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Carbon Tax Scenarios and their Effects on the Irish Energy Sector

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Carbon Tax Scenarios and their Effects on the Irish Energy Sector

Valeria Di Cosmo and Marie Hyland [*]

Abstract

In this paper we use annual time series data from 1960 to 2008 to estimate the long run price and income elasticities underlying energy demand in Ireland. The Irish economy is divided into five sectors: residential, industrial, commercial, agricultural and transport, and separate energy demand equations are estimated for all sectors. Energy demand is broken down by fuel type, and price and income elasticitieis are estimated for the primary fuels in the Irish fuel mix. Using the estimated price and income elasticities we forecast Irish sectoral energy demand out to 2025. The share of electricity in the Irish fuel mix is predicted to grow over time, as the share of carbon intensive fuels such as coal, oil and peat, falls. The share of electricity in total energy demand grows most in the industrial and commercial sectors, while oil remains an important fuel in the residential and transport sectors.

Having estimated the baseline forecasts, two different carbon tax scenarios are imposed and the impact of these scenarios on energy demand, carbon dioxide emissions, and government revenue is assessed. If it is assumed that the level of the carbon tax will track the futures price of carbon under the EU-ETS, the carbon tax will rise from €21.50 per tonne CO_2 in 2012 (the first year forecasted) to €41 in 2025. Results show that under this scenario total emissions would be reduced by approximately 861,000 tonnes of CO_2 in 2025 relative to a zero carbon tax scenario, and that such a tax would generate €1.1 billion in revenue in the same year. We also examine a high tax scenario under which emissions reductions and revenue generated will be greater.

Finally, in order to assess the macroeconomic effects of a carbon tax, the carbon tax scenarios were run in HERMES, the ESRI's medium-term macroeconomic model. The results from HERMES show that, a carbon tax of €41 per tonne CO_2 would lead to a 0.21 per cent contraction in GDP, and a 0.08 per cent reduction in employment. A higher carbon tax would lead to greater contractions in output.

J.E.L. Classification Numbers: Q4,Q52,Q54.

Keywords: Environmental tax, Energy demand, CO_2 emissions, income distribution.

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1 Introduction

In November 2010 the Irish government produced a National Recovery Plan for 2011-2014 which *"provides a blueprint for a return to sustainable growth in [the Irish] economy"* (Department of Finance, 2010). As part of this proposal the government at the time specifically outlined plans for a carbon tax. They proposed that this carbon tax be included in the 2011 budget at at cost of €15 per tonne CO_2, and be increased gradually to €30 per tonne by 2014. The document states that the tax will "encourage behavioural change", and potential benefits which will accrue from the tax include reduced import dependency, improved environmental sustainability and increased tax revenue. A carbon tax was introduced in the 2010 budget at a rate of €15 per tonne CO_2. At present, the tax only applies to oil and gas, and its application to coal and peat is subject to a commencement order. Electricity is excluded as emissions from electricity generation are already covered under the EU Emissions Trading System (ETS).

While there is much evidence supporting the Irish government's view that implementing a carbon tax is a cost-effective method of achieving a significant cut in CO_2 emissions (see, for example, Pearce, 1991, or McIlven and Helm, 2010), the evidence from countries which have already imposed this tax is mixed (Lin and Li, 2011). In light of this proposed budgetary measure we aim to assess the costs and benefits of a carbon tax in Ireland.

In order to estimate the impact of the tax on consumption patterns we build a model of energy demand for five sectors of the Irish economy: residential, industrial, commercial and public, agricultural, and transport. This energy demand model allows us to estimate price and income elasticities for all the major fuels used in the Irish economy. We find that the price elasticities vary significantly by sector and by fuel, and this will determine how effectively the carbon tax will deliver a reduction in CO_2 emissions. As Ireland is a small country, even a large reduction in CO_2 emissions will not, by itself, make a significant contribution to combating the problem of global warming. However, as Tol et al. (2008) note, it will provide an important signal to other countries, and also to households and industry within Ireland, that the Irish government are serious about tackling climate change.

Our model allows us to estimate the effect of a carbon tax, which is increasing over time, on the fuel mix of the Irish economy, on CO_2 emissions, and on government revenue. This gives us an estimate of some of the potential benefits of the carbon tax, however it is also important to look at the likely costs. Thus, using HERMES, a medium-term model of the Irish economy, we look at the contractionary effect a carbon tax will have on some important macroeconomic variables.

The next section of the paper outlines some of the literature that looks at the realised and the potential benefits of a carbon tax, which have been estimated for Ireland and for other countries. Section 3 of the paper gives an overview of the data used in our estimation and it also introduces the carbon tax scenarios we impose, and gives an explanation for why these particular scenarios were chosen. Section 4 presents the energy demand model we have estimated, and gives the main results of the model by sector. Section 5 discusses the effects of the carbon tax on CO_2 emissions and on government revenue. Section 6 presents forecasts from HERMES on how the carbon tax will affect some important macroeconomic variables. Finally, section 7 concludes.

2 Related Literature

Numerous studies have been carried out to analyse the effectiveness of using a carbon tax to achieve a significant cut in CO_2 emissions, and to analyse their broader economic impact. These studies show that carbon taxes have been introduced in different countries with varying degrees of success. Rapanos and Polemis (2005) estimate income and price elasticities for residential energy in Greece using data from 1965-1998. Using co-integration techniques, they find significant, negative price elasticities of demand for both oil and electricity. At -0.39 and -0.69 respectively, the long run price elasticities for oil and electricity indicate that a contraction in energy demand would occur in the face of rising prices. However, their simulations show that while the imposition of a carbon tax does result in a drop in demand, and thus emissions, even under the highest tax scenario considered, this contraction will not be enough to bring Greek emissions in line with its Kyoto targets. The authors thus conclude that other policy instruments must be combined with a carbon tax to achieve the emissions reduction target.

Lin and Li (2011) use difference-in-differences estimation to examine, ex-post, the effect of a carbon tax on carbon emissions in five northern European countries. Using panel data they find that, of the five countries studied (Norway, Sweden, Denmark, Finland and the Netherlands), only in Finland did the carbon tax cause a significant reduction in CO_2 emissions. In Norway they found that a carbon tax actually led to an increase in CO_2 emissions. In the remaining countries, a carbon tax led to a decrease in emissions which was not statistically significant.The authors conclude that the reason for the ineffectiveness of the carbon tax in these countries is due to the tax reliefs and exemptions granted to energy-intensive industries. In Norway the exemptions granted to energy-intensive industries improved their international competitiveness which led to an increase in CO_2 emissions.

Similar results were found by Bruvoll and Larsen (2004) who also found carbon taxes to be largely ineffective in Norway. They used an applied general equilibrium analysis to decompose observed emissions from the 1990-1999 period. Again, they found that the ineffectiveness of the carbon tax was primarily due to the fact that many energy-intensive industries were exempt from paying the tax. They also found that in the residential sector, the inelasticity of demand for transport fuels, with respect to price, meant that a high tax did not result in a significant decline in consumption.

On the other hand, a number of studies have found that a carbon tax can yield significant reductions in CO_2 emissions at a modest cost. For example, a paper by Lu, Tong and Liu (2010) examines the potential effect of a carbon tax on the Chinese economy using a dynamic recursive general equilibrium model. They find that while a carbon tax will adversely affect competitiveness and consumption, the revenue from a carbon tax could be recycled to minimise these negative impacts. They find that even under the highest carbon tax considered, GDP would only fall by 1.1% whereas emissions would fall by 17.45%, and they thus conclude that a carbon tax would be an effective policy tool.

Using a top-down energy demand model Gerlagh and van der Zwaan (2006) analyse various instruments which could be used to achieve a deep cut in CO_2 emissions, and they find that taxing emissions is almost always a cost-effective way of achieving a deep cut in emissions. They also find that the cost of achieving these cuts can be greatly reduced if the revenue from the carbon tax were used to support non-carbon energy sources.

Wissema and Dellink (2007) look specifically at the case for Ireland. The authors use an applied general equilibrium analysis to estimate the effect of two different taxes - one a carbon tax and the other a uniform tax on energy regardless of the carbon content of the fuel, to achieve a 25.8% reduction in CO_2 emissions relative to 1998 levels. They find that such a reduction can be achieved at a tax as low as €10-15 per tonne CO_2. Furthermore, using the Hicksian Equivalent Variation approach, they analyse the impact of a carbon tax on welfare and find that achieving this emission reduction target using a carbon tax would result in a decline of only 0.3% in welfare.

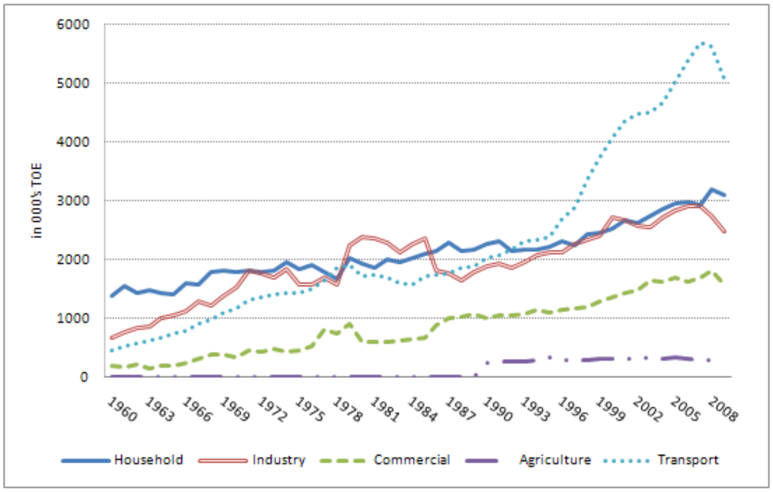
Ghalwash (2007) estimates an almost ideal demand system to analyse the effect of environmental taxes on consumption. The author finds that carbon taxes would be effective in reducing emissions from home heating, but that they would be much less effective at reducing emissions from transport.

Finally, Conefrey et al (2008) examine in the impacts of a carbon tax on emissions and economic growth, using the HERMES medium-term model of the Irish economy. Imposing a carbon tax of €20 per tonne CO_2 would, they find, result in a modest decline in emissions (between 2% and 2.5%). However, they find that a carbon tax could have a positive effect on GDP if the revenue from the tax is used to reduce income taxes. They note that, in the long run, a carbon tax is likely to have a stronger impact on emissions as it will incentivise research and development.

3 Data description

The consumption of energy in Ireland has dramatically increased during the last 20 years across different sectors, as shown by Figure 1; this is reflected in the higher consumption of different fuels, which have varying levels of carbon intensity.

Figure 1: ENERGY CONSUMPTION BY DIFFERENT FUELS (1960-2009)



Data source:IEA

As the European, and thus the Irish, agenda is committed to consistently reducing the quantity of the emissions by 2020, it is important to understand the fuel mix in the different sectors of the Irish economy, and to forecast the impact of a carbon tax on sectoral emissions.

In order to avoid double-regulation, we wish to apply the carbon tax only to those sectors which are not already covered by the EU-ETS [1]. As power generation is regulated under EU-ETS we exclude all emissions from this sector in our analysis. However, as we are using aggregated data it is more difficult to differentiate, in our data, other sub-sectors that are included under EU-ETS. We do know that the majority of coal consumed in the industrial sector is used by cement manufacturing plants and, as cement manufacturing is regulated by the ETS, we do not apply the carbon tax to coal used in the industrial sector. In all other sectors we assume the carbon tax can be applied to all non-electric fuels.

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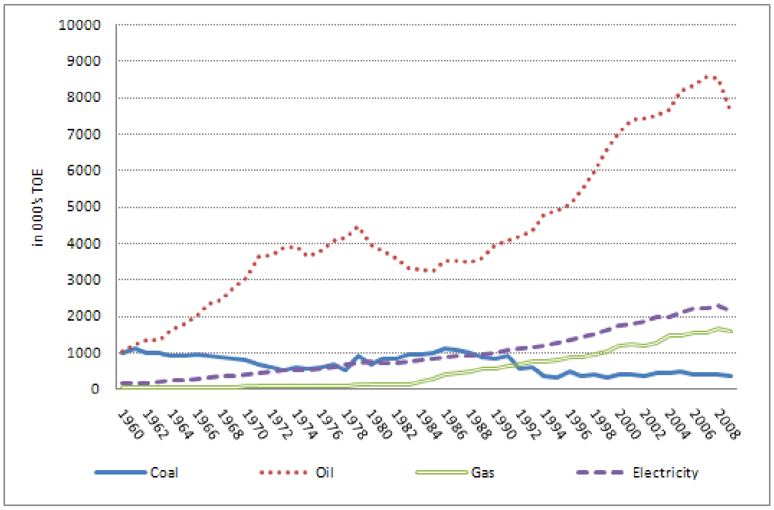
[1] The European Union's Emissions Trading System is the world's largest scheme for trading carbon permits. It covers CO_2 emissions from power generation and large industries, and approximately half of the EU's CO_2 emissions are regulated under it.

Figure 2: FUEL CONSUMPTION IN DIFFERENT SECTORS (1960-2009)



Data source:IEA

As shown in Figure 2, oil demand represents a high share of the total energy demand, but we would expect that the introduction of a carbon tax would encourage substituting from heavy-pollutant fuels, such as oil, towards other, cleaner energy sources.

In order to determine the impact of the carbon tax, we use IEA annual data from 1960 to 2009 to estimate the energy consumption in five different sectors of the Irish economy: the residential, or household, sector (HH), the industrial sector (IND), the commercial sector (CS), the transport sector (TR), and the agricultural sector (AGR).[2]

For each sector we develop a specific model for the consumption of electricity and for the other main fuels used, which gives us the income and price elasticities needed to project fuel consumption out to 2025. As the carbon tax will affect the fuel prices, we can estimate how the demand for individual fuels reacts to the imposition of the tax. In particular, we assume that separability between energy and electricity holds in the household sector, as gas became available only in the late '80s and it is basically used only for heating purposes. We don't assume separability between energy and electricity in the industrial and in the commercial sector, as it is quite difficult to separate the use of electricity or other fuels in the productive process.

We consider three different carbon tax scenarios. In the first scenario (the baseline), we assume that no carbon tax is imposed and we simply forecast future energy consumption based on past realisations. In the second scenario, we consider the imposition of a carbon tax that is equal to the forward curve of the EU allowance units traded on the European Climate Exchange; for semplicity, we call this scenario "ETS". As

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[2] There are some data issues when producing estimates of energy demand in Ireland. These limitations have hampered previous research in the area. Historical energy price data is 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. A notable 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.

our forecast results are heavily dependent on the carbon tax imposed to the model, we fix the EUA forward curve at the path proposed in the latest version of the SEAI (Sustainable Energy Authority for Ireland) report. [3]

Finally, we consider a "high tax" scenario (i.e.: higher than the EU-ETS level scenario) in which the level of carbon tax imposed on the Irish economy gradually increases to a nominal value of €50 per tonne CO_2 in 2025. The two carbon tax scenarios are outlined in the below:

Table 1: CARBON TAX SCENARIOS

YEAR	2012	2015	2018	2020	2023	2025
ETS LEVEL TAX	21.50	26.00	30.50	33.50	38.00	41.00
HIGHER LEVEL TAX	22.50	31.82	37.27	40.91	46.36	50.00

To link our estimation results to the macroeconomic forecasts we proceed as follows: firstly, we impose the three different tax scenarios on the HERMES macroeconomic model, hypothesising that the revenues that come from the carbon tax are used to repay the Irish deficit.[4] We then take the HERMES forecasts of the main macroeconomic variables under the three scenarios, as these are used as exogenous variables in our energy demand model. Next, we impose the carbon tax on the energy prices, and using the previously estimated income and price elasticities, we project the consumption of energy based upon the macroeconomic variables forecasted by HERMES. Finally, applying the carbon coefficients for each fuel, we calculate the CO_2 emissions associated with the forecasted fuel consumption.

It should be noted that electricity price is not forecasted by the HERMES model, but by the IDEM model, under the assumption that the price of EU- ETS permits gradually increases to €41 (nominal value) per tonne CO_2 in 2025.

The IDEM model (Diffney et al., 2009) is an optimal dispatch model which computes the least-cost way of producing electricity for each half-hour period of a given year. Annual growth estimates of electricity demand for each year are applied to the half-hourly electricity demand profile for 2008. This is a static model which computes the cost of producing electricity in each year separately. As the IDEM model forecasts the short run electric price, we have applied different coefficients to include capacity payments and taxes for the industrial and the household sectors.[5]

As stated previously, we assume that the carbon tax applies to all non-electric fuels, including coal and peat which are currently exempt from the carbon tax introduced in budget 2010.

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[3] The assumptions are stated at page 12 of the report available here: `http://www.seai.ie/Publications/Statistics_Publications/Energy_Modelling_Group/Energy_Forecasts_for_Ireland_to_2020-2010_report.pdf`

[4] For a description of the HERMES macroeconomic model, see the Appendix

[5] For a description of the electricity price behaviour see Devitt et.al. (2009)

4 Estimation results

As highlighted by Rapanos and Polemis (2005) demand series for electricity and other fuels often present non-stationary dynamics. Moreover, these variables are frequently cointegrated with important economic variables such as GDP or fuel prices. In order to detect the presence of non-stationarity in our series we firstly perform unit root tests. If these tests indicate the presence of a unit root in the endogenous and exogenous variables, we test for the presence of cointegrating relationships. If results from these tests indicate that cointegrating relationships exist, we follow the two step Engel-Granger (EG) procedure for cointegration modeling. 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 and short run relationships separately, which is consistent with the specification adopted by Rapanos and Polemis (2005) and by Hennessy and FitzGerald (2011), in which they used error correction models to estimate the main energy equations.

The results of the Augmented Dickey Fuller tests for unit roots, and the the tests for cointegration are reported in the Appendix; here it is important to highlight that when cointegration is detected, the error correction term estimated in the short run specification is always negative and strongly significant, which implies that the short run deviations will converge to the long run equilibrium.

Moreover, the elasticities have all the expected signs, as the price elasticities are always negative and significant, and the income or value-added elasticities are always positive and significant. All the results of the estimated equations are reported in the Appendix.

4.1 Residential sector

Demand for energy in the residential sector accounts for approximately 23% of total energy consumption in Ireland. Energy consumption in this sector has grown significantly over the last 40 years due to increasing population levels and improving economic conditions. The energy mix of this sector has also undergone significant changes in this time; the demand for electricity has experienced a steady upward trend, as has the demand for gas since it was brought on-stream in the 1980's.

Residential energy demand is divided between the demand for electricity and the demand for non-electric energy. This reflects that fact that in Ireland, electricity has traditionally been used for appliance usage, and non-electric energy sources such as coal, oil and gas, as home-heating fuels.

We assume that this sector is characterized by the presence of a representative household, and that the consumption of different fuels could be represented by the following equation:

$$ln(c_i) = \alpha_0 + \alpha_1 ln(income) + \alpha_2 ln(price_i) + \alpha_3 trend \tag{1}$$

in which i is the fuel considered. For the residential sector we estimate the consumption of peat, coal, gas and electricity, and calculate the demand for oil as a residual.

The demand for electricity is modeled as a function of the price of electricity and the housing stock.[6] The results from the long run equation indicate that the elasticity of demand for electricity with respect to the housing stock is high at 0.84. However, the price elasticity of demand is low at minus 0.07, indicating that, in the face of rising electricity prices, households have limited scope to switch to other sources of energy, even in the long-run. The coefficient on the error term in the ECM is -0.38, which implies that 38% of the adjustment to the long run equilibrium will take place within the first year.

To estimate the demand for non-electric energy in the residential sector, we again follow the two step Engle-Granger procedure. The demand for non-electric energy is modeled as a function of a weighted price index variable, representing the average price of fuels used by the residential sector, and as a function of the housing stock. Results from this equation are similar to those from the electricity demand equation; the long run income elasticity with respect to the housing stock is high at 0.78 but the long run price elasticity is much lower at minus 0.15. The coefficient on the error correction term is -0.71, which implies a quick return the equilibrium value.

The demand for individual fuels are expressed as the demand share of the fuel in total non-electric energy demand, and are modelled as a function of time and prices. Having calculated the demand shares of coal, gas and peat, the demand for oil is calculated as a residual, in order to impose the adding-up constraint, as the sum of the share of different fuels should be equal to 1.

In both the coal and peat demand equations the price variable proved insignificant, and thus the equations are modeled as a function of time. In both equations, the coefficient on the time trend variable is negative and significant reflecting the fact that the demand shares of both coal and peat are falling over time. The coefficients on the time trend in the coal and peat equations are -0.08 and -0.02 respectively, and then asymptotically both of them are equal to zero.

The demand for gas is modelled as a function of its price relative to the other fuels and real personal

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[6] The number of heating degree days was included in the initial analysis but excluded from the final model specification as it proved to be insignificant.

disposable income. The elasticity of gas with respect to income is 0.69, and the price elasticity of demand is minus 0.32, indicating that, in the long run, households have some scope to substitute away from gas in the face of rising gas prices.

4.2 Industrial sector

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. Data from the IEA highlight the fact that consumption of coal gas in gas works stopped in 1985, as coal gas was no longer being converted to town gas. Furthermore, the closure of Ireland's main steel plant contributed to the significant changes experienced in the industrial sector from 2001 onwards.

It is quite difficult to disentangle the energy uses in this sector, as the aggregate demand for different fuels, including electricity, can be ascribed either to space heating or to the production of goods. While in the residential 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. Furthermore, in recent years some firms have opted to move to self-generation to benefit from cost savings in the long-run. In such cases, these companies would have switched their consumption from electricity to gas, which makes it more difficult to correctly ascribe energy consumption to its various uses.

We therefore relax the separability assumption that we have introduced for the household sector. To account for these effects, we estimate the electricity demand and then the demand for energy as a whole. Finally, we derive the demand for other fuels in the sector.

It is worth noting that coal is the main fuel used in the cement industry and, as the cement industry is an important component of the entire industrial sector, this strongly affects the total coal consumption. However, for the purpose of this analysis, we ignore the cement sector entirely as it is already regulated by the EU-ETS, and thus we do not apply the carbon tax to coal consumed in the industrial sector.

In order to model energy demand in the industrial sector, we assume that the consumption of fuels and electricity is characterised by the following equation:

$$ln(c_i) = \alpha_0 + \alpha_1 ln(ValueAdded_{IND}) + \alpha_2 ln(price_i) \tag{2}$$

in which i is the fuel considered. The consumption of gas, light fuel oil and heavy fuel oil are driven by their prices (with negative elasticities equal to -0.374, -0.170 and -0.191 respectively). The consumption of light fuel oil is positively related to value-added in the industrial sector, with an elasticity of 0.2.

The demand for electricity in this sector is non-stationary, and it is driven by the price of electricity (the long run price elasticity is equal to -0.275) and sectoral value-added (with an elasticity equal to 0.572). As shown in the Appendix, the estimated error correction term is negative and strongly significant.

4.3 Commercial sector

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. 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.

As in the industrial sector, we relax the separability assumption between electricity and total energy; we model the demand for electricity, the demand for the different fuels, and finally we impose that the sum of the different fuels used plus electricity gives the total consumption of energy. No cointegreting relationships were found for this sector; then we model the consumption of different fuels and electricity as follows:

$$ln(c_i) = \alpha_0 + \alpha_1 ln(ValueAdded_{CS}) + \alpha_2 ln(price_i) \tag{3}$$

in which, again, i is the fuel considered. Tests show that the demand series for electricity in this sector is stationary, but that the residuals are autocorrelated. Therefore, we model electricity consumption as a function of price, a lagged dependent variable, and value-added. The coefficients all have the expected signs, the price elasticity is negative and equal to -0.02 but this variable was found to be not statistically significant, whereas the elasticity with respect to the value added, which is significant, is positive and equal to 0.239. Both the consumption of gas and oil in this sector are driven by their respective prices and sectoral value-added, the coefficients are all strongly significant and they are reported in the Appendix.

4.4 Agricultural sector

In 2009, the demand for energy in the agricultural sector accounted for only 2.2% of total energy demand. Oil, specifically diesel, accounts for the majority of energy consumed in this sector (78% in 2009), and electricity accounts for the remainder.

The demand for electricity in this sector is modeled as a function of the price of electricity, agricultural output and a time trend. The long run price elasticity was estimated at minus 0.38 and the elasticity with respect to output is 0.71. To model the short and long run elasticities, we adopted the Engle-Granger two-step estimation procedure. The error correction term in the short run equation has a coefficient of -0.5.

The demand for oil in this sector is modeled as a function of the price of diesel and a time trend. The price elasticity of demand for oil is minus 23%. Unlike the other main equations in our model, the demand for oil was not modeled using an error correction model, as a Dickey Fuller test indicated that the series was stationary.

The total demand for energy in the agricultural sector is then calculated as the sum of electricity and oil demand.

4.5 Private transport sector

The demand for energy in the car sector is not only the largest of the individual sectors; it is also the sector where demand is increasing the fastest. Demand can be divided between the consumption of petrol and diesel, as the use of kerosene is predominantly confined to the aviation sector.

We estimate the demand for these two fuels and find that the demand for petrol is driven by the efficiency of the stock of cars, the price of petrol and real disposable income. The demand for diesel is driven by the price of diesel and a time trend.

The estimated equations and the results are presented in the Appendix.

5 Forecasting results

5.1 Energy demand

Having estimated the income and price elasticities for fuels used in the residential, industrial, commercial, agricultural and transport sectors, we apply these coefficients to the values for prices and income given by the HERMES macroeconomic model. The baseline prices given by HERMES do not include a carbon tax, but do account for the cost of carbon in electricity generation as it is charged under the EU-ETS. The carbon tax is added to the remaining fuels using the carbon coefficients given below:

Table 2: CARBON COEFFICIENTS (EXPRESSED AS TONNES OF CO_2 PER TONNE OF OIL EQUIVALENT)

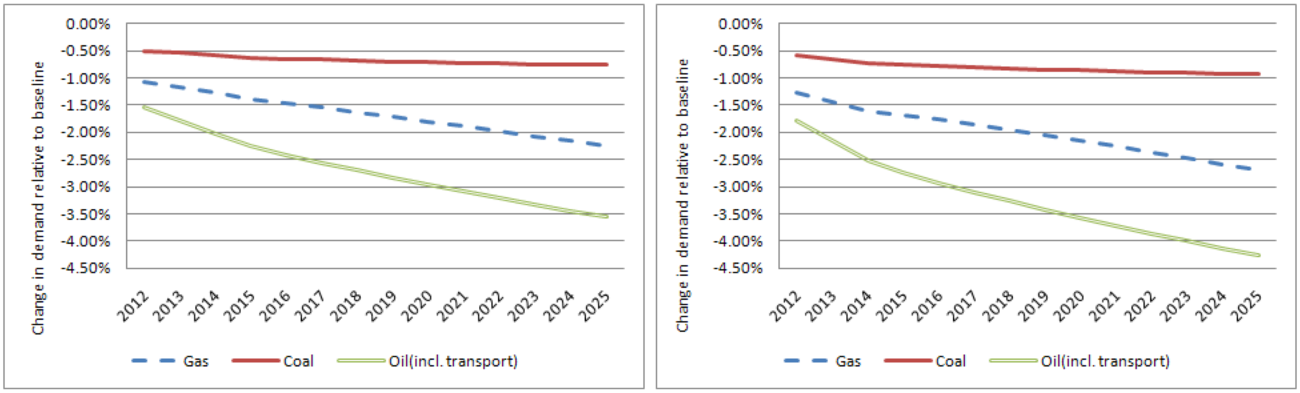
FUEL	COEF
GAS	2.30
COAL	3.96
OIL	3.07
PEAT	4.14

Applying these carbon coefficients to the various fuels gives us the new price for fuels including a carbon tax, i.e.:

$$Price_{WithTax} = Price_{NoTax} + (Carbon\_Tax * Carbon\_Coefficient).$$

Thus, how much the demand for a fuel responds to the carbon tax depends upon the price elasticity of demand for the fuel, and upon the carbon content of the fuel.

Figure 3: EFFECTS OF CARBON TAX ON FUEL DEMAND



(a) ETS LEVEL TAX

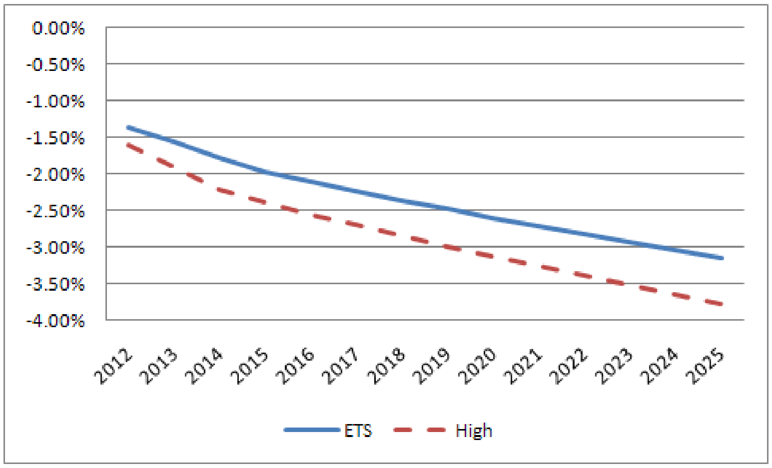
(b) HIGH LEVEL TAX

Figure 5 above shows that, despite the high carbon content of coal, the effect of a carbon tax on its demand is minimal - this is because the demand for coal is highly inelastic. Furthermore, as discussed previously, the carbon tax has no effect on the price of coal in the industrial sector, as most of the coal used in this sector is covered under the EU-ETS and therefore unaffected by the carbon tax. Gas and oil react more strongly as their price elasticities are greater; the effect of the carbon tax on oil demand is particularly strong due its high carbon content.

5.2 Emissions

As we would expect, a drop in the demand for energy leads to a decrease in carbon dioxide emissions. Our forecasts project that the imposition of a carbon tax would result in a level of emissions in 2025 that is between 3.1% and 3.8% below the baseline level depending upon whether we impose the low or high carbon tax scenario. This is illustrated below.

Figure 4: EFFECTS OF CARBON TAX ON CO_2 EMISSIONS



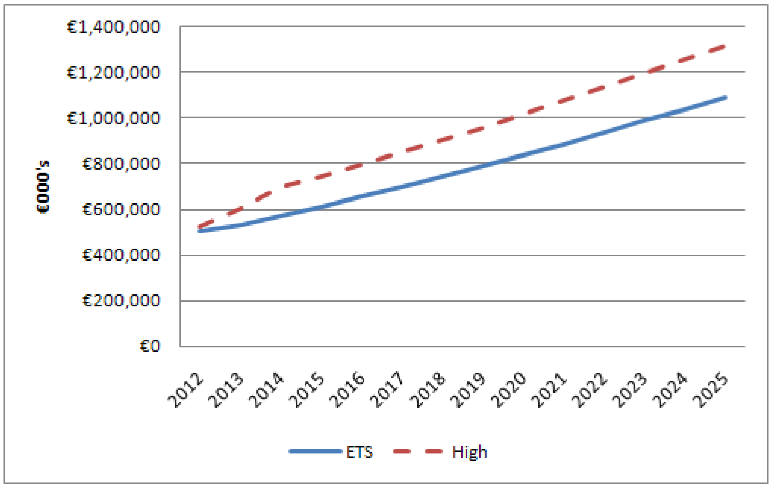
This shows a stronger impact of a carbon tax than what has been previously found: a previous study of the effect of a carbon tax in Ireland (Conefrey et al, 2008) found that if the carbon tax rose to €38 per tonne CO_2 in 2020, the level of emissions (excluding emissions from power generation) would be 1.7% less than in the baseline (no tax) scenario. We find that at the same tax level, CO_2 emissions would be almost 3% below the baseline scenario. In both cases these results come from a scenario in which revenue recycling does not occur.

Conefrey et al (2008) and Ekins and Barker (2001) note that such simulations tend to under-estimate the quantity of emissions avoided, as it is likely that a carbon tax would, in the long run, incentivise research and development which would lead to more efficient energy usage, and thus to lower emissions. However, Conefrey et al (2008) point out that the incentive to carry out R&D would be much weaker if the carbon tax was limited to Ireland.

5.3 Revenue

A carbon tax would be a significant source of revenue to the Irish economy, and in our simulations we assume that, given Ireland's current economic conditions, the revenue raised is used to reduce the Irish deficit. Assuming the carbon tax rises in line with the projected price of EU-ETS permits, the tax would bring in approximately €11 billion in revenue over 14 years. If the higher carbon tax scenario was imposed, the revenue over 14 years would be just over €13 billion. Figure 5 below shows how the annual carbon tax revenue would grow over the period as the level of the tax rises.

Figure 5: REVENUE FROM THE CARBON TAX



However, this is not to suggest that a higher level of tax is necessarily better; imposing a carbon tax can have significant negative impacts on the economy, as will be discussed in the next section.

6 Effects on the Macroeconomy

Using the HERMES medium-term model of the Irish economy, we look at the effects of two hypothetical levels of carbon tax on some important macroeconomic variables. We assume that the revenue from the carbon tax is used to reduce the deficit of the Irish economy. It has been shown that carbon taxes are regressive (see Tol et al 2008) and thus will disproportionately affect poorer households. Tol et al (2008) look at how the revenue from the carbon tax could be recycled in order to reverse these negative impacts; however, given Ireland's current fiscal crisis we have assumed that any revenue from the carbon tax must be used to reduce the Irish deficit. As such, revenue recycling is not currently an option. Our results show that imposing a carbon tax will have a contractionary effect on the Irish economy, and that the effect will be larger under the higher carbon tax scenario. Of course, many macroeconomic variables will be affected by the carbon tax, but in this paper we specifically analyse the effects upon the balance of payments (BOP) [7]; consumption (CONS); GDP; total investment (INV); total employment (TOT EMPL) industrial employment (IND EMP); net migration (NET MIGR); and the unemployment rate (UNEMP).

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[7] Here we are referring to the balance of payments rate which is the balance of payments surplus as a percentage of GNP

Table 3: EFFECTS OF ETS/HIGHER LEVEL CARBON TAX RELATIVE TO A NO-TAX SCENARIO

(a) ETS LEVEL CARBON TAX

	2013	2014	2015	2020	2025
BOP	0.43	0.48	0.51	0.69	0.93
CONS	-0.29%	-0.32%	-0.33%	-0.37%	-0.37%
GDP	-0.13%	-0.15%	-0.16%	-0.19%	-0.21%
INV	-0.17%	-0.15%	-0.13%	-0.06%	0.00%
IND EMP	-0.08%	-0.08%	-0.08%	-0.03%	0.05%
NET MIGR	1.42%	1.80%	4.07%	-0.36%	0.17%
UNEMP	0.012	0.012	0.011	0.003	-0.003
TOT EMPL	-0.07%	-0.08%	-0.08%	-0.08%	-0.08%
DEBT TO GNP	-2.02	-2.51	-2.99	-5.78	-9.42
DEFICIT TO GNP	-0.50	-0.54	-0.57	-0.76	-1.01

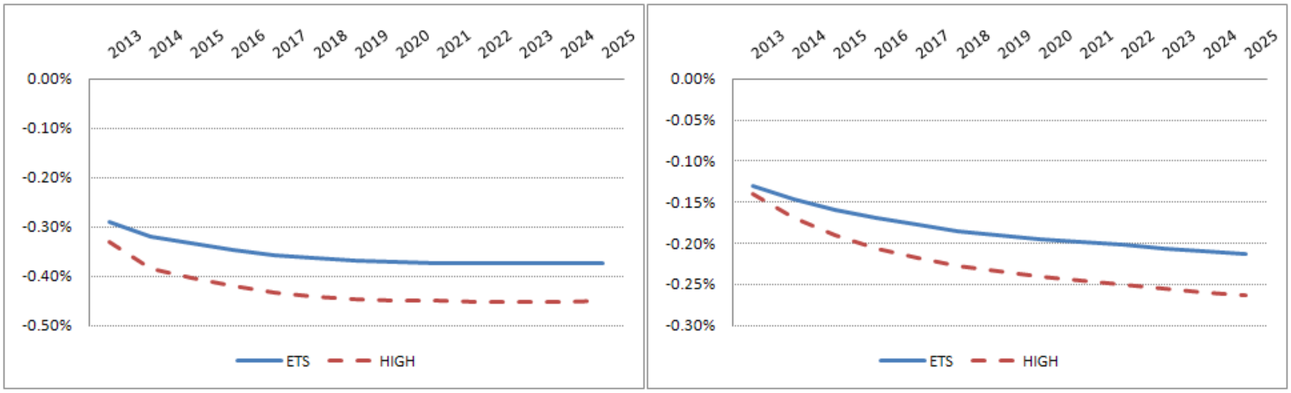
(b) HIGH LEVEL CARBON TAX

	2013	2014	2015	2020	2025
BOP	0.49	0.57	0.62	0.84	1.13
CONS	-0.33%	-0.38%	-0.40%	-0.45%	-0.45%
GDP	-0.14%	-0.17%	-0.19%	-0.24%	-0.26%
INV	-0.19%	-0.19%	-0.18%	-0.08%	-0.01%
IND EMP	-0.10%	-0.11%	-0.11%	-0.06%	0.03%
NET MIGR	1.74%	2.79%	7.81%	-0.61%	0.13%
UNEMP	0.020	0.021	0.017	0.004	-0.003
TOT EMPL	-0.08%	-0.10%	-0.10%	-0.11%	-0.10%
DEBT TO GNP	-2.15	-2.78	-3.36	-6.76	-11.19
DEFICIT TO GNP	-0.56	-0.64	-0.68	-0.92	-1.21

Note: All variables are expressed as percentage changes relative to the baseline except for the balance of payments, the unemployment rate, and the debt and deficit to GNP ratios, all of which are expressed as differences, in percentage points, from the baseline

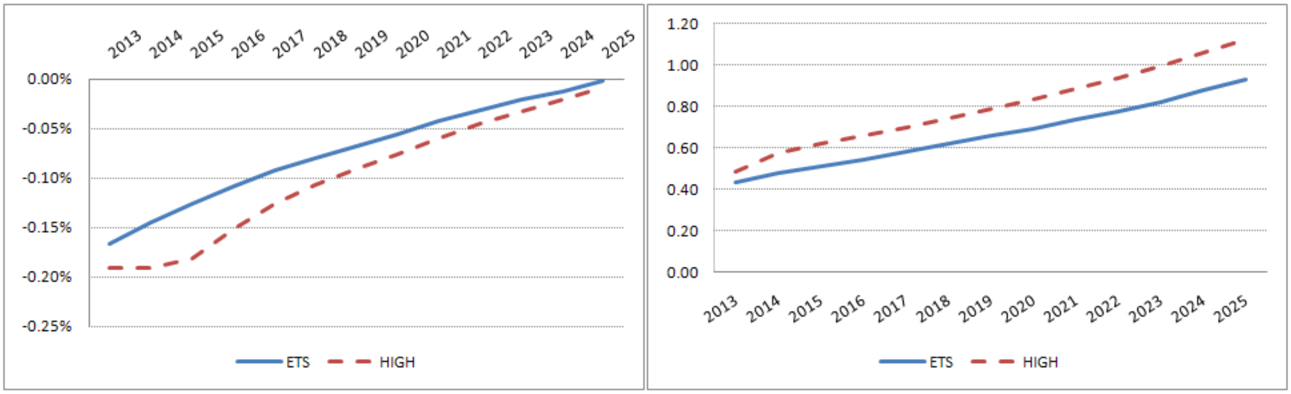
The reaction of the main macroeconomic variables after the imposition of the two carbon tax scenarios is represented in the following Figure:

Figure 6: EFFECTS OF ETS/ HIGH CARBON TAXES ON MACROECONOMIC VARIABLES



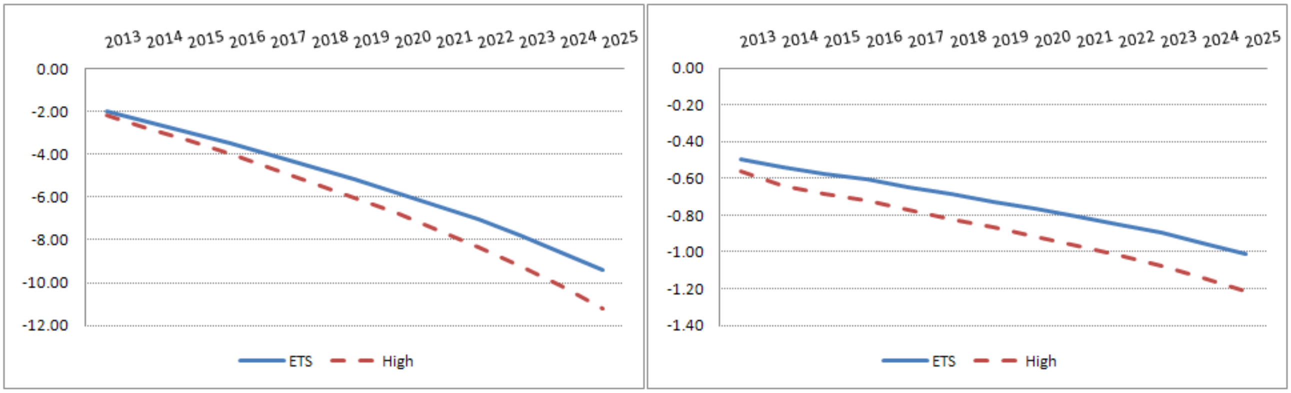
(a) CONSUMPTION

(b) GDP



(c) INVESTMENT

(d) BALANCE OF PAYMENTS



(e) DEBT TO GNP RATIO

(f) DEFICIT TO GNP RATIO

Note: Consumption, GDP and Investment are expressed as percentage changes from the baseline scenario. The Balance of Payments refers to the balance of payments surplus as a percentage of GNP, and is represented here as the difference in percentage points from the baseline. Likewise the Debt and Deficit to GNP ratios are expressed as differences in percentage points from the baseline.

As can be seen from the results above, under an ETS-level carbon tax, the GDP in 2025 will be reduced by 0.21% as a result of the imposition of the carbon tax. Other significant negative impacts of the carbon tax include a decrease in total employment by 0.08%, and a decrease in consumption by 0.37%.

As would be expected, the negative impacts of the carbon tax are exacerbated in the higher tax scenario: here we see that GDP would fall by 0.26% in 2025, relative to the no-tax scenario, total employment would fall by 0.10%, and that consumption would decrease by 0.45%.

On the other hand, as it was assumed that the revenue from the carbon tax will be used to reduce Ireland's deficit, having a higher carbon tax would make a positive contribution to the balance of payments: in the ETS-level scenario, the balance of payments surplus (relative to GNP) in 2025 would be 0.933 percentage points higher than in the no-tax scenario, and, in the same year, under the higher tax scenario it would be 1.13 percentage points higher.

7 Conclusion

In this paper we have estimated price and income elasticities for all the primary fuels in the Irish fuel mix. We show that the elasticities vary significantly between fuels and sectors. We found that for the main energy demand equations, cointegrating relationships exist between demand, price and income; therefore, we model the short and long run equations using the Engle-Granger two-step estimation procedure.

The varying price elasticities between fuels and sectors mean that the imposition of a carbon tax on the Irish economy would cause demand for fuels, and thus CO_2 emissions, to contract more in some sectors than in others.

The main benefits of imposing this carbon tax are a significant decline in CO_2 emissions and a substantial inflow of revenue from the new tax; under an "EU-ETS" level tax, in 2015 the carbon tax would bring in €612 billion in revenue and would result in the abatement of 471,000 tonnes of CO_2.

However, it is important to examine the negative impacts of this tax. Macroeconomic results show that while the carbon tax has a positive effect on the balance of payments, it will lead to a contraction in GDP, consumption, investment and employment, and to an increase in net migration.

These results are primarily driven by the fact that the deep economic crisis that affected Ireland in 2010 made it compulsory to invest the carbon tax revenue in reducing the deficit of the Irish economy. Imposing a carbon tax without any form of revenue recycling leads to a regressive tax.

However, two arguments in favour of the ETS-level carbon tax emerge. Firstly, a carbon already exists for certain sectors of the economy and it has been argued (see Tol et al 2008) that the economically efficient way of reducing CO_2 emissions is to set a uniform price on carbon regardless of it emission source. This implies that the level of the Irish carbon tax for non-ETS sectors of the economy should be set equal to the price of carbon under the ETS. Secondly, in order to comply with its obligations under the Kyoto protocol and under EU targets, Ireland must cut its CO_2 emissions; setting the carbon tax at the ETS level will bring us closer to these targets while limiting the negative macroeconomic consequences that will result from the tax.

Due to the negative effects on GDP and employment that we forecast in this paper, we recommend implementing a carbon tax at the ETS level in order to benefit from emissions reduction while limiting the contractionary effects on the economy.

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8 Appendix

8.1 HERMES model of the Irish Economy

Here we give a brief overview of the HERMES model, a more detailed explanation can be found in Conefrey et al (2008) and in the Appendix of Fitz Gerald et al (2008).

The HERMES model is the ESRI's medium term model of the Irish economy. As explained by Conefrey et al (2008), it is a model in which there is generally limited involuntary unemployment in the long run, as the wage rate adjusts to clear the labour market, and in which the labour market is highly elastic. Conefrey et al (2008) note that the share of the market services sector that is traded is increasing over time, and there is substantial foreign direct investment (FDI) in both the manufacturing and market services sector. As a consequence of the high level of FDI, there is large scale repatriation of profits. They explain further that firms in the market services sector are price setters as they can pass on any increase in input costs to consumers, whereas firms in the manufacturing sector are price takers and compete on the international market. The authors note that government debt is funded on international markets due to the small size of the economy.

The model focuses on the production relationships and examines downstream income and expenditure consequences. Following Conefrey et al (2008), some important features of the model are:

- the tradable sector is driven by global demand, by elements of domestic demand and by cost competitiveness
- the market for building and some market services (the sheltered market sector) is driven by domestic demand
- the public sector is policy driven, and decisions on taxes and expenditure are treated as exogenous
- the demand for labour is derived from factor demand system for the individual sectors of the economy
- in the manufacturing sector the demand for energy and other inputs are assumed to be used in fixed proportion, and in the services sector energy does not enter the production function

The HERMES model was last estimated in 2009, based on 2006 data.

8.2 ADF tests for non-stationarity

	Lags	**Test stat**	**1% critical value**
Electricity HH			
Demand	1	**-0.439**	**-3.696**
1/Hstock	1	**-0.616**	**-3.689**
Price	1	**-1.909**	**-3.689**
Residual Energy HH			
Demand	1	**0.415**	**-3.655**
Price	1	**-1.092**	**-3.662**
Electricity IND			
Demand	1	**-1.725**	**-3.743**
Price	1	**-0.318**	**-3.743**
Value Added	1	**-0.909**	**-3.743**
Electricity CS			
Demand	1	-3.485	-3.594
Price	1	**-2.403**	**-3.689**
Value added	1	**0.641**	**-3.689**
Electricity AG			
Demand	1	**-1.937**	**-3.75**
Price	1	**-2.667**	**-3.587**
Value added	1	**-1.988**	**-3.587**
Petrol CAR			
Demand	1	**-1.504**	**-3.75**
Price	1	**1.938**	**-3.75**
GDP	1	**-2.308**	**-4.38**
Efficiency	1	**-0.899**	**-3.75**
Diesel CAR			
Demand	1	-3.175	-4.362
Price	1	-4.321	-4.362

Both demand and price in diesel equation are trend stationary.

8.3 ADF tests for cointegration

	Test stat	**1% critical value**
$u_{Elec_{HH}}$	-3.975	-3.696
$u_{ResEnergy_{HH}}$	-4.530	-3.662
$u_{Elec_{IND}}$	-3.959	-3.743
$u_{Elec_{AGR}}$	-4.133	-4.380
$u_{Petrol_{CAR}}$	-3.207	-3.750

8.4 Estimated equations

8.4.1 Household Sector

Electricity: long run relations

$$ln(ELEC_{HH}) = \alpha_{HH} ln\left(\frac{1}{HousStock}\right) + \beta_{HH} ln(P\_ELEC_{HH}) + \gamma_{HH} trend \tag{4}$$

Variables	ln(ELEC$_{HH}$)
ln$\left(\frac{1}{HousStock}\right)$	-0.838***
	(0.0212)
ln(P_ELEC$_{HH}$)	-0.0680***
	(0.0236)
trend	0.0162***
	(0.000800)
Observations	33
R-squared	0.9866

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

In this equation housing stock is expressed as a reciprocal, which allows the output elasticity to fall over time. While data are available from the 1960s, results from a Chow test indicate that there is a structural break in the data in 1976, and thus the equation is estimated for the period 1976-2009.

Electricity: short run relations

$$\Delta ln(ELEC_{HH}) = \alpha_{HH}\Delta ln\left(\frac{1}{HousStock}\right) + \beta_{HH}\Delta ln(P\_ELEC_{HHt-1}) + \gamma_{HH}u_{Elec_{HHt-1}} \tag{5}$$

Variables	$\Delta ln(ELEC_{HH})$
$\Delta ln(P\_ELEC_{HHt-1})$	0.101
	(0.156)
$\Delta ln\left(\frac{1}{HousStock}\right)$	-0.987**
	(0.457)
$u_{Elec_{HHt-1}}$	-0.441***
	(0.132)
Constant	0.00893
	(0.0122)
Observations	33
R-squared	0.330

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Residual energy: long run relations

$$ln(Resid\_energy_{HH}) = \alpha_{Resid} + \beta_{Resid}ln(P\_Index\_Energy) + \gamma_{Resid}ln\left(\frac{1}{HousStock}\right) \tag{6}$$

Variables	Resid_Energy$_{HH}$
ln(P_ Index_Energy)	-0.147**
	(0.0667)
$\ln\left(\frac{1}{HousStock}\right)$	-0.785***
	(0.0602)
Constant	2.877***
	(0.266)
Observations	39
R-squared	0.908

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Residual energy: short run relations

$$\Delta ln(Resid\_energy_{HH}) = \alpha_{Resid}+\beta_{Resid}\Delta ln(P\_Index\_Energy_{t-1})+\gamma_{Resid}\Delta ln\left(\frac{1}{HousStock}\right)+\delta_{Resid}u_{ResEnergy_{HHt-1}} \tag{7}$$

Variables	$\Delta ln(Resid\_energy_{HH})$
$\Delta ln(P\_Index\_Energy_{t-1})$	0.0582
	(0.0902)
$\Delta ln\left(\frac{1}{HousStock}\right)$	-0.116
	(0.770)
$u_{ResEnergy_{HHt-1}}$	-0.736***
	(0.156)
Constant	0.00822
	(0.0180)
Observations	38
R-squared	0.402

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Fuels

$$ln(GasShare_{HH}) = \alpha_{GasShare_{HH}} + \beta_{Gas_{HH}} ln\left(\frac{PGas_{HH}}{P\_Index\_Energy}\right) + \gamma_{Gas_{HH}} ln(GDP) \tag{8}$$

$$ln(CoalShare_{HH}) = \alpha_{CoalShare_{HH}} + \beta_{Coal_{HH}} trend \tag{9}$$

$$ln(PeatShare_{HH}) = \alpha_{PeatShare_{HH}} + \beta_{Peat_{HH}} trend \tag{10}$$

Fuels	ln(GasShare$_{HH}$)	ln(CoalShare$_{HH}$)	ln(PeatShare$_{HH}$)
Constant	-8.967***	1.153***	-0.760***
	(0.942)	(0.245)	(0.0898)
ln(GDP$_{HH}$)	0.693***		
	(0.0841)	-	-
ln(Fuel Price$_{HH}$)	-0.316*		
	(0.166)		
trend		-0.0767***	-0.0219***
		(0.00652)	(0.00313)
Observations	14	28	49
R-squared	0.946	0.842	0.510

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Due to structural breaks in the series and a limited number of observations for some of the variables, the data did not allow us to estimate cross price elasticities between the fuels.Results of the Chow test performed to investigate the presence of structural breaks are available upon request.

8.4.2 Industrial Sector

Electricity: long run relations

$$ln(ELEC_{IND}) = \alpha_{IND} + \beta_{IND} ln(P\_ELEC_{IND}) + \gamma_{IND} ln\left(\frac{1}{VA_{IND}}\right) \tag{11}$$

Variables	ln(ELEC$_{IND}$)
ln(P_ELEC$_{IND}$)	-0.275***
	(0.0610)
$\ln\left(\frac{1}{VA_{IND}}\right)$	-0.573***
	(0.0215)
Constant	2.226***
	(0.328)
Observations	26
R-squared	0.975

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Electricity: short run relations

$$\Delta ln(ELEC_{IND}) = \alpha_{IND} + \beta_{IND} + \Delta ln(ELEC_{INDt-1}) + \gamma_{IND}\Delta ln(P\_Elec_{IND}) + \delta_{IND}\Delta ln\left(\frac{1}{VA_{IND}}\right) + \lambda u_{Elec_{INDt-1}} \tag{12}$$

Variables	$\Delta ln(elec_{IND})$
$\Delta ln(ELEC_{INDt-1})$	0.626***
	(0.179)
$\Delta ln(P\_ELEC_{IND})$	-0.00804
	(0.0802)
$\Delta ln\left(\frac{1}{VA_{IND}}\right)$	-0.495***
	(0.171)
$u_{Elec_{INDt-1}}$	-0.877***
	(0.170)
Constant	-0.0227
	(0.0134)
Observations	26
R-squared	0.648

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Fuels

$$ln(Gas_{IND}) = \alpha_{Gas_{IND}} + \beta_{Gas_{IND}} ln(PGas_{IND}) \tag{13}$$

$$ln(LFO_{IND}) = \alpha_{LFO_{IND}} + \beta_{HFO_{IND}} ln(P\_LFO_{IND}) + \gamma_{LFO_{IND}} ln(VA_{IND}) \tag{14}$$

$$ln(HFO_{IND}) = \alpha_{HFO_{IND}} + \beta_{HFO_{IND}} ln(HFO_{IND(t-1)}) + \gamma_{HFO_{IND}} ln(P\_HFO_{IND}) \tag{15}$$

Fuels	Gas	LFO	HFO
Constant	8.518***	4.155***	2.009**
	(0.851)	(-0.444)	(0.776)
$\ln(\text{Fuel}_{IND_{t-1}})$	-	-	0.847***
			(0.111)
$\ln\left(\frac{1}{VA_{IND}}\right)$	-	-0.200***	-
		(0.0367)	
$\ln(\text{Fuel Price}_{IND})$	-0.191**	-0.1703	-0.191**
	(0.0760)	(-0.101)	(0.0760)
Observations	24	21	20
R-squared	0.229	0.682	0.784

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

8.4.3 Commercial and Services Sector

Electricity

$$ln(ELEC_{CST}) = \alpha_{CS} + \beta_{CS} ln(ELEC_{CS_{t-1}}) + \gamma_{CS} ln\left(\frac{1}{VA_{CS}}\right) + \delta_{CS} ln(P\_ELEC_{IND}) \tag{16}$$

Variables	$\ln(\mathrm{ELEC}_{CST})$
$\ln(\mathrm{ELEC}_{CS_{t-1}})$	0.855***
	(0.100)
$\ln(\mathrm{P\_ELEC}_{IND})$	-0.0233
	(0.0291)
$\ln\left(\frac{1}{VA_{CS}}\right)$	-0.233*
	(0.135)
Constant	-1.467
	(0.949)
Observations	33
R-squared	0.996

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Fuels

$$ln(Gas_{CS}) = \alpha_{Gas_{CS}} + \beta_{Gas_{CS}} ln(PGas_{CS}) + \gamma_{Gas_{CS}} ln\left(\frac{1}{VA_{CS}}\right) \tag{17}$$

$$ln(Oil_{CS}) = \alpha_{Oil_{CS}} + \beta_{Oil_{CS}} ln(POil_{CS}) + \gamma_{Oil_{CS}} ln\left(\frac{1}{VA_{CS}}\right) \tag{18}$$

Fuels	$\ln(\mathrm{Gas}_{CS})$	$\ln(\mathrm{Oil}_{CS})$
Constant	-5.762***	8.9728***
	(0.615)	(-1.1927)
$\ln\left(\frac{1}{VA_{CS}}\right)$	-0.519***	-0.1633***
	(0.0571)	(-0.0775)
$\ln(\mathrm{Fuel\ Price}_{CS})$	-0.157*	-0.6849***
	(0.0806)	(-0.1473)
Observations	13	27
R-squared	0.898	0.5024

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

8.4.4 Agricultural Sector

Electricity: long run relations

$$ln(Elec_{AGR}) = \alpha_{AGR} ln(P\_ELEC_{HH}) + \beta_{AGR} ln(VA_{AGR}) + \gamma_{AGR} trend \tag{19}$$

Variables	ln(Elec$_{AGR}$)
ln(P_ELEC$_{HH}$)	-0.375***
	(0.0808)
ln(VA$_{AGR}$)	0.714***
	(0.0723)
trend	0.0140***
	(0.00164)
Observations	20
R-squared	1.000

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Electricity: short run relations

$$\Delta ln(Elec_{AGR}) = \alpha_{AGR} \Delta ln(P\_ELEC_{HH}) + \beta_{AGR} \Delta ln(ELEC_{AGRt-1}) + \gamma_{AGR} \Delta ln(VA_{AGR}) + \delta_{AGR} u_{Elec_{AGRt-1}} \tag{20}$$

Variables	$\Delta ln(Elec_{AGR})$
$\Delta ln(ELEC_{AGRt-1})$	0.140
	(0.264)
$\Delta ln(P\_Elec_{HH})$	0.169
	(0.262)
$\Delta ln(GDP_{AGR})$	0.842
	(0.517)
$u_{Elec_{AGRt-1}}$	-0.614**
	(0.257)
Constant	0.00874
	(0.0126)
Observations	18
R-squared	0.331

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Oil

$$ln(Oil_{AGR}) = \alpha_{Oil\_AGR} + \beta_{Oil\_AGR} ln(P\_Oil_{HH}) + \gamma_{Oil\_AGR} * trend \tag{21}$$

Variables	$\ln(\mathrm{Oil}_{AGR})$
$\ln(\mathrm{P\_Oil}_{HH})$	-0.229**
	(0.0978)
trend	0.0132***
	(0.00326)
Constant	6.467***
	(0.545)
Observations	20
R-squared	0.493

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

8.4.5 Private transport sector

Car petrol

$$ln(Petrol_{CAR_P}) = \alpha_{CAR_P} ln(Income) + \beta_{CAR_P} ln(P\_Petrol_{CAR_P}) + \gamma_{CAR_P} EFFSTOCK \tag{22}$$

Variables	ln(Petrol$_{CAR_P}$)
EFFSTOCK	0.0872*
	(0.0437)
ln(P_Petrol$_{CAR_P}$)	-0.315***
	(0.0467)
ln(Income)	0.655***
	(0.164)
Constant	-0.898**
	(0.338)
Observations	19
R-squared	0.995

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Car diesel

$$ln(Diesel_{CAR_D}) = \alpha_{CAR_D} + \beta_{CAR_D} ln(P\_Diesel_{CAR_D}) + \gamma_{CAR_D} trend \tag{23}$$

Variables	$\ln(\text{Diesel}_{CAR_D})$
$\ln(\text{P\_Diesel}_{CAR_D})$	-0.443***
	(0.0937)
trend	0.0318***
	(0.00459)
Constant	7.772***
	(0.566)
Observations	28
R-squared	0.793

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

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