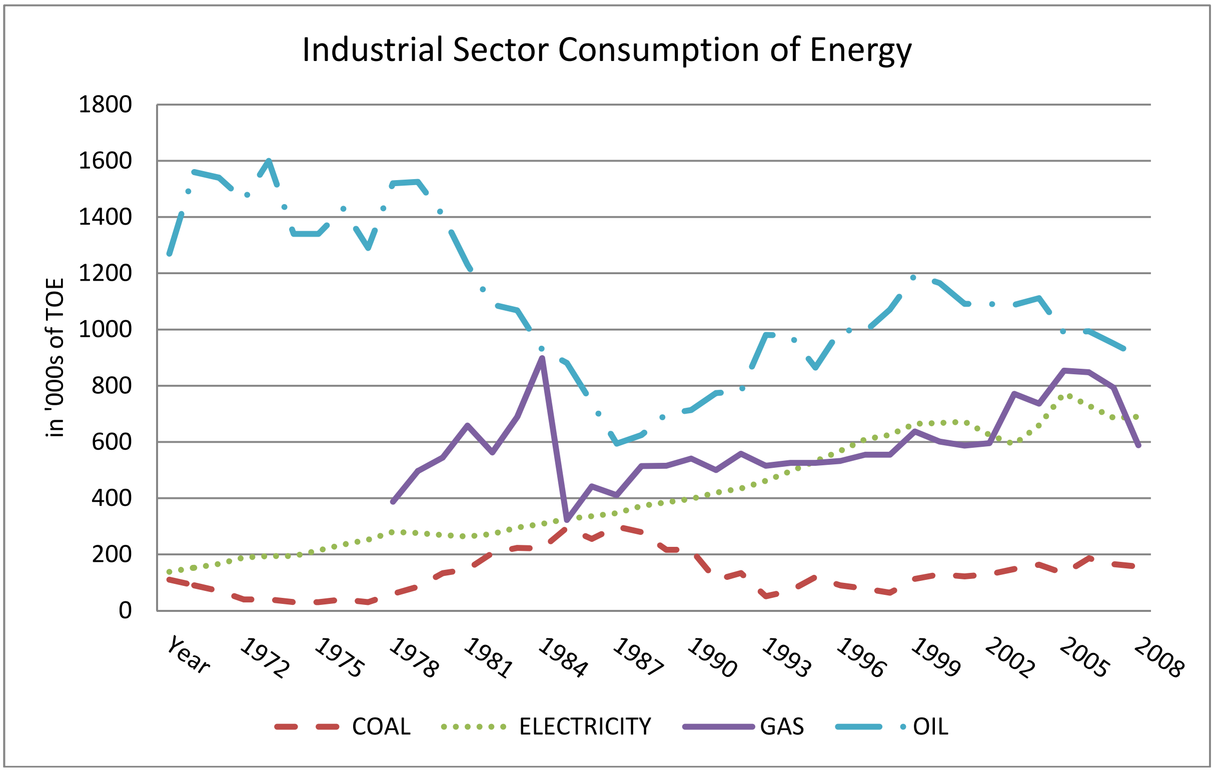

Figure 2: Industrial Sector Consumption of Energy

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. The use of gas and electricity has risen notably in recent years. This has all been in the context of a significant increase in industrial output.

Consumption of gas produced in gas works stopped in 1985 with the introduction of natural gas. Furthermore, the closure of Ireland's main steel plant contributed to the decrease in gas consumption experienced in the industrial sector after 2000.

It is quite difficult to disentangle the energy uses in this sector, as the aggregate industrial demand for different fuels, including electricity, could be ascribed either to the building's heating or to the production of goods. Although in the household sector non-electric energy is mainly used for heating and electricity generally used for appliances (TV, washing machines, etc.), in the industrial sector it is almost impossible to detect which type of energy is used for production as opposed to heating using aggregate data. Furthermore, some firms opted to move to self-generation of electricity to benefit from cost savings in the long-run. Such companies would have switched their consumption from electricity to gas, which makes it more difficult to correctly ascribe energy consumption to its various uses.

To account for these effects, we estimate the electricity demand and then the demand for energy as a whole. Finally, we estimate the demand for other fuels in the sector. Simulation results show that there are both substitution and complementary effects between electricity and other fuels. The dominance of one of these effects over the other primarily depends upon the share of electricity in total energy consumption. It is important to account for these effects when forecasting both the electricity and the non-electric energy demand.

3.2.1 Industrial sector demand for electricity

The demand for electricity in the industrial sector (EN7I) is modelled using electricity prices (PEN7I), deflated by the deflator for gross output in industry (PQGIMT), and the inverse of income in the sector. The choice of the inverse of the income reflects the fact that the energy intensity of this sector is falling over time. The DF test performed on the series highlights the presence of non stationarity. As the residuals of the cointegrating regression are stationary, we estimate the ECM model, in which the lagged value of the residual is negative and significant (-0.878). We estimate this equation using data from 1982 to 2008.

$$\ln(EN7I_T) = C1_{EN7I} + C2_{EN7I} * \ln\left(\frac{PEN7I_T}{PQGIMT}\right) + C3_{EN7I} * \text{INV\_OI} \quad (8)$$

Where:

$EN7I_T$ = Consumption of electricity by industry in kTOE.

$\frac{PEN7I_T}{PQGIMT}$ = Price of electricity for industrial users.

INV_OI = Inverse of gross value added in the industrial sector, used as a proxy for income

The coefficients are numbered from EN7I_C1 to EN7I_C3.

The equation is well specified with a standard error of 5 per cent. The price elasticity is -0.275, and the coefficient on the inverse of income is -0.572. Finally, the error correction term is negative and strongly significant meaning that the short run deviations will converge to the long run equilibrium.

609: ln(EN7I_T)=C1_EN7I+C2_EN7I*ln(EN7I_(T-1))+C3_EN7I*ln(PEN7I_T)+C4_EN7I*ln(INV_OI)				
	ESTIMATE	**STER**	**TSTAT**	**P-VAL**
LN(PEN7I_T)	-0.2755	0.0610	-4.52	0.000
LN(INV_OI)	-0.5725	0.0215	-26.62	0.000
_cons	2.2255	0.3277	6.79	0.000
R-squared	0.9748			
R-squared-adjusted	0.9726			
NOB	26.0000			
SER	0.0528			
F	445.0600			

3.2.2 Industrial sector fuel mix

In the industrial sector the demand for renewable energy was treated as exogenous. We then estimate the demand for light and heavy fuel oil and the demand for gas. We impose the restriction that the demand for all the fuels, including electricity, sums to total energy demand in the industrial sector.

3.2.3.1 Industrial sector demand for coal

Prior to the 1990s, the demand for coal in the industrial sector remained quite stable. However, since the early 1990s this demand has fallen considerably and the share of coal in total energy demand in the industrial sector dropped from 19% in 1988 to 6% in 2006. The equation was estimated from 1998 to account for a structural break in the data. The demand for coal $\ln(EN1I_T)$, is simply modelled using the price of coal deflated by the energy input deflator PQEIMT and a constant term. The equation is estimated from 1998 to 2008.

$$\ln(EN1I_T)\,,= C1_{EN1I} + \; C2_{EN1I}{}^{*} \ln\left(\frac{PEN1I_T}{PQEIMT}\right) \qquad (9)$$

Where:

$\frac{PEN1IT}{PQEIMT}$ = Price for coal, deflated by the energy input deflator PQEIMT, in €/TOE

610: ln(EN1I_T)=C1_EN1I + C2_EN1I*LN(PEN1I_T/PQEIMT)				
	ESTIMATE	STER	TSTAT	P-VAL
LN_PEN1I_T	-2.0771	0.4278	-4.86	0.00021
_cons	14.2735	1.9651	7.26	0.000
R-squared-adjusted	0.6110			
NOB	0.5852			
SER	17.0000			
F	0.2363			
R-squared	23.5711			

3.2.3.2 Industrial sector demand for gas and oil

The demand for gas is modelled as a function of its own price and a constant. As natural gas only came on stream in Ireland in the middle of the 80s, we estimate this equation from 1985 onwards. The data show that price elasticity of demand for gas is -0.37.

611: ln(EN6I_T)=C1_EN6I+C2_EN6I* ln(PEN6I_T/PQEIMT)				
	ESTIMATE	STER	TSTAT	P-VAL
LN_PEN6I_T	-0.3742	0.1464	-2.555474	0.0180
_cons	8.5183	0.8510	10.00991	0.0000
R-squared	0.2290			
R-squared-adjusted	0.1938			
NOB	24.0000			
SER	0.2029			
F	6.5304			

The demand for oil is divided between light fuel oil (EN42I) and heavy fuel oil (EN43I).

The demand for light fuel oil (LFO) depends on its own price (with an elasticity of -0.17), on the inverse of value added in the industrial sector (with an elasticity of -0.20) and on a constant. We estimate this equation from 1988 onwards to account for a structural break.

$$\ln(EN42I_T) = C1_{EN42I} + C2_{EN42I} * \ln\left(\frac{PEN42I_T}{PQEIMT}\right) + C3_{EN42I} * INV\_OI \qquad (10)$$

Where:

$EN42I_T$ = Demand for LFO, in kTOE

$\frac{PEN42I_T}{PQEIMT}$ = Price of LFO deflated by the energy input deflator PQEIMT, in €/kTOE

INV_OI = inverse of the total industrial value added.

The results are presented below:

612:ln(EN42I_T)=C1_EN42I+C2_EN42I*ln((PEN42I_T)/(PQEIMT)+C3_EN42I*ln(INV_OI)				
	ESTIMATE	STER	TSTAT	P-VAL
LN_PEN42I_T	-0.1703	0.1018	-1.67	0.1115911
LN_INV_OI	-0.2000	0.0367	-5.45	0.0000352
_cons	4.1549	0.4444	9.35	2.48E-08
R-squared	0.6820			
R-squared-adjusted	0.6465			
NOB	21.0000			
SER	0.06021			
F	19.2899			

The demand of heavy fuel oil (HFO) depends on its own price (with an elasticity of -0.28), and on a lagged dependent variable, and on a constant.

$$\ln(EN43I_T) = C1_{EN42I} + C2_{EN42I} * \ln(EN43I_{T-1}) + C3_{EN42I} * \ln\left(\frac{PEN43I_T}{PQEIMT}\right) \quad (11)$$

Where:

$EN43I_T$ = Demand for HFO, in kTOE

$\left(\frac{PEN43I_T}{PQEIMT}\right)$ = Price of HFO deflated by the energy input deflator PQEIMT, in €/kTOE

The results are presented below:

613:ln(EN43I_T)=C1_EN43I+C2_EN43I*ln(EN43I_(T-1))+C3_EN43I*ln((PEN43I_T)/(PQEIMT)				
Column1	**ESTIMATE**	**STER**	**TSTAT**	**P-VAL**
	ESTIMATE	STER	TSTAT	P-VAL
LN_EN43I_(T-1)	0.8468	0.1111	7.62	0.000000698
LN_PEN43I_T	-0.1910	0.0760	-2.51	0.0222796
_cons	2.0088	0.7764	2.59	0.0191698
R-squared	0.7840			
R-squared-adjusted	0.7585			
NOB	20.0000			
SER	0.0970			
F	30.8399			

3.2.3 Industrial sector demand for aggregate energy

To determine the demand for aggregate energy we impose the following restrictions:

EN4I_T = EN42I_T+EN43I_T

And that the total demand for energy is the sum of the different fuels demand and the electricity:

$$ENI\_T = EN1I\_T+EN4I\_T+EN6I\_T+EN7I\_T \qquad (12)$$

3.3 Commercial and public sector demand for energy

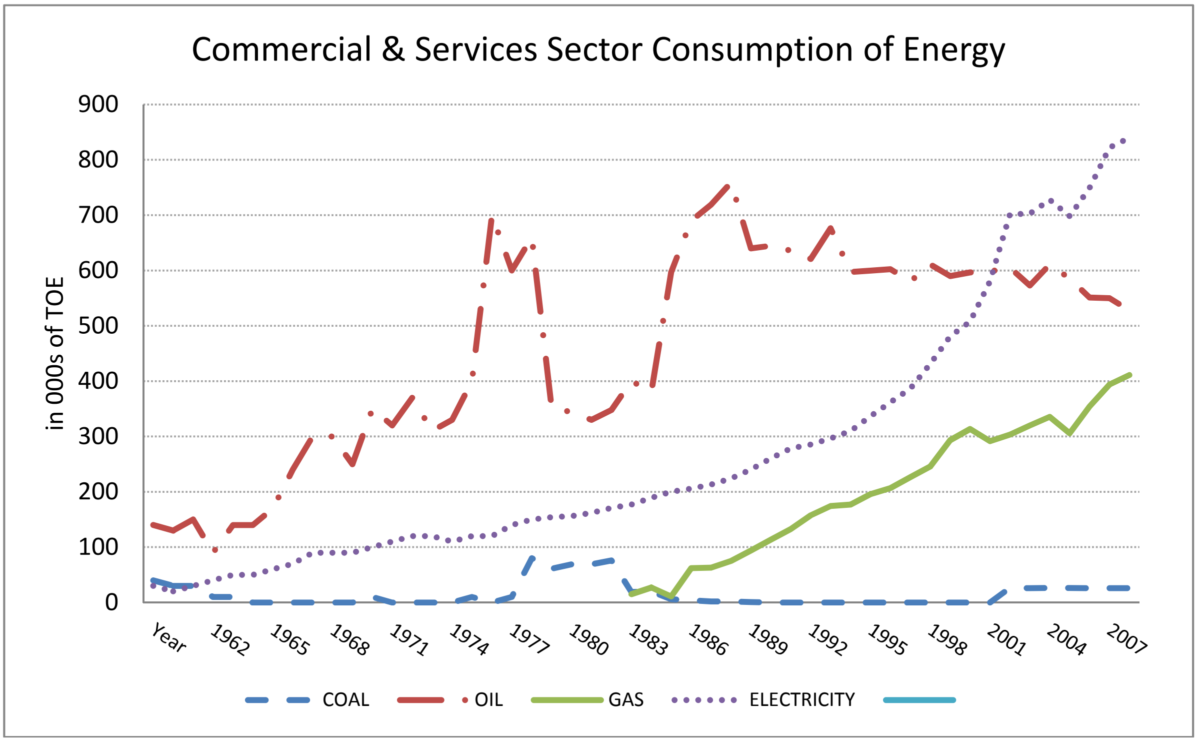

Figure 3: Commercial & Services Sector Consumption of Energy

In the Commercial and Public sector, electricity, gas and oil account for the vast majority of energy consumed. In 2009, these fuels accounted for approximately 98% of energy demand in this sector. Natural gas, since it came on stream in the late 1980s, has replaced much of the oil used for central heating purposes. In 2009, energy demand in this sector accounted for 14% of energy demand in Ireland. Figure 2 shows that energy consumption has grown significantly in this sector since the 1980's. However given the current economic conditions, the rate of growth has slowed in recent years.

The method used to model the demand for energy in this sector is similar to that adopted for the industrial sector; we model the demand for electricity, the demand for the different fuels, and finally we assume that the sum of different fuels and electricity gives the total consumption of energy.

3.3.1 Commercial and Public Sector demand for electricity

Consumption of electricity in the Commercial and Public sector is modelled as a function of a lagged dependent variable, the price of electricity[7], and GDP[8] in the sector. GDP is modelled

[7] Using the price of electricity to industrial users deflated by the personal consumption deflator

as a reciprocal which allows the energy intensity of the sector to decrease over time. As we wish to capture the elasticity of demand with respect to the explanatory variables, all variables are expressed as logs. The following equation was estimated:

$$\ln(EN7S_t) = C1_{EN7S_T} + C2_{EN7S_T} * EN7S_{t-1} + C3_{EN7S} * \ln\left(\frac{1}{OSM + OSN}\right) + C4_{EN7S} * \ln\left(\frac{PEN7I_T}{PC}\right) \quad (13)$$

Where:

$EN7S_T$ = Consumption of electricity in the commercial and public sector, in kTOE.

$\frac{1}{OSM+OSN}$ = Sum of value added in the market and non-market sectors in constant prices (€Million)

$\frac{PEN7I_t}{PC}$ = Electricity price in the industrial sector divided by the price deflator for personal consumption (PC)

The coefficients are numbered from EN7S_C1 to EN7S_C4.

The price elasticity of demand for electricity in this sector is -0.026 which suggests that only very limited opportunities exist for firms to substitute away from electricity in the face of rising electricity prices. The coefficient with respect to the inverse of the value added is -0.239.

Including a lagged dependent variable controls for autocorrelation, and the results from the Portmanteau test suggest that the residuals are generated by a white noise process. Furthermore, a Dickey-Fuller unit root test concludes that the endogenous variable is stationary, and thus our equation is not spurious. The regression results are presented below:

616: ln(EN7S_t)=C1_EN7S_(T-1)+ C2_EN7S* ln(1/(OSM+OSN))+C3_EN7s*ln((PEN7I_T)/PC)				
	ESTIMATE	**STER**	**TSTAT**	**P-VAL**
LN_EN7S_(t-1)	0.8559	0.0323	26.4600	0.0000
LN_PEN7I_t	-0.0263	0.0147	-1.7800	0.0820
LN(1/OSM+OSN+OSO)	-0.2390	0.0516	-4.6300	0.0000
_cons	-1.5217	0.3834	-3.9700	0.0000
R-squared	0.9977			
R-squared-adjusted	0.9976			
NOB	48.0000			
SER	0.0440			
F	6392.8300			

[8] Value added is used as a proxy for GDP in this sector. This is the sum of value added in the market and non-market sectors (which includes public administration, health care, education and defence).

In the commercial sector, as in the industrial sector, it is quite difficult to separate the energy type used for heating from the type of fuels used for the appliances. Thus we decided to estimate the fuel mix in levels, following the procedure adopted for the industrial sector, and then to impose that the total amount of energy used is strictly equal to the sum of the fuels used in the sector.

3.3.2 Commercial and Public Sector inter-fuel mix

As the demand for both coal and peat in this sector is negligible, they are assumed to be exogenous. We modelled the demand for both gas and oil.

The consumption of gas was modelled as a function of the price of gas and value added in the sector.

$$\ln EN6S_T = C1_{EN6S} + C2_{EN6S} * \ln\mathrm{PGAS} + C3_{EN6S} * \ln\left(\frac{1}{OSM + OSN}\right) \tag{14}$$

Where:

$\ln EN6S_T$ = Demand for gas, in kTOE

$PGAS$ = Price of gas, in €/ kTOE

The price elasticity for gas was low at -0.20, indicating that there exists limited opportunities for firms that use gas to switch to another form of non-electric energy in the face of increasing gas prices. The relationship with the value added was positive (i.e. the relationship with the inverse of value added was negative), confirming that the consumption of gas as sectoral income increases.

617:ln(EN6S_T)= C1_EN6S+C2_EN6S*ln(1/OSM+OSN)+ C3_EN6S* ln(PEN6C_T)				
	ESTIMATE	**STER**	**TSTAT**	**P-VAL**
LN(1/OSM+OSN)	-0.8609	0.0754	-11.4200	0.0000
LN(PGAS)	-0.2019	0.1076	-1.8800	0.0000
_cons	-2.3747	0.7610	-3.1200	0.0000
R-squared	0.9327			
R-squared-adjusted	0.9204			
NOB	14.0000			
SER	0.0602			
F	76.1800			

The consumption of oil was modelled as a function of the price of oil and the sectoral value added.

$$\ln EN4S_T = C1_{EN4S} + C2_{EN4S} * \ln\mathrm{POIL} + C3_{EN4S} * \ln\left(\frac{1}{OSM + OSN}\right) \tag{15}$$

Where:

$\ln EN4S_T$ = Demand for oil, in kTOE
$POIL$ = Price of oil, in €/ kTOE

The price elasticity for oil was high at -0.68, whereas the elasticity with respect to income was low, at 0.16.

618: ln(EN4S_T)= C1_EN4S+ C2_EN4S*ln(PEN422C_T)+ C2_EN4S*ln(1/OSM+OSN)				
	ESTIMATE	STER	TSTAT	P-VAL
LN(POIL)	-0.6849	0.1473	-4.65	0
LN(1/OSM+OSN)	-0.1633	0.0775	-2.11	0.046
_cons	8.9728	1.1927	7.52	0
R-squared	0.5024			
R-squared-adjusted	0.4609			
NOB	27.0000			
SER	0.1518			
F	12.1200			

Finally, as for the industrial sector, we impose that the demand of energy in the commercial sector is simply equal to the sum of different fuels and electricity:

$$ENS\_T = EN4S\_T+EN6S\_T+EN7S\_T \quad (16)$$

3.4 Agriculture energy demand

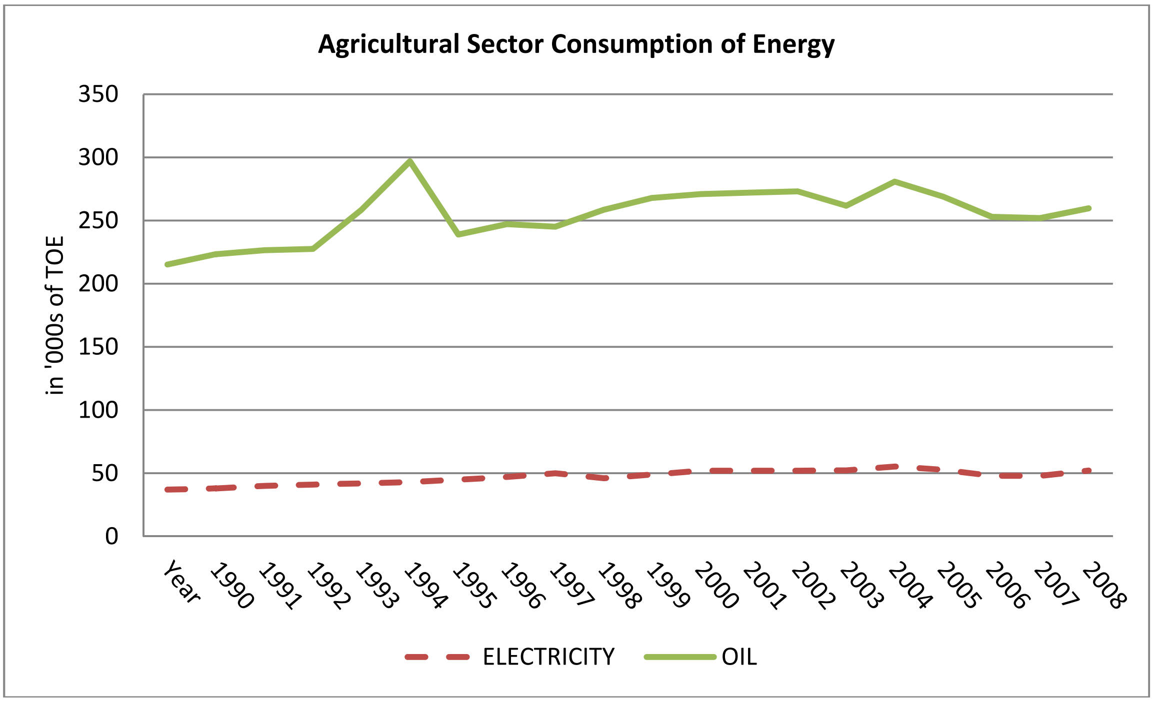

Figure 4: Agriculture Sector Demand for Energy

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 (2.2% in 2009) of total energy demand. This figure has decreased over time. As well as this, energy itself is forming a decreasing proportion of agricultural inputs since the 1990s. The vast majority of agricultural energy demand is made up of electricity and oil (in this case, diesel).

As a result of this, we only estimate two equations, namely the demand for oil and the demand for electricity. Total demand is then calculated as a sum of these two.

3.4.1 Agriculture sector demand for electricity

The demand for electricity in agriculture is modelled as a function of its own price (PEN7A), agricultural output (QGA) and a time trend. The DF test performed on the series highlights the presence of non-stationarity. However, the residuals of the cointegrating regression are stationary and we therefore estimate an error correction model. In the ECM the lagged value of the residual is negative with a coefficient of -0.504. We estimate this equation using data from 1990 to 2009.

The price elasticity is equal to -0.38 and the elasticity with respect to output is equal to 0.71.

$$\ln(EN7A) = C1_{EN7A} * \ln(PEN7A) + C2_{EN7A} * \ln(\mathrm{QGA}) + C3_{EN7A} * \mathrm{Trend} \qquad (17)$$

Where:

$EN7A$ = Electricity demand in agriculture, in kTOE

$PEN7A$ = Electricity price in agriculture, in €/kTOE

QGA = Gross output in agriculture, in €Million

The results are presented below:

619: ln(EN7A)=C1_EN7A*trend+C2_EN7A*ln(PEN7A)+C3_EN7A*ln(QGA)				
	ESTIMATE	STER	TSTAT	P-VAL
LN_PEN7A	-0.37528	0.0807537	-4.65	0.00
LN_QGA	0.71444	0.0723106	9.88	0.00
trend	0.01396	0.001642	8.5	0.00
R-squared	0.99990			
R-squared-adjusted	0.9999			
NOB	20.0000			
SER	0.0407			
F	59528.7700			

3.4.2 Agriculture sector demand oil

The demand for oil in agriculture is modelled as a function of the price of oil and a trend. A Dickey Fuller test performed on the EN4A_T series indicates that the series is stationary.

$$\ln(EN4A_T) = C1_{EN4A} + C2_{EN4A} * \ln(PEN4A) + C3_{EN4A} * Trend \qquad (18)$$

Where:

$EN4A_T$ = Oil consumption in the agricultural sector, in kTOE

$PEN4A$ = Oil price in agriculture, in €/kTOE

The price elasticity is -0.23, and the trend term is positive with a coefficient of 0.01.

620: ln(EN4A)=C1_EN4A + C2_EN4A*ln(PEN4A)+C3_EN4A*Trend				
	ESTIMATE	STER	TSTAT	P-VAL
LN_PEN4A	-0.2293	0.0978	-2.34	0.031
Trend	0.0132	0.0033	4.04	0.001
_cons	6.4669	0.5451	11.86	0.000
R-squared	0.4929			
R-squared-adjusted	0.4333			
NOB	20			
SER	0.0626			
F	8.26			

As the demand for renewables in this sector (EN9A_T) is very low, we treat it as exogenous. Thus we impose again the restriction that the total demand for energy in this sector is given as follows:

$$ENA\_T = EN7A\_T+EN4A\_T \quad (19)$$

3.5 Transport energy demand

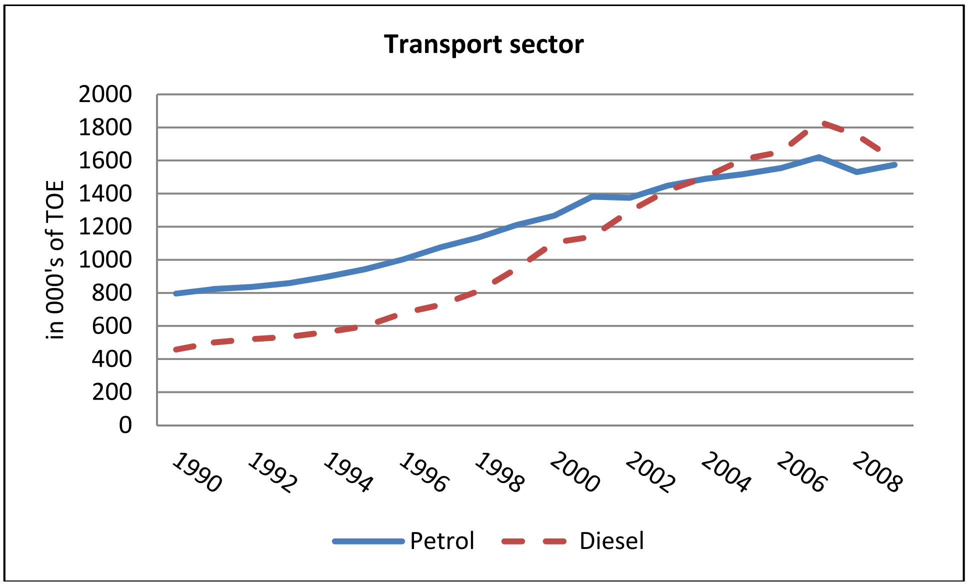

Figure 5: Transport Sector Consumption of Energy

As displayed in Figure 4, the demand for energy in the transport sector is not only the largest of the individual sectors; it is also the sector where demand is increasing the fastest. Energy demand in this sector 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 directly estimate 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 a disaggregated demographic model of the stock of cars. The volume of freight, along with the car stock model, 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.

3.5.1 Private car sector

The HERMES macroeconomic model forecasts the number of cars in the economy.[9] However, this is at an aggregate level and tells us little about the respective demand for oil-based fuels. We use a bottom-up type methodology to construct a disaggregated model the total car stock, which was made by Tol and Hennessy (2010).

These authors use the HERMES exogenous car stock model to give the total number of cars. They then disaggregate this number into car stock by fuel type, age and engine size. This is done in the following way: they specify a multi-nominal regression with the 9 categories of engine size as the dependent variable and estimate income elasticities for each engine size[10]. Then they use these income elasticities to forecast the number of cars per engine size using information on future levels of disposable income, taken from the HERMES model.

Table A1. Income semi-elasticities of demand for cars by engine size.*

Engine size	Income semi-elasticity	
<900 cc	-0.3301	(0.0934)
900-1000 cc	-0.3301	(0.0934)
1301-1400 cc	-0.0898	(0.0808)
1401-1500 cc	-0.0640	(0.1029)
1501-1600 cc	0.4114	(0.0874)
1601-2000 cc	0.5691	(0.0861)
2001-2400 cc	0.7287	(0.1220)
>2400 cc	1.1377	(0.1938)

* Standard deviations between brackets.

The historical progression of the diesel car stock is tracked in the model but this trend cannot simply be extrapolated to predict the future size of the diesel car stock, due to recent policy changes. This has essentially caused a structural break in the series. For this reason, Tol and Hennessy apply a breakeven distance methodology along with information on the mileage distribution by engine size, to forecast the diesel car stock by engine size. This works as follows: Diesel cars are more expensive to buy and to own, but cheaper to drive. So, a diesel is more attractive to people who drive long distances – anyone who drives more than the break-even distance. The mileage distribution function specifies the fraction of the

9 The car demographic model distinguishes 9 engine sizes and 25 age classes. The dynamic equations are

$$C_{t,1,s,f} = S_{t,1,s,f}$$

$$C_{t,a,s,f} = (1-\rho_a)C_{t-1,a-1,s,f} \quad a = 2,3,\ldots,25$$

where $C_{t,a,s,f}$ is the stock of private cars in year t, of age a, of engine size s and of fuel f; S is the sales, and ρ_a denotes the scrappage rate.
The probability of scrapping a car is constant over time for every car of age a, independent of engine size and fuel. Cars are assumed to be scrapped at the end of 25 years.

10 We also run separate regressions by fuel type, as the estimates were very similar we chose to use the aggregated income elasticities.

population who drive more than any distance, and thus also gives the market share of diesel cars. This type of approach has been used previously to explain the share of diesels in new car sales (Rouweldal, 1999; Mayeres and Proost, 2001). Similar approaches have also been used to examine the model share of rail in freight choice (Van Schijndel et al., 2000). Existing research (Mayeres and Proost, 2001) on the share of diesel cars is limited by the assumption that all diesel cars are homogenous and will be distributed evenly across all engine classes. Tol and Hennessy methodology is disaggregated by engine size which allows them to predict the diesel share in each of the engine classes that have been constructed within the model.

They estimate these using various data sources on new cars to construct representative cars. This gives us computed Break-Even distance figures for each engine class. However, this alone tells us little about the rational share of diesel sales. They use mileage distribution data to compute these diesel market shares. This distribution data shows that there are clear differences in the driving profiles of the different engine classes. This allows them to compute a market share for each engine class. These methods give a projected disaggregated car stock into the future.

3.5.2 Distance Model

The CSO provides information on average distance travelled by type of car. For the distance driven per year, we account for the impact of change in the composition of the car stock. Specifically, distance $D_{i,j,t}$ is given by:

$$\mathrm{D_{i,j,t+1}} = \left(1 + e_{\mathrm{i}}(1 - \frac{\mathrm{P_{i,j,t+1}}}{\mathrm{P_{i,j,t}}})\right) \mathrm{D_{i,j,t}} \, \Delta \, \frac{\mathrm{C_{i,j,t}}}{\mathrm{C_t}} \tag{20}$$

where $C_{i,j,t}$ is the number of cars of size *i* and fuel *j* at time *t*; The parameter coefficient e_{i} is imposed equal to -0.23[11] which represents the price elasticity of fuel demand (see also Hayashi et al. 2001).

In theory, this elasticity should be lower for higher engine sizes as the higher incomes associated with larger cars make the owners more inelastic in the consumption patterns. Conversely, the elasticity estimates are higher for small cars. This is indeed the case with elasticities on the two largest engine sizes not being statistically different from zero. Equation (20) has been calibrated against data on distance travelled from the years 2000-2008. Thus, Equation (20) estimates distance driven by engine size and is driven by elasticity estimates, changes in the composition of the car stock and the change in the relative price.[12]

3.5.3 Fuel demand

In order to estimate the consumption of petrol and diesel by the car sector, we then consider in the regressions the efficiency and the stock of the cars predicted by the Tol and Hennessy work described below.

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[11] This parameter is checked using the 2004/2005 Household Budget Survey (2005). There is no evidence that this international parameter is statistically different for Ireland

[12] For more details on this model see http://ideas.repec.org/p/esr/wpaper/wp349.html and http://ideas.repec.org/p/esr/wpaper/wp342.html .

This allows us to have more precise results than following a top-down regression method based on aggregate data by fuel type.

To calculate the demand for petrol and diesel we need the fuel efficiency for each of the representative cars, as the model developed by Tol and Hennessy has already approximated the composition of the car stock and the distance travelled.

From the SEAI fuel efficiency estimates, we simply extrapolate the trend out to 2030. This combined with our earlier data gives a fuel efficiency estimate of each car by its engine size, age and fuel type. Significant improvements have been made in engine efficiency so our simple extrapolation will mean that cars in the future will be more efficient than current ones.

Since the National Car Test compels cars to remain road worthy, we also assume that there is no depreciation of cars in terms of fuel efficiency and that any significant effects of age on efficiency will result in scrappage.

Finally, as we have information on car stock, the car efficiency and the price of petrol and diesel, we can calculate the demands for different fuels.

3.5.3.1 Demand for petrol

The determinants of the demand for petrol are income, the car stock and the efficiency of the car stock, and the price of the petrol in Ireland relative to the price of petrol in Northern Ireland in a common currency.

Then, the relation between consumption of gasoline and the exogenous variables is given by the following:

$$\ln(\mathrm{Cons}_{\mathrm{Petrol}}) = \beta_1 + \beta_2 \ln(\mathrm{income}) + \beta_3 \ln\left(\frac{\mathrm{PetrolPrice}_{€}}{\mathrm{PetrolPrice}_{£} * \mathrm{ExchRate}}\right) + \beta_4 \mathrm{Stock} * \mathrm{Efficiency} \quad (21)$$

Where: $\mathrm{Cons}_{\mathrm{Petrol}}$ is the consumption of gasoline in the private car sector, in kTOE, Income is the total income of the household sector, $\frac{\mathrm{PetrolPrice}_{€}}{\mathrm{PetrolPrice}_{£} * \mathrm{ExchRate}}$ is the Irish price of petrol relative to the UK price, thus β_3 picks up the scope for fuel tourism. Finally, Stock*Efficiency is the interaction term between the total car stock and the estimated car efficiency.

As expected the income elasticity is significant and positive (0.38) whereas β_3 is negative and significant (-0.25). Finally, the multiplicative variable of stock and efficiency is positive and significant at the 10% significance level (0.09).

LOG(Cons_Petrol) = A1+A2*LOG(PetrolPrice_€/(PetrolPrice_£*ExchRate))+A3*LOG(Income)+A4*LOG(Stock*Efficiency)				
	ESTIMATE	STER	TSTAT	P-VAL
β_1	0.3893	0.8277	0.47	0.421
β_2	-0.2214	0.0267	-8.28	0
β_3	0.4226	0.1820	2.32	0.030
β_4	0.0584	0.0454	1.29	0.100
R-squared	0.9949			
R-squared-adjusted	0.9957			
NOB	19.0000			
SER	0.0169			
F	1167.9600			

3.5.3.1 Demand for diesel

We model the demand for diesel for freight and for private cars separately. Data on diesel consumption are taken from the HERMES database, as well as from the price variables.

Private cars

As determinants of the demand for diesel for private cars we consider the price of diesel and a time trend, which approximates the car efficiency in this sector. The demand for diesel can be expressed as follows:

$$\ln(Diesel_{Cars}) = \beta_1 + \beta_2 \ln(DieselPrice_{Cars}) + \beta_3(trend) \quad (22)$$

Unfortunately, neither the stock of diesel cars nor their efficiency proved to be significant. We also tried to estimate fuel tourism in this sector but the coefficient of the euro price relative to the GB price was always insignificant. The coefficient of the diesel price is negative and significant and equals to -0.33.

LOG(Cons_Diesel_Cars) = A1+A2*LOG(DieselPrice_Cars)+A3*trend				
	ESTIMATE	STER	TSTAT	P-VAL
β_1	7.2343	0.5222	13.85	0
β_2	-0.3308	0.0933	-3.55	0.003
β_3	0.0516	0.0033	15.88	0.000
R-squared	0.9807			
R-squared-adjusted	0.9949			
NOB	19.0000			
SER	0.0169			
F	405.7800			

Freight

In order to determine the demand for diesel from freight we follow FitzGerald and Hennessy (2011) and firstly estimate the stock of freight transport:

$$\text{Stock}_{\text{Freight}} = \beta_1 + \beta_2 \ln(GDP) + \beta_3 \left(\frac{DieselPrice_{Freight}}{Deflator}\right) \quad (23)$$

In which the deflator of the price is given by the consumption deflator.

Once we have determined the stock of freight transport in the economy we determine the demand for diesel used for freight:

$$\ln(Diesel_{Freight}) = \beta_1 + \beta_2 DieselPrice_{Freight} + \beta_3 \mathrm{Stock}_{\mathrm{Freight}} \tag{24}$$

In which $\mathrm{Stock}_{\mathrm{Freight}}$ is determined following Eq. (23) and the trend variable approximates the efficiency of the stock of the freight over time.

All the variables have the expected signs; in particular, the stock of freight is strongly significant and positive (0.99) while the price variable is significant and equal to -0.24. Again, the variable which captures the GB price proved to be insignificant.

LOG(Cons_Diesel_Freight) = A1+A2*LOG(DieselPrice_Freight)+A3*Stock				
	ESTIMATE	STER	TSTAT	P-VAL
β_1	-1.1181	0.6064	-1.84	0.085
β_2	-0.2414	0.0793	-3.04	0.008
β_3	0.9960	0.0714	13.95	0.000
R-squared	0.9961			
R-squared-adjusted	0.9956			
NOB	19.0000			
SER	0.0348			
F	2032.8100			

3.5.3.1 Demand for kerosene

Finally, we model the demand of kerosene just by adding a trend to the present kerosene consumption.

3.6 Identities to aggregate sectoral data

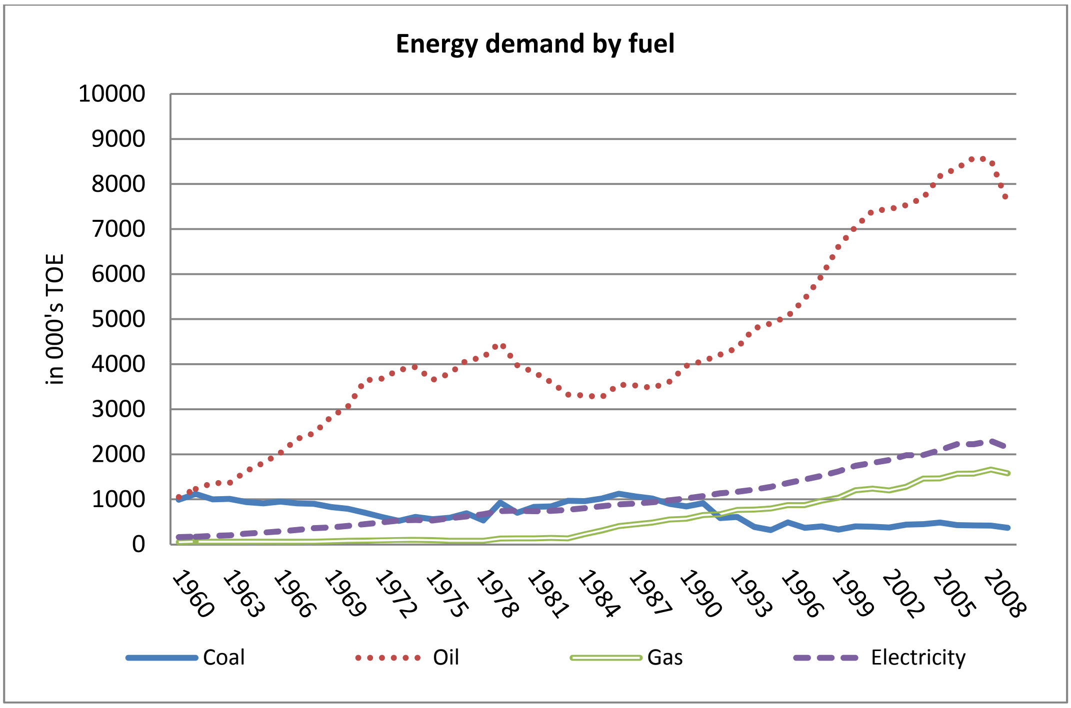

Figure 6: Consumption of Energy by Fuel Type

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. We aggregate the sectoral final consumption of energy to derive total final consumption (Suffix FC relates to final consumption). The total final consumption of energy in the economy is given as follows:

$$ENFC\_T = EN1FC\_T+EN4FC\_T+EN6FC\_T+EN7FC\_T+EN8FC\_T+EN9FC\_T \quad (25)$$

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 include these losses in the primary energy demand Using a series of identities.

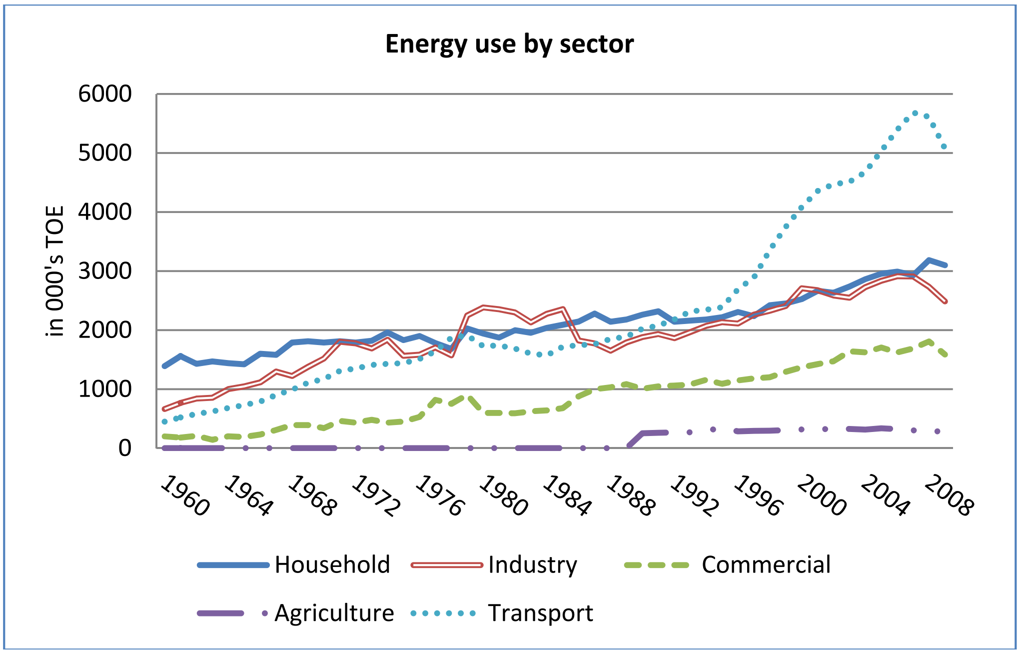

Figure 7: Consumption of Energy by Sector

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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

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