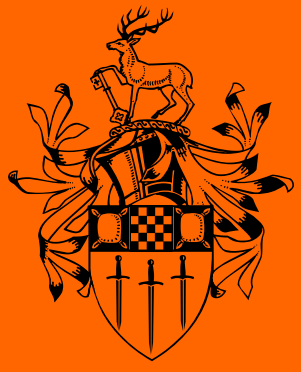
**SEEDS**
**S**urrey **E**nergy **E**conomics
**D**iscussion paper **S**eries

**S**URREY
**E**NERGY
**E**CONOMICS
**C**ENTRE

# An Application of the Double Hurdle Model to Petrol and Diesel Household Expenditures in Ireland

John Eakins

March 2014



SEEDS 145
ISSN 1749-8384

School of Economics
University of Surrey

The **Surrey Energy Economics Centre (SEEC)** consists of members of the School of Economics who work on energy economics, environmental economics and regulation. The School of Economics has a long-standing tradition of energy economics research from its early origins under the leadership of Professor Colin Robinson. This was consolidated in 1983 when the University established SEEC, with Colin as the Director; to study the economics of energy and energy markets.

SEEC undertakes original energy economics research and since being established it has conducted research across the whole spectrum of energy economics, including the international oil market, North Sea oil & gas, UK & international coal, gas privatisation & regulation, electricity privatisation & regulation, measurement of efficiency in energy industries, energy & development, energy demand modelling & forecasting, and energy & the environment.

SEEC research output includes SEEDS - Surrey Energy Economic Discussion paper Series and SEERS - Surrey Energy Economic Report Series (details at www.seec.surrey.ac.uk/Research/SEEDS.htm) as well as a range of other academic papers, books and monographs. SEEC also runs workshops and conferences that bring together academics and practitioners to explore and discuss the important energy issues of the day

SEEC also attracts a large proportion of the School's PhD students and oversees the MSc in Energy Economics & Policy. Many students have successfully completed their MSc and/or PhD in energy economics and gone on to very interesting and rewarding careers, both in academia and the energy industry.


Enquiries:

***Director of SEEC and Editor of SEEDS*:**
Lester C Hunt
**SEEC,**
School of Economics,
University of Surrey,
Guildford GU2 7XH,
UK.

Tel: +44 (0)1483 686956
Fax: +44 (0)1483 689548
Email: L.Hunt@surrey.ac.uk


**www.seec.surrey.ac.uk**

Surrey Energy Economics Centre (SEEC)
School of Economics
University of Surrey

SEEDS 145
ISSN 1749-8384

# AN APPLICATION OF THE DOUBLE HURDLE MODEL TO PETROL AND DIESEL HOUSEHOLD EXPENDITURES IN IRELAND

John Eakins

March 2014

## ABSTRACT

The objective of this study is to examine the determinants of household petrol and diesel expenditures using a large micro data set of Irish households. This research is timely given the switch in purchases from petrol cars to diesel cars arising out of changes in how vehicle registration tax and motor tax rates are calculated. The study finds that households living in urban areas, households that spend money on public transport and households that do not possess a car will spend less on both petrol and diesel. In contrast, households in possession of higher number of cars, households with more occupants working and households with higher level of household spending will spend more on petrol and diesel. The econometric methodology employed takes into account the fact that the dependent variable contains zero expenditures. Such an approach has never previously been applied to analyse Irish household transport use and provides interesting insights. In particular the effect that the explanatory variables have on participation in the market is quite different for petrol and diesel. For example, the model predicts a much larger increase in the probability that households will participate in the diesel market relative to the petrol market as income increases. This finding has implications for the design of policy toward reducing transport emissions as the Irish economy recovers and average household income increases.



*JEL Classifications:* C34, D12, Q41.

*Key Words:* Household Transport Demand, Petrol, Diesel, Double Hurdle Model, Income Elasticities.

# An Application of the Double Hurdle Model to Petrol and Diesel Household Expenditures in Ireland

**John Eakins**

**School of Economics, University College Cork and**

**Surrey Energy Economics Centre (SEEC), School of Economics, University of Surrey.**

**E-mail: j.eakins@ucc.ie**

## 1: INTRODUCTION

The objective of this study is to examine the determinants of household transport expenditures in Ireland using a large micro data set, the Irish Household Budget Survey. Two transport expenditures in particular are analysed, petrol and diesel, which are the primary transport fuels in Ireland. According to the Central Statistics Office (CSO), the total vehicle population in Ireland[1] in 2011 was equal to 2,419,523. Practically all of these vehicles used either petrol or diesel as their fuel with 58.5% of the total based on petrol and 40.9% based on diesel. Private cars comprise the majority of the total vehicle population in Ireland at 78% (or 1,886,421 vehicles) and within this category 71.2% were petrol based and 39.5% were diesel based. The CSO also produce figures on the total amount of kilometres travelled by Irish vehicles. In 2011 this value was equal to 41,681 million kilometres of which 20,091 million kilometres (or 48.2%) were driven by petrol vehicles and 21,341 million kilometres (or 51.2%) were driven by diesel vehicles. Private cars drove 31,638 million kilometres (75.9% of the total amount) of which 19,371 million kilometres (or 61.2%) were driven by petrol based private cars and 12,027 million kilometres (or 38%) were driven by diesel based private cars. The average distance driven by petrol private cars in 2011 was 14,430 kilometres while for diesel private cars it was 22,677 kilometres. These figures would support the commonly held view that petrol is the more conventional transport fuel for Irish households and is used for short to mid-range journeys while diesel is less common and more preferred for longer journeys as it is the more efficient fuel per kilometre travelled.

[1] Defined by the CSO as the number of vehicles continuously active throughout the reference year.

A further example of the importance of petrol and diesel use can be illustrated by looking at trends in energy use on a national basis. Between 1990 and 2012 Ireland's final energy consumption increased from 7,249 kilo tonnes of oil equivalent (ktoe) to 10,761ktoe. The biggest contributor to this increase came from the transport sector which increased from 2,019ktoe to 4,195ktoe, or 3.4% on average annually over the period. In 2012, the share of overall energy use attributable to the transport sector stood at 39%, the largest of all sectors in the economy. In fuel terms, oil based petroleum products make up the predominant fuel used by the country at 6,116ktoe or 56.8 per cent of the national share. The transport sector is heavily dependent on petroleum products with 4,107ktoe of its 4,195ktoe total coming from this source. In turn petrol and diesel consumption contributes 3,521ktoe combined, representing 83.9% of the transport sectors total and 32.7% of the overall national total. This reliance on carbon based petroleum products, especially in the transport sector, is currently adding to the difficulty in Ireland meeting its targets set out in a number of climate agreements both at global and European levels[2]. An analysis of spending patterns on these fuels could therefore provide some insights into the design of policy at national level.

This study uses micro data taken from the Irish Household Budget Survey (HBS) which is a survey of a representative random sample of all private households in the Republic of Ireland. The most recent survey took place in 2009/10. The main purpose of the HBS is to collect detailed information on the amount of money spent by households on a wide variety of commodities. This includes data on petrol and diesel expenditures. In addition to this, the HBS provides information on a wide range of household and dwelling characteristics such as location, age, gender, marital status, number of workers, etc. It also provides information on the number of motor vehicles possessed by the household and various income measures. All of these variables can be used to build a disaggregated model which captures the relationship between petrol/diesel expenditures and its determinants. In addition to the most recent survey carried out in 2009/10, data from the previous survey carried out in 2004/05 will also be examined. This will allow for a comparison to be made of the estimated relationship between two time periods but perhaps more interestingly two time periods which cover two different

[2] The latest projections from Irelands, Environmental Protection Agency indicate that Greenhouse Gas emissions are approximately 4.1 to 5.1 Mtonnes of $CO_2$ equivalent ($CO_2e$) above the 5 year Kyoto protocol limit. Under the EU Commission's 'Energy and Climate Package' Ireland is required to deliver a 20 per cent reduction in non-ETS Greenhouse Gas emissions by 2020 (relative to 2005 levels). The current projections indicate that total non-ETS emissions will be approximately 4.1 to 7.8 Mtonnes of $CO_2e$ above the 2020 target.

phases of the Irish economy, one when the Celtic tiger was at its height (2004/05) and the other (2009/10) which covers the period following the global slowdown and financial crisis which had a significant effect on the Irish economy in particular.

A final motivation for this study is to present an alternative econometric approach to analyse petrol and diesel expenditures. This approach takes in account the fact that there are a number of households who do not make any purchases of petrol or diesel, that is they have zero expenditures. The Tobit Model was the original model developed to analyse what are more commonly known as censored dependent variables. The Tobit model has some limitations however and a number of generalisations to the Tobit approach have been developed in the literature. One of these is Cragg's (1971) double hurdle model. It employs a methodology which models the household's decision to purchase a fuel item as separate participation and expenditure decisions. In particular, it postulates that individuals must pass two separate hurdles before they are observed with a positive level of expenditure. The first hurdle corresponds to factors affecting participation in the market for the good and the second to the level of expenditure on the good. A different latent variable is used to model each decision process. The double hurdle model has been applied to other commodities before but this study is its first application to petrol and diesel expenditures specifically.

The next section outlines previous research in this area. Section 3 describes the HBS data set in more detail while section 4 outlines Cragg's double hurdle model. Section 5 presents the econometric results and section 6 concludes.

## 2: PREVIOUS RESEARCH

The majority of international research on household petrol consumption has come from the United States and Canada which is not surprising given that gasoline (as it is called there) is such an important commodity to households in these countries. The main objective of the majority of these studies is to estimate price and income elasticities for gasoline consumption. Greening et al. (1995) use micro data and a translog model formulation to estimate short run demand for miles travelled and gasoline consumed. An important element of their analysis is the difference in price and income marginal effects among socio-demographic groups. In particular they find that subgroups defined based on occupation, life cycle stage and location respond to price and income changes in statistically different ways. Wadud et al. (2010) follow a similar approach and also find substantial heterogeneity in price and income

elasticities across different demographic and income groups. They find that a household‘s price and income elasticity depends on the number of vehicles owned, the number of wage earners and the location of the household.

Schmalensee and Stoker (1999), Yatchew and No (2001) and Manzan and Zerom (2010) in contrast estimate semiparametric econometric models which combine elements of both parametric and nonparametric regression techniques. This is done in order to develop a flexible model which allows for differing responses to price and income changes for different level of prices and incomes. For example Schmalensee and Stoker (1999) allow prices, income and age to have a nonparametric effect on demand while the other control variables remain linear. Yatchew and No (2001) and Manzan and Zerom (2010) build on Schmalensee and Stoker's approach and in particular the specification of the price variable, with Yatchew and No using price data from Canadian households (as opposed to Schmalensee and Stoker who used US household data) and Manzan and Zerom using vehicle-level data within US households to construct an alternative measure of the price of gasoline.

An alternative methodological approach to single equation estimation is to look at the problem is a more holistic manner and estimate a system of equations across a range of different fuels. This type of approach uses the two-stage budgeting procedure as its conceptual basis and is attractive as individual commodities can be analysed within a broad category. It also allows for the testing of certain demand restrictions as well as the estimation of cross-price effects. The AIDS model of Deaton and Muellbauer (1980) is one of the most widely applied models of this type. West and Williams (2004) estimate an AIDS model defined over gasoline, leisure, and a composite of all other goods. Nicol (2003) and Labandeira et al. (2006) apply the quadratic extension of the AIDS developed by Banks et al. (1997). Nicol (2003) estimates demand models for six household expenditure categories including food consumed at home, alcoholic beverages, clothing, gasoline, other automobile operation and public transportation while Labandeira et al. (2006) uses data from Spanish households to analyse the demand for electricity, gas, LPG and car fuels.

The research described above focuses on the determinants of just one household decision, that is, how much petrol to consume. As previously mentioned in the introduction, this study employs a methodology which models the household's decision to purchase a fuel item as separate participation and expenditure decisions. There have been a number of previous

studies which have attempted to model such household behaviour. Mannering and Winston (1985) is generally considered to be the pioneering article in this area. Using data from both a cross section and panel of U.S. households they estimate a discrete/continuous model of vehicle quantity, vehicle type and utilisation choice. Both vehicle quantity and vehicle type were estimated using the discrete model and utilisation choice was estimated using the continuous model. Many authors have since followed Mannering and Winston's (1985) approach by modelling the joint decisions of car ownership and car use using a variety of econometric methodologies. These include De Jong (1990), Bjorner (1999), Kayser (2000) Asensio et al. (2002) and Johansson-Stenman (2002).

The econometric methodology utilised by Kayser (2000), Asensio et al. (2002) and Johansson-Stenman (2002) most closely fits with the proposed econometric methodology in these study. They model the first stage decision of car ownership using a discrete model and the second stage using a continuous model. The second stage continuous model includes an extra term, estimated from the first stage discrete model, which corrects for the fact that some households with zero car ownership are not included in the second stage estimation. This procedure is referred to as a Heckman selection correction model (Heckman, 1979). Johansson-Stenman (2002) also estimate a version of Cragg's (1971) double hurdle model including a third decision to model the following: whether a household decides to have a car not, whether a household decides to drive the car or not given that they have a car and the final decision of how much to drive assuming that this is a driving distance which is larger than zero. The first two decisions are modelled using a probit model while the last decision is modelled using a truncated regression model. In estimating both the Cragg model and the Heckman model, Johansson-Stenman (2002) find some evidence to indicate that the Cragg model fits the data better, albeit evidence which the author admits not to be wholly conclusive.

Irish research on household petrol use is quite limited. Most research in the area tends to focus on car ownership (Nolan, 2003, 2010, Caulfield, 2012) or on the determinants of mode of transport to work (Commins and Nolan, 2010). Nolan (2003) appears to be the only Irish study which has carried out an analysis of household expenditures on petrol. Using cross-sectional micro-data from the 1994/1995 Irish HBS she estimates a Tobit model with petrol expenditures as the dependent variable and various characteristics of the household as independent variables. She finds that location, gender of the HOH, the presence of workers in

the home, the number of adults and children and household income are all significant explanatory factors. She calculates an income elasticity equal to 0.51 indicating that petrol use is a necessity. It should be noted however that Nolan (2003) confined her analysis to those households in possession of one car only which may limit the applicability of the results. It should also be noted that Nolan (2003) did not consider diesel in her analysis and thus this study will be the first to analyse that fuel from an Irish context.

**3: DATA**

The data set that will be used in this paper is a large anonymised micro data set of Irish households, the Household Budget Survey (HBS). The survey has been carried out by the Central Statistics Office (CSO) at regular intervals since 1951 and on a five yearly basis since 1994. The most recent results came out of a survey of households that took place in 2009/10. The main purpose of the survey "is to determine in detail the pattern of household expenditure in order to update the weighting basis of the Consumer Price Index" (CSO, 2013: 7). As well as recording information on household expenditures, the HBS also gives detailed information on all sources of household income as well as a wide range of household and house characteristics.

Table 1 displays summary statistics for petrol and diesel expenditures from both the 2004/05 and 2009/10 HBS. As can be seen from the table average weekly spending on petrol is much higher compared to average weekly spending on diesel. The gap is narrowing however with only a small increase in petrol expenditures between 2004/05 and 2009/10 compared to a much larger relative increase in diesel expenditures. This can be further illustrated by looking at the share of petrol and diesel purchases out of total household expenditures. In 2004/05 these values were 3% and 0.7% for petrol and diesel respectively. In 2009/10 the petrol share increased marginally to 3.3% while the diesel share increased more significantly to 1.2%. The values in the table are in fact slightly misleading at they incorporate price increases. Removing the effects of inflation in petrol and diesel prices between the 2004/05 and 2009/10 period, petrol expenditures actually decreased by 8.6% while diesel expenditures increased by 41.6%[3].

[3] Data used here is the national average price (€ per ltr.) of petrol and diesel and is taken from the Central Statistics Office website. Between 2004/05 and 2009/10 petrol increased from €1.03 to €1.20 or 16.6% while diesel increased from €1.01 to €1.14 or 13.6%. Prices for the periods were averaged across the months in which the HBS was taken.

**Table 1: Summary Statistics Petrol and Diesel Expenditures, 2004/05 and 2009/10 HBS**

| | Mean Expenditure, €/week | St. Dev. Expenditure, €/week | Min. Expenditure, €/week | Max. Expenditure, €/week |
|---|---|---|---|---|
| 2004/05 HBS (Sample Size = 6,884) | | | | |
| **Petrol** | 24.34 | 26.44 | 0 | 220.00 |
| **Diesel** | 6.30 | 17.66 | 0 | 278.10 |
| 2009/10 HBS (Sample Size = 5,891) | | | | |
| **Petrol** | 25.94 | 30.14 | 0 | 277.52 |
| **Diesel** | 10.13 | 24.40 | 0 | 267.50 |

Another aspect of the petrol and diesel expenditure data is the prevalence of zero expenditures. This could be due to the fact that certain householders cannot drive because of income constraints (i.e. cannot afford a car or cannot afford to purchase petrol/diesel) or because of other non-economic factors, such as age, an inability to drive a car or the fact that the household does not require the use of a car in their day to day lives. Another possibility is that the survey period is too short, that is householders that normally drive but don't during the survey period for one reason or another. It is difficult to gauge the number of households falling in this category but given that petrol/diesel are relatively frequent purchases one would expect the amount to be small[4].

Table 2 displays summary statistics for the positive petrol and diesel expenditures only. In 2004/05 approximately 70% of households had positive petrol expenditures and a little over 18% had positive diesel expenditures. The average amounts spent on the two fuels were interestingly about the same in this period with a slightly lower median diesel spend. As alluded to already, and further illustrated here, there appears to be a change in petrol and diesel purchases in the 2009/10 survey. Whilst spending on both fuels has increased (in nominal terms), purchases of diesel are now on average higher than petrol. The median spend on diesel is also higher. Furthermore, the proportion of households with positive diesel expenditures has increased between the two surveys while the corresponding proportion for petrol has decreased.

[4] The expenditure data is based on the maintenance of a detailed diary of household expenditure over a two-week period by the surveyed households.

**Table 2: Summary Statistics Positive Petrol and Diesel Expenditures only, 2004/05 and 2009/10 HBS**

| | Sample size (Number and % of total sample) | | Mean Expenditure, €/week | Median Expenditure, €/week | St. Dev. Expenditure, €/week |
|---|---|---|---|---|---|
| | N | % | | | |
| 2004/05 HBS (Sample Size = 6,884) | | | | | |
| **Petrol** | 4814 | 69.9 | 34.80 | 29.27 | 25.21 |
| **Diesel** | 1261 | 18.3 | 34.38 | 27.50 | 27.14 |
| 2009/10 HBS (Sample Size = 5,891) | | | | | |
| **Petrol** | 3773 | 64.0 | 40.50 | 33.00 | 28.78 |
| **Diesel** | 1356 | 23.0 | 44.02 | 35.00 | 33.09 |

The main reason for the shift from petrol to diesel cars over this period has been the introduction of a new system of taxing new private cars in Ireland in July 2008. Prior to July 2008, vehicle registration tax (VRT) and motor tax rates were based on engine size but now they are based on emissions per kilometre. One litre of diesel does produce greater emissions than one litre of petrol but as one litre of diesel covers a greater distance relative to petrol, emissions per kilometre travelled are lower for diesel cars (of equivalent size). Hennessy and Tol (2011a,b) and Rogan et al. (2011) both look at the effect of this policy change and find that it has resulted in a significant shift from petrol cars to diesel cars. Hennessy and Tol (2011b) predict that the overall market share of diesel cars will increase from 25% to 58% as a direct result of the tax reform. Rogan et al. (2011) similarly estimate that the tax change resulted in a doubling of the share of diesel cars in new private car sales from 27% in 2007 to 55% in the first year after the tax change.

Table 3 provides summary statistics for the socioeconomic characteristics of the household that will be used as explanatory variables in the petrol and diesel models. These variables include many of those previously used in the literature described in section 2. Location is broken down by urban/rural and region of which there are three, BMW (which comprises the Border, Midlands and Western regions), Mid-South (which comprises the South West, South East, Mid West and Mid East regions) and the greater Dublin region which comprises both urban and rural areas as the number of rural households in Dublin is quite small. Whether lifecycle effects are present will also be investigated. Nolan (2010) in her study of car ownership in Ireland, describes the influence of age as a lifecycle effect, that is, car ownership increasing with the age of the household head up to about the age of 50 and

**Table 3: Summary Statistics, 2004/05 and 2009/10 HBS**

| | 2004/05 HBS | | | | | 2009/10 HBS | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Std. Dev.** | **Min.** | **Max.** | | **Mean** | **Std. Dev.** | **Min.** | **Max.** |
| *Location:* | | | | | *Location:* | | | | |
| BMW Rural | 0.159 | 0.366 | 0 | 1 | BMW Rural | 0.142 | 0.350 | 0 | 1 |
| BMW Urban | 0.133 | 0.340 | 0 | 1 | BMW Urban | 0.125 | 0.330 | 0 | 1 |
| Mid-South Rural | 0.169 | 0.375 | 0 | 1 | Mid-South Rural | 0.170 | 0.376 | 0 | 1 |
| Mid-South Urban | 0.252 | 0.434 | 0 | 1 | Mid-South Urban | 0.257 | 0.437 | 0 | 1 |
| Dublin | 0.286 | 0.452 | 0 | 1 | Dublin | 0.306 | 0.461 | 0 | 1 |
| *Lifecycle of HOH:* | | | | | *Lifecycle of HOH:* | | | | |
| Single, Young (<44), No Children | 0.069 | 0.253 | 0 | 1 | Single, Young (<44), No Children | 0.169 | 0.375 | 0 | 1 |
| Single, Young (<44), Children | 0.033 | 0.177 | 0 | 1 | Single, Young (<44), Children | 0.110 | 0.313 | 0 | 1 |
| Single, Middle aged (45-64), No Children | 0.069 | 0.253 | 0 | 1 | Single, Middle aged (45-64), No Children | 0.109 | 0.312 | 0 | 1 |
| Single, Middle aged (45-64), Children | 0.012 | 0.108 | 0 | 1 | Single, Middle aged (45-64), Children | 0.023 | 0.149 | 0 | 1 |
| Single, Old (>65), No Children | 0.111 | 0.314 | 0 | 1 | Single, Old (>65), No Children | 0.084 | 0.277 | 0 | 1 |
| Single, Old (>65), Children | 0.001 | 0.024 | 0 | 1 | Single, Old (>65), Children | 0.001 | 0.029 | 0 | 1 |
| Married, Young (<44), No Children | 0.059 | 0.236 | 0 | 1 | Married, Young (<44), No Children | 0.044 | 0.205 | 0 | 1 |
| Married, Young (<44), Children | 0.248 | 0.432 | 0 | 1 | Married, Young (<44), Children | 0.191 | 0.393 | 0 | 1 |
| Married, Middle aged (45-64), No Children | 0.164 | 0.370 | 0 | 1 | Married, Middle aged (45-64), No Children | 0.110 | 0.313 | 0 | 1 |
| Married, Middle aged (45-64), Children | 0.138 | 0.345 | 0 | 1 | Married, Middle aged (45-64), Children | 0.086 | 0.280 | 0 | 1 |
| Married, Old (>65), No Children | 0.095 | 0.294 | 0 | 1 | Married, Old (>65), No Children | 0.072 | 0.259 | 0 | 1 |
| Married, Old (>65), Children | 0.003 | 0.052 | 0 | 1 | Married, Old (>65), Children | 0.002 | 0.041 | 0 | 1 |
| *Sex of HOH:* | | | | | *Sex of HOH:* | | | | |
| Male | 0.599 | 0.490 | 0 | 1 | Male | 0.523 | 0.500 | 0 | 1 |
| Female | 0.401 | 0.490 | 0 | 1 | Female | 0.477 | 0.500 | 0 | 1 |
| *Education of HOH:* | | | | | *Education of HOH:* | | | | |
| No education or Primary education | 0.238 | 0.426 | 0 | 1 | No education or Primary education | 0.114 | 0.318 | 0 | 1 |
| Secondary education | 0.481 | 0.500 | 0 | 1 | Secondary education | 0.319 | 0.466 | 0 | 1 |
| Third Level education | 0.281 | 0.449 | 0 | 1 | Third Level education | 0.468 | 0.499 | 0 | 1 |
| *Public Transport Dummy:* | | | | | *Public Transport Dummy:* | | | | |
| Zero Public Transport Spend | 0.725 | 0.446 | 0 | 1 | Zero Public Transport Spend | 0.729 | 0.445 | 0 | 1 |
| Positive Public Transport Spend | 0.275 | 0.446 | 0 | 1 | Positive Public Transport Spend | 0.271 | 0.445 | 0 | 1 |
| *Number of cars possessed:* | | | | | *Number of cars possessed:* | | | | |
| None | 0.182 | 0.386 | 0 | 1 | None | 0.184 | 0.387 | 0 | 1 |
| One | 0.457 | 0.498 | 0 | 1 | One | 0.506 | 0.500 | 0 | 1 |
| Two | 0.314 | 0.464 | 0 | 1 | Two | 0.274 | 0.446 | 0 | 1 |
| Three + | 0.048 | 0.214 | 0 | 1 | Three + | 0.035 | 0.185 | 0 | 1 |
| *Number of Workers:* | | | | | *Number of Workers:* | | | | |
| None | 0.245 | 0.430 | 0 | 1 | None | 0.329 | 0.470 | 0 | 1 |
| One | 0.340 | 0.474 | 0 | 1 | One | 0.348 | 0.476 | 0 | 1 |
| Two | 0.337 | 0.473 | 0 | 1 | Two | 0.284 | 0.451 | 0 | 1 |
| Three + | 0.078 | 0.268 | 0 | 1 | Three + | 0.039 | 0.193 | 0 | 1 |
| Number of Equivalent Adults | 2.23 | 0.97 | 1.00 | 7.60 | Number of Equivalent Adults | 1.97 | 0.81 | 0.30 | 6.50 |
| Total Household Expenditure (€/week) | 851.45 | 602.36 | 20.73 | 9174.63 | Total Household Expenditure (€/week) | 815.37 | 553.83 | 47.19 | 8245.17 |

thereafter decreasing. Manzan and Zerom (2010) also found some lifecycle effects to be present in their study. Twelve dummy variables are created based on marital status of the HOH (married or unmarried), age of the HOH (young, middle aged or old) and whether children are present or not (children defined as aged 17 or under)[5]. Dummy variables representing the gender and education level of the HOH will also be included.

Dummies representing whether a household possesses none, one, two or three or more cars and the purchase of public transport during the survey period are included to capture the effect that increasing levels of car ownership have on petrol and diesel use and to see if public transport use is a strong or weak substitute for petrol/diesel use. The number of workers present in the household is included as traveling to work by private car is the most common daily journey undertaken by households[6]. Finally two continuous variables are included, the first representing the number of equivalent adults[7] present in the household and the second representing income.

In this study data on total household expenditure is used instead of the data on income. There are a number of reasons for this. Firstly the CSO themselves, state that the income data that is collected in the HBS is not the primary source of data on income in Ireland. An alternative micro data survey, EU Survey on Income and Living Conditions (EU-SILC) also collected by the CSO, is recognised as the primary source of income data. Secondly, incomes, such as those of self-employed people, can fluctuate over time whereas total household expenditure can be seen as measuring expected or average levels of income over a long period and thus provides a better long run gauge of incomes. As it is a cross sectional survey, the HBS does not provide any price data and so price elasticities cannot be calculated. An appropriate examination of price effects would only be possible if repeated cross sections of households were surveyed and price changes were tracked. As the analysis is the study looks at each HBS separately, the assumption is that each household faces the same price for each fuel. Lastly as the HBS data is collected over different times of the year consideration needs to be

[5] In the final specification, the 'single old children' category of households is merged with the 'single middle aged children' category and the 'married old children' category of households is merged with the 'single middle aged children' category due to small number of observations.
[6] The National Travel Survey carried out by the Central Statistics Office in 2009 found that 25% of daily journeys undertaken are work related travel.
[7] Where an equivalent adult is defined as Head of Household = 1, Other Adults 14+ in household = 0.7, Children < 14 = 0.5

taken for the potential seasonality in the expenditure data. It is particularly important to deseasonalise the data when additional variables representing household characteristics are being included in the model so that a true measure of their effect is captured rather than a possible hidden seasonal effect. Both petrol and diesel expenditures and total household expenditure are deseasonalised by removing the average seasonal effect of each quarter from the expenditure data using a simple procedure of regressing the expenditure variable on the quarter variable and calculating the difference between the actual values and fitted values.

## 4: ECONOMETRIC METHODOLOGY

The presence of zero expenditures in the dependent variable, seen in table 2 for petrol and diesel, poses difficulties when analysing micro-data. Using ordinary least squares regression results in biased results of the parameter estimates because the estimated regression line simply fits the scatter of points and does not take into account the fact that the data is limited at one end. The bias would be especially severe when the dependent variable is zero for a substantial proportion of the population. There are three reasons given in the literature for zero observations (see Newman et al, 2001); corner solutions, non-participation in the market or purchase infrequency. Corner solutions specify that a household chooses not to purchase a product at existing prices and income. Non-participation in the market occurs if a household chooses not to purchase a product due to reasons that are independent of prices and income. Purchase infrequency normally applies to durable goods whose purchasing cycle may be longer than the survey period.

Econometric models where the dependent variable of interest has zero observations use a latent variable representation of the dependent, that is, each household has an unobserved or latent expenditure which for some households is known and given by the actual expenditures and for some households is unknown and is denoted by zero (for example). Econometric models where the dependent variable is incompletely observed are known as censored models[8]. The Tobit Model developed by James Tobin (Tobin, 1958) was the original model developed to analyse censored dependent variables. In the Tobit model censoring is assumed

[8] There is also another family of models where the dependent variable is incompletely observed known as truncated models. A censored model arises where information on the dependent variable is lost but not data on the independent variables. Household survey data where information on the level of expenditures for certain commodities is incomplete (i.e. zero) but information on household characteristics and income is known, would be an example of censored data. Truncated data occurs where only a sub-sample of the population is surveyed e.g. over 65's only, and so observations on both the dependent and independent variables are lost for the rest of the population.

to represent a standard corner solution. This in itself is a restrictive assumption especially for household expenditure items. For example in the case of petrol and diesel a household may have the means available to them to purchase these items but do not do so because of other factors such as age, inability to drive or location. A further limitation of the Tobit model is that it assumes the same variables affect the probability of a non-zero observation (the participation decision) as well as the level of a positive observation (the expenditure decision) and moreover with the same sign. It may be more reasonable to allow the size and nature of the factors that affect the two decisions to be different.

As a result of these shortcomings, a number of generalisations to the Tobit model have been developed. One generalisation which is popular in the literature is the double hurdle model, originally formulated by Cragg (1971)[9]. The model postulates that individuals must pass two separate hurdles before they are observed with a positive level of expenditure. The first hurdle corresponds to factors affecting participation in the market for the good and the second to the level of expenditure on the good. A different latent variable is used to model each decision process, with a probit determining the participation process and a Tobit determining the expenditure level.

The popularity of the double hurdle model in empirical work can be traced back to the work of Jones (1989) and Pudney (1989) who are commonly associated with developing the econometric specification of the model as well as formally integrating it into consumer choice theory. A number of applications did precede these studies including work by Atkinson et al. (1984) and Blundell et al. (1987). The double hurdle model can be specified as follows (Blundell and Meghir, 1987, Newman et al, 2003),

$$y^*_{i1} = w_i\alpha + u_i \qquad \text{Participation Decision} \qquad (1a)$$

$$y^*_{i2} = x_i\beta + v_i \qquad \text{Expenditure Decision} \qquad (1b)$$

$$y_i = x_i\beta + v_i \qquad \text{if } y^*_{i1} > 0 \text{ and } y^*_{i2} > 0 \qquad (1c)$$

[9] Cragg (1971) put forward a number of two-part extensions to the Tobit model in his original research. Unfortunately this has created a situation where different Cragg models are used in the literature. The Cragg model used by Johansson-Stenman (2002) for example is different to the one that will be utilised here. The double hurdle specification is however the most popular in the literature and is one (as mentioned in the text) that is grounded in consumer choice theory. For reference, equations (5) and (6) in the Cragg article refer to the double-hurdle model discussed here.

$y_i = 0$ otherwise (1d)

where $y^*_{i1}$ is a latent endogenous variable representing an individual or households participation decision, $y^*_{i2}$ is a latent endogenous variable representing an individual or households expenditure decision, $y_i$ is the observed dependent variable (petrol/diesel expenditures), $w_i$ is a set of individual characteristics explaining the participation decision, $x_i$ is variables explaining the expenditure decision and $u_i$ and $v_i$ are independent, homoscedastic, normally distributed error terms.

The double hurdle model is estimated using maximum likelihood techniques with the log likelihood given as follows,

$$LL_{DoubleHurdle} = \sum_{0} ln\left[1 - \Phi(w_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma_i}\right)\right] + \sum_{+} ln\left[\Phi(w_i\alpha)\frac{1}{\sigma_i}\phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right)\right] \quad (2)$$

It is worth noting that the standard Tobit model is a nested version of the Cragg model when $w_i\alpha$ is equal to 1 (i.e. the log likelihood of the Tobit model equals that of the Cragg model when there is no participation equation). Thus the Cragg model is effectively a Tobit model that allows for estimates of the participation equation to be made separately from the expenditure equation.

The double hurdle model is particularly popular for analysing tobacco and alcohol household expenditures mainly due to the early work of Atkinson et al. (1984), Pudney (1989) and Jones (1989) who advocated the use of double-hurdle models in cross-section studies of smoking using UK household survey data. The studies on tobacco and alcohol household expenditures following from this early work include Jones (1992), Garcia and Labeaga (1996) and Aristei and Pieroni (2008) on UK, Spanish and Italian household tobacco expenditures respectively and Blaylock and Blisard (1993) and Yen and Jensen (1996) on US household alcohol expenditures. The double hurdle has also been applied to analyse other household expenditures including lottery expenditures (Humphreys et al. 2010 and Crowley et al. 2012), meat expenditures and expenditure on prepared meals for Irish households (Newman et al., 2001 and 2003), food expenditure away from the home for Spanish households (Mutlu and Garcia, 2006) and even US household consumption of cheese (Yen and Jones, 1997). Finally

there are a number of non-food or non-drink applications including Carroll et al. (2005) who studied the determinants of charitable donations by Irish households. The application of the double hurdle model to Irish petrol and diesel expenditures in this paper thus represents a significant addition to the existing literature in the area.

The double hurdle model can be compared with Heckman's sample selection models on the basis of the assumption of dominance. This relates to whether one considers the possibility of zero observations in the expenditure decision or not. If one assumes that a zero observation is due to non-participation solely, then the expenditure decision includes only non-zero observations. This is known as first hurdle dominance. Under this assumption the Heckman model should be used. In contrast if one assumes that a zero observation could be due to either non-participation or participation but non-expenditure (i.e. no first hurdle dominance) then Cragg's double hurdle model is the most appropriate to use.

In effect the Cragg model can be thought of as a flexible version of both the Tobit and Heckman model. The Tobit model assumes that the participation and expenditure decision can be modelled as one equation whereas the Cragg model relaxes this assumption and models both decision separately. In the Heckman model, zero observations arise due to non-participation solely whereas the Cragg model relaxes this assumption and allows zero observations to arise in both the participation hurdle and expenditure hurdle. The Cragg model therefore features both the selection mechanism of the Heckman model (which is not a feature of the Tobit model) and the censoring mechanism of the Tobit model (which is not a feature of the Heckman model).

To assess the impact of the regressors on the dependent variable, marginal effects can be calculated using the maximum likelihood results obtained from the double hurdle model. Three different marginal effects can be calculated based on three different definitions of the expected value of the dependent variable $y_i$. Of most interest is the overall effect on the dependent variable, that is, the expected value of $y_i$ for values of the explanatory variables, $x$. In the Tobit model and its various generalisations, this is more commonly known as the unconditional expectation (or unconditional mean) of $y_i$ and is written as $E[y_i \mid x]$. The unconditional expectation can be decomposed into two parts, the conditional expectation, $E[y_i \mid x, y_i > 0]$ which is the expected value of $y_i$ for values of the explanatory variables, $x$,

conditional of $y_i > 0$ and the probability of a positive value of $y_i$ for values of the explanatory variables, $x$, $P[y_i > 0 \mid x]$.

The decomposition of the unconditional expectation into the probability of participation and the conditional expectation is based on the work by McDonald and Moffitt (1980) in their decomposition of the unconditional mean of the dependent variable in the Tobit model and can be summarised by the following equation:

$$E[y_i \mid x] = P[y_i > 0 \mid x] * E[y_i \mid x, y_i > 0] \tag{3}$$

In the double hurdle model the probability of participation and the level of expenditure conditional on participation are (Yen and Su, 1995, Mutlu and Garcia, 2006):

$$P[y_i > 0 \mid x] = \Phi(w_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma_i}\right) \tag{4}$$

$$E[y_i \mid y_i > 0, x] = x_i\beta + \sigma_i\left(\frac{\phi\left(\frac{x_i\beta}{\sigma_i}\right)}{\Phi\left(\frac{x_i\beta}{\sigma_i}\right)}\right) \tag{5}$$

Marginal effects can be calculated by differentiating each of the above equations with respect to each explanatory variable. These equations are given by (Yen and Su, 1995, Mutlu and Garcia, 2006):

$$\frac{\partial P[y_i > 0 \mid x]}{\partial x_j} = \alpha_j\phi(w_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma_i}\right) + \beta_j\Phi(w_i\alpha)\phi\left(\frac{x_i\beta}{\sigma_i}\right) \tag{6}$$

$$\frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} = \beta_j - \beta_j * \left[\frac{\phi\left(\frac{x_i\beta}{\sigma_i}\right)}{\Phi\left(\frac{x_i\beta}{\sigma_i}\right)}\right] * \left[\frac{x_i\beta}{\sigma_i} + \left(\frac{\phi\left(\frac{x_i\beta}{\sigma_i}\right)}{\Phi\left(\frac{x_i\beta}{\sigma_i}\right)}\right)\right] \tag{7}$$

where $\alpha_j$ and $\beta_j$ are the coefficients on the explanatory variable $x_j$ from the participation and expenditure equations respectively. For the discrete explanatory variables, the estimated marginal effects represent the absolute change in the probability of a positive value, the conditional expectation and the unconditional expectation when the value of the variable shifts from zero to one, holding all the other variables constant.

The marginal effect for the unconditional level of expenditure can be derived by applying the product rule of differentiation to equation (3)[10]:

$$\frac{\partial E[y_i \mid x]}{\partial x_j} = \frac{\partial P[y_i > 0 \mid x]}{\partial x_j} * E[y_i \mid y_i > 0, x] + \frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} * P[y_i > 0 \mid x] \tag{8}$$

that is the marginal effect of the unconditional expectation equals the marginal effect of the probability of a positive value times the conditional expectation plus the marginal effect of the conditional expectation times the probability of a positive value.

For the continuous explanatory variables such as total household expenditure, the marginal effects can be used to calculate elasticities for the probability of a positive expenditure ($e_j^P$), the conditional level of expenditure ($e_j^{CC}$) and the unconditional level of expenditure ($e_j$) i.e. the total effect on $y_i$, as follows:

$$e_j^P = \frac{\partial P[y_i > 0 \mid x]}{\partial x_j} * \frac{x_j}{P[y_i > 0 \mid x]} \tag{9}$$

$$e_j^{CC} = \frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} * \frac{x_j}{E[y_i \mid y_i > 0, x]} \tag{10}$$

$$e_j = \frac{\partial E[y_i \mid x]}{\partial x_j} * \frac{x_j}{E[y_i \mid x]} = e_j^P + e_j^{CC} \tag{11}$$

[10] The derivative of the product f(X) = g(X)*h(X) is f'(X) = g'(X)*h(X) + g(X)*h'(X)

where the last equation states that the elasticity on the unconditional level of expenditure is equal to the addition of the elasticity of the probability of participation and the elasticity of the conditional level of expenditure. This holds because of equations (3) and (8)[11]. For the discrete explanatory variables, $e_j^P$, $e_j^{CC}$, and $e_j$ represent the proportional change in the probability of a positive value, the conditional expectation and the unconditional expectation when the value of the variable shifts from zero to one, holding all the other variables constant.

The model can be modified to allow for heteroscedasticity by specifying the variance of the errors as a function of a set of continuous variables (Newman et al, 2003 and Aristei and Pieroni, 2008) as follows:

$$\sigma_i = \exp(z_i h) \qquad (12)$$

where $z_i$ represents the continuous variables in $x_i$, the set of variables explaining the expenditure decision. The exponential specification is chosen as it imposes the desirable property that the standard deviation $\sigma_i$ be strictly positive (Yen and Su, 1995).

## 5: ECONOMETRIC RESULTS

### 5.1 Econometric Specification and Choice of Model

Previous research has highlighted a particular difficulty in specifying and estimating the double hurdle model. According to Pudney (1989), the original research by Cragg did not ground the double hurdle model within any formal choice theory. Thus no guidance was given on what variables should be included in the participation and expenditure equations. In

[11] Multiplying equation (8) by $\frac{x_j}{E[y_i \mid x]}$ gives

$$\frac{\partial E[y_i \mid x]}{\partial x_j} * \frac{x_j}{E[y_i \mid x]} = \frac{\partial P[y_i > 0 \mid x]}{\partial x_j} * E[y_i \mid y_i > 0, x] * \frac{x_j}{E[y_i \mid x]} + \frac{\partial E[y_i \mid y_i > 0, x]}{\partial x_j} * P[y_i > 0 \mid x] * \frac{x_j}{E[y_i \mid x]}.$$

Using equation (3), $\frac{E[y_i \mid y_i > 0, x]}{E[y_i \mid x]} = \frac{1}{P[y_i > 0 \mid x]}$ in the first addend and $\frac{P[y_i > 0 \mid x]}{E[y_i \mid x]} = \frac{1}{E[y_i \mid y_i > 0, x]}$ in the second addend.

addition, Newman et al. (2003) suggest that the inclusion of the same set of regressors in each hurdle can make parameter identification difficult and exclusion restrictions must be imposed. Pudney (1989) interprets the first stage participation hurdle as arising from "social, psychological or ethical distinction, and is unconnected with the levels of prices and income" (1989: 160). Under this interpretation, income (or total household expenditure) can be excluded from the participation equation and this has been the approach adopted by subsequent researchers (Newman et al., 2003, Aristei and Pieroni, 2008). This line of reasoning also relates back to the reasons for presence of zero observations in household expenditure surveys given previously. The first reason is the standard corner solution which forms the basis of the Tobit model. The second reason is that households do not participate in the market due to reasons that are independent of prices and income. This in effect describes the first hurdle of the double hurdle model and would suggest that if an exclusion restriction were to be imposed, the logical approach would be to drop total household expenditure from the first hurdle. Total household expenditure is included in the second hurdle as this represents the Tobit part of the double hurdle model.

In order to assess whether a normal double hurdle model or a heteroscedastic version is to be estimated a likelihood ratio test can be applied as one version (the homoscedastic double hurdle model) nests the other (the heteroscedastic double hurdle model). The likelihood ratio test statistic is computed as follows:

$$LR = -2*(\ln L_{DH} - \ln L_{HETDH}) \sim \chi^2_k \qquad (13)$$

where

$\ln L_{DH}$ = log likelihood of the homoscedastic double hurdle model model (the restricted model)

$\ln L_{HETDH}$ = log likelihood of the heteroscedastic double hurdle model (the unrestricted model)

$\chi^2_k$ = chi-squared distribution with k degrees of freedom, k = the number of variables in the heteroscedastic equation i.e. the number of coefficients that are assumed to be zero under the restricted model. In the petrol model the number of equivalent adults and total household

expenditure are included in the heteroscedastic equation while in the diesel model only total household expenditure is included[12].

Table 4 presents the results of applying this likelihood ratio test to the 2004/05 and 2009/10 HBS data. In all cases, the heteroscedastic Double Hurdle model is favoured over the homoscedastic version. Thus the results that follow are based on the heteroscedastic Double Hurdle model in all cases. They are given in two parts. Firstly maximum likelihood estimates for the 2009/10 data set are presented and discussed. Secondly, in order to assess the impact of the explanatory variables on the dependent variable, elasticities are presented. For the binary explanatory variables in the model, the elasticities are based on the discrete change in the variable and its proportionate effect on the dependent variable while for the continuous explanatory variables in the model, the elasticities are based on the proportionate change in the variable and its proportionate effect on the dependent variable. This section will present results from both the 2004/05 and 2009/10 HBS data in order to assess if there has been any significant change in the impact of the explanatory variables on the dependent variable.

**Table 4: Likelihood Ratio tests Homoscedastic Double Hurdle model versus Heteroscedastic Double Hurdle model.**

| | **Petrol** | | **Diesel** | |
|---|---|---|---|---|
| | **2004/05** | **2009/10** | **2004/05** | **2009/10** |
| Restricted ($H_0$): Double Hurdle Log-likelihood | -23375.41 | -19899.64 | -8179.82 | -9022.02 |
| Unrestricted ($H_1$): Hetero Double Hurdle Log-likelihood | -23654.02 | -19735.82 | -8195.11 | -9017.22 |
| Test statistic: (-2*(Restricted-Unrestricted)) | 557.22 | 327.62 | 30.59 | 9.60 |
| Critical value 5% | 5.99 | 5.99 | 3.84 | 3.84 |
| P-value | 0.000 | 0.000 | 0.000 | 0.00 |

[12] In preliminary estimations of the heteroscedastic double hurdle diesel model, the number of equivalent adults was insignificant in the heteroscedastic equation and on the basis of a likelihood ratio test removing it was the favoured option.

### 5.2 Maximum Likelihood (ML) Heteroscedastic Double Hurdle results 2009/10 HBS

Before analysing the results in table 5 it is worth reiterating what exactly they represent. The values in table 5 correspond to $\alpha$ and $\beta$ in equations (1a) and (1b), that is, the vector of coefficients that illustrate the effect on the participation and expenditure decisions respectively. The magnitude of the ML estimates in the double hurdle model cannot be interpreted in the same fashion as say OLS estimates as they are based on latent expenditures. However the sign of the estimates can be interpreted and can present a clearer intuitive interpretation of the factors determining household energy expenditures over single equation estimation models such as the Tobit.

Looking at the binary variables first we see that location effects are present in both the petrol and diesel models. These effects could be due to the quality and quantity of infrastructure in these regions. For example in the diesel model, households in the BMW rural region spend more on average relative to all other households which would link in with the fact that this region has the poorest quality and lowest quantity of infrastructure in relative terms. Similar results are found in the petrol model with households in the mid-south urban and Dublin regions spending less on average relative to households in the BMW rural region. However there are positive participation effects for these households. This highlights one of the advantages of using a double hurdle model, that is, it allows for the participation and expenditure effects to be different for the same variable. It suggests in this case that households in the mid-south urban and Dublin regions are more likely to participate in the market for petrol relative to households in the BMW rural region. Again assuming that the mid-south urban and Dublin regions have the best quality and largest quantity of infrastructure in relative terms this result is plausible from an access to the market point of view.

Lifecycle effects do not appear on a consistent basis in either model. In the petrol model, households with a married HOH aged under 44 and no children spend less on petrol relative to a single HOH aged under 44 and no children while in the diesel model, households with a single HOH, aged between 45 and 64 and no children spend more on diesel relative to the single HOH aged under 44 and no children. Male HOH's spend more on petrol relative to female HOH's but female HOH's are more likely to participate in the market for petrol. This

**Table 5: Heteroscedastic Double Hurdle Maximum Likelihood estimates – Petrol and Diesel Expenditures, 2009/10 HBS**

| | Petrol | | | Diesel | | |
|---|---|---|---|---|---|---|
| | **Participation** | **Expenditure** | **Hetero** | **Participation** | **Expenditure** | **Hetero** |
| *Location:* | | | | | | |
| BMW Rural (ref) | | | | | | |
| BMW Urban | 0.022 | -2.831 | | 0.082 | -19.340*** | |
| Mid-South Rural | -0.045 | 1.098 | | 0.168 | -12.327*** | |
| Mid-South Urban | 0.440*** | -7.054*** | | -0.157 | -34.913*** | |
| Dublin | 0.430*** | -11.051*** | | 0.107 | -55.788*** | |
| *Lifecycle of HOH:* | | | | | | |
| Single, <44, No Children (ref) | | | | | | |
| Single, <44, Children | 0.233 | 0.615 | | 0.099 | -7.406 | |
| Single, 45-64, No Children | 0.165 | -2.144 | | -0.429 | 17.002*** | |
| Single, >45, Children | 0.129 | 2.153 | | -0.392 | -5.106 | |
| Single, >65, No Children | 0.300 | -2.918 | | -0.126 | 6.552 | |
| Married, <44, No Children | 0.417 | -4.858* | | 0.643 | 2.918 | |
| Married, <44, Children | 0.142 | -2.218 | | 3.922 | -4.989 | |
| Married, 45-64, No Children | 0.043 | -2.280 | | 0.900 | 5.600 | |
| Married, >45, Children | 0.177 | 0.127 | | 5.531 | 1.342 | |
| Married, >65, No Children | 0.293 | -1.275 | | 1.251 | -3.096 | |
| *Sex of HOH:* | | | | | | |
| Male | -0.177** | 2.153** | | 5.730 | -6.022* | |
| Female (ref) | | | | | | |
| *Education of HOH:* | | | | | | |
| No education or Primary education (ref) | | | | | | |
| Secondary education | -0.032 | -0.624 | | -0.413 | 2.681 | |
| Third Level education | 0.008 | -1.594 | | 0.053 | -0.584 | |
| *Public Transport Dummy:* | | | | | | |
| Zero Public Transport Spend (ref) | | | | | | |
| Positive Public Transport Spend | 0.325*** | -6.107*** | | -0.121 | -17.802*** | |
| *Number of cars possessed:* | | | | | | |
| None | -1.675*** | -22.741*** | | -0.664** | -7.886* | |
| One (ref) | | | | | | |
| Two | 0.365*** | 10.959*** | | 0.522 | -4.778 | |
| Three + | 0.700*** | 23.214*** | | 5.774 | 1.864 | |
| *Number of Workers:* | | | | | | |
| None (ref) | | | | | | |
| One | -0.054 | 2.525* | | 0.486* | 7.175* | |
| Two | -0.016 | 2.794 | | 0.380 | 11.835*** | |
| Three + | 0.129 | 7.633** | | -0.194 | 11.743 | |
| | | | | | | |
| Number of Equivalent Adults | 0.007 | -1.511 | 0.078*** | 0.706*** | 5.229** | |
| Natural Log of Total Household Expenditure | | 14.457*** | 0.402*** | | 27.592*** | 0.124*** |
| Wald $\chi 2$ statistic | | 808.73*** | | | 388.11*** | |

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

could possibly reflect a general trend toward increased participation from female drivers in an overall context as most males already participate. In the diesel model, households with a male HOH spend less on diesel relative to households with a female HOH's. This result runs somewhat counter intuitive to what was expected but it could be the case that a female HOH also has other working adults in the household while a household with a male HOH may only possibly have one working adult i.e. themselves.

Those households with positive public transport expenditures spend less on petrol and diesel relative to those households with zero public transport expenditures. In the petrol model participation effects are positive. This can be interpreted in much the same way as the urban location effects previously discussed, that is, those households with access to public transport also have greater access to private transportation. Not surprisingly, the number of cars possessed by a household has significant effects on both the petrol and diesel models. The effects are present for each variable in the petrol model with negative participation and expenditure effects for households possessing zero cars and positive participation and expenditure effects for households possessing two or more cars. In the diesel model only the possession of no cars variable exhibits significance with negative participation and expenditure effects. Thus being in possession of more than one car has a greater influence on petrol purchases than diesel purchases presumably because households will have at most of one diesel car in their possession.

The more working adults in the household the more is spent on both petrol and diesel highlighting the important role than working status plays on transport costs. Looking specifically at a variable which represents the size of the household we see significant and positive participation and expenditure effects in the diesel model but insignificant results in the petrol model. This may reflect a preference of bigger families toward the purchase of a diesel car, whether that be the first or second car. Finally total household expenditure is significant and positively signed in both models.

### 5.3 Estimated Marginal Effects 2004/05 and 2009/10 HBS

As previously indicated the magnitude of the ML estimates in the double hurdle model cannot be interpreted in a sensible manner so marginal effects need to be estimated. Tables 6 and 7 present the estimated elasticities based on results derived from a heteroscedastic double

hurdle using data from the 2004/05 and 2009/10 HBS. These elasticities were calculated using equations (9)-(11) described in section 4 with the additional aspect of assuming a heteroscedastic error term defined by equation (12). Table 6 presents results for petrol expenditure data and table 7 present results for diesel expenditure data.

Concentrating on the 2009/10 petrol results firstly, it can be seen that possessing two or more cars, increases in total household expenditure and increasing numbers of workers in the household all have positive effects on overall petrol expenditures. In contrast, possessing zero cars, living in Dublin or urban areas of the mid-south region and having a positive spend on public transport all have negative effects on overall petrol expenditures. Male HOH's spend more on petrol relative to females but this is only significant for the conditional level of $y_i$ while lifestyle and education effects are generally non-existent. The results here replicate much of what has been previously found in the literature on petrol expenditures. The fact that households located in urban areas consume less petrol on average has been found previously by Schmalensee and Stoker (1999), Kayser (2000, Yatchew and No (2001), Johansson-Stenman (2002) and Manzan and Zerom (2010). Asensio et al. (2002) find that petrol expenditures increase with the number of employed members in the household and almost all previous studies have found a positive and significant income effect. In relation to the insignificant variables, Kayser (2000) also found education to have no influence but on the other hand Kayser (2000) and Johansson-Stenman (2002) did find gender effects to be present in their respective studies while Manzan and Zerom (2010) did find lifestyle effects.

In terms of the contribution to the overall effect on petrol expenditures, only the elasticity on the conditional expectation is significant for the Mid-South Urban variable while both the elasticity on the probability of a positive value and the elasticity on the conditional expectation is significant for the Dublin variable. For both variables the conditional expectation elasticity is larger suggesting that the effect is greater for those households with positive petrol expenditures in these regions. A similar line of reasoning can be applied to the public transport variable. That is, public transport does not significantly affect a household's likelihood of purchasing petrol but does reduce levels of spending on the good. However the negative public transport effect is not as great as living in urban areas which suggests that other forms of transport such as walking and cycling possibly play a part in reducing petrol purchases in urban areas. In contrast, the elasticities for the probability of a positive value on

**Table 6: Estimated Elasticities – Petrol Expenditures, 2004/05 and 2009/10 HBS**

| | 2004/05 | | | 2009/10 | | |
|---|---|---|---|---|---|---|
| | $P[y_i > 0 \mid x]$ | $E[y_i \mid x, y_i > 0]$ | E[yi \| x] | $P[y_i > 0 \mid x]$ | $E[y_i \mid x, y_i > 0]$ | E[yi \| x] |
| *Location:* | | | | | | |
| BMW Rural (ref) | | | | | | |
| BMW Urban | 0.032 | -0.047 | -0.015 | -0.057 | -0.053 | -0.110 |
| Mid-South Rural | 0.057 | -0.026 | 0.031 | 0.006 | 0.021 | 0.027 |
| Mid-South Urban | 0.062 | -0.080*** | -0.019 | -0.012 | -0.132*** | -0.144** |
| Dublin | 0.004 | -0.192*** | -0.188*** | -0.112** | -0.208*** | -0.319*** |
| *Lifecycle of HOH:* | | | | | | |
| Single, <44, No Children (ref) | | | | | | |
| Single, <44, Children | 0.025 | -0.041 | -0.016 | 0.098** | 0.012 | 0.109 |
| Single, 45-64, No Children | 0.062 | -0.016 | 0.046 | 0.012 | -0.040 | -0.028 |
| Single, >45, Children | 0.065 | 0.052 | 0.117 | 0.093 | 0.041 | 0.134 |
| Single, >65, No Children | 0.019 | -0.127*** | -0.108 | 0.039 | -0.055 | -0.016 |
| Married, <44, No Children | 0.183*** | 0.067 | 0.251*** | 0.018 | -0.091* | -0.074 |
| Married, <44, Children | 0.139** | 0.000 | 0.140 | 0.002 | -0.041 | -0.039 |
| Married, 45-64, No Children | 0.158*** | 0.032 | 0.190*** | -0.036 | -0.043 | -0.079 |
| Married, >45, Children | 0.095 | 0.029 | 0.125 | 0.067 | 0.002 | 0.070 |
| Married, >65, No Children | 0.037 | -0.071 | -0.034 | 0.073 | -0.024 | 0.049 |
| *Sex of HOH:* | | | | | | |
| Male | -0.028 | 0.004 | -0.024 | -0.022 | 0.041** | 0.019 |
| Female (ref) | | | | | | |
| *Education of HOH:* | | | | | | |
| No education or Primary education (ref) | | | | | | |
| Secondary education | -0.087** | -0.041* | -0.128*** | -0.027 | -0.012 | -0.038 |
| Third Level education | -0.043 | -0.104*** | -0.147** | -0.032 | -0.030 | -0.062 |
| *Public Transport Dummy:* | | | | | | |
| Zero Public Transport Spend (ref) | | | | | | |
| Positive Public Transport Spend | -0.006 | -0.066*** | -0.071 | -0.027 | -0.115*** | -0.142*** |
| *Number of cars possessed:* | | | | | | |
| None | -2.022*** | -0.368*** | -2.390*** | -1.553*** | -0.435*** | -1.988*** |
| One (ref) | | | | | | |
| Two | 0.247*** | 0.211*** | 0.458*** | 0.330*** | 0.208*** | 0.538*** |
| Three + | 0.338*** | 0.617*** | 0.955*** | 0.513*** | 0.432*** | 0.945*** |
| *Number of Workers:* | | | | | | |
| None (ref) | | | | | | |
| One | -0.037 | -0.014 | -0.051 | 0.033 | 0.048* | 0.081* |
| Two | 0.037 | -0.032 | 0.005 | 0.053 | 0.053 | 0.106* |
| Three + | 0.237*** | 0.178*** | 0.415*** | 0.192** | 0.144** | 0.336*** |
| | | | | | | |
| Number of Equivalent Adults | 0.012 | 0.115*** | 0.127* | -0.061 | 0.032 | -0.029 |
| Natural Log of Total Household Expenditure | 0.208*** | 0.442*** | 0.651*** | 0.321*** | 0.506*** | 0.828*** |

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

the possession of cars variables are larger relative to the conditional expectation elasticities implying that these variables increase (and decrease in the case of zero car possession) the probability of a positive value to a much greater extent than the conditional level of petrol expenditures. This makes sense in that car possession (or non-car possession) should have a more sizable impact on whether a household makes a purchase of petrol rather than its level. It is also not surprising that relative to the other variables, the car possession variables display the largest probability of a positive value elasticities, and in particular the non-car possession variable highlighting its importance. The number of workers in the household has a positive but relatively weak effect on the conditional and overall level of petrol spending. Only those households with 3 or more workers are there positive and significant effects present for both the probability of a positive value and the conditional level of petrol spending. Finally there doesn't appear to be any household size effects present and total household expenditure is as expected positive and significant with a larger conditional elasticity relative to the probability of a positive value elasticity.

A comparison with the results from the 2004/05 also given in table 6 is instructive at this time. The results generally match those found for the 2009/10 data with similar significant coefficients on variables such as location, public transport spend, car possession and total household expenditure. Some differences do exist however with a greater number of significant coefficients on the lifestyle and education variables especially. In particular for some of the married HOH variables, positive and significant coefficients are present for the probability of a positive value and the overall level of expenditure, effects which disappear in the 2009/10 data set. There are also negative and significant coefficients present for the education variables in the 2004/05 which then subsequently disappear in the 2009/10 data set. The negative values for education may appear strange at first but could reflect a hidden urban effect, in that the more highly educated heads of households are located in urban centres. The fact that the effect of lifestyle and education disappears in the 2009/10 could represent a trend toward greater levels of homogeneity amongst Irish households in relation to petrol consumption. As was seen in table 3, there are a greater proportion of single young households with no children in the 2009/10 sample which have rebalanced lifestyle differences found in the 2004/05 survey. Similarly there are a greater proportion of heads of households with third level education in the 2009/10 which again may have equalised differences across these groups.

Comparisons can be made across the two samples in terms of the size of the estimated elasticities as they are based on proportional changes in the dependent variable. On this basis, urban location has a greater proportional effect on petrol purchases in the 2009/10 survey relative to the 2004/05 survey. This shows the effects of increased urbanisation as households move to areas where there are jobs available and thus use less petrol for travelling purposes. The increased in the size of the elasticity on the public transport variables also reflects this although it could be hypothesised that the downturn in the economy also increased the numbers availing of public transport. The estimates on the variables representing the level of car possession are interesting in that the values representing the probability of a positive expenditure and the conditional expectation are moving in opposite directions with the former increasing in size (or getting less negative) and the latter decreasing in size (or getting more negative). This would suggest that there are two competing effects taking place, the first indicating a greater ease of access into the petrol market, possibly because of improvements in the quality of road infrastructure and the second a consequence of the downturn in the economy which has reduced the demand for petrol. The only other variable where comparisons can be made is households with 3+ workers. In this instance the elasticities are decreasing between the two surveys which would indicate its reduced importance in explaining petrol use.

Looking next to table 7 and concentrating on the 2009/10 estimates first, we find the number of workers, the number of equivalent adults and total household expenditure to be strong positive influences on diesel expenditures. And similar to petrol, living in urban areas, possessing zero cars and having a positive spend on public transport all have negative effects on diesel expenditures. Interestingly the negative effects are much larger for diesel compared to petrol. This is because diesel is used on a less widespread basis and so locational differences, for example, are more pronounced. In looking at the contribution to the overall effect on diesel expenditures it is universally the case that the participation effect outweighs the conditional effect. This is normally the case when the dependent variable is censored to a large extent as is the case with diesel expenditures. It reflects a greater potential for participation (or non-participation) in the diesel market for a change in an explanatory variable.

The 2004/05 diesel results given in table 7 are quite different to the corresponding 2009/10 results. Practically all of the lifecycle variables are significant in the 2004/05 results whereas

only a select few are significant in the 2009/10 results. Similarly there are differences in the significance of the car possession variables between the two sets of results. This would suggest that diesel use in Ireland underwent much change in the 2004/04 to 2009/10 period. The changes in the VRT system described previously would appear to be the main cause of this and is changing the underlying patterns of household demand. In particular the absence of lifecycle effects in the 2009/10 data suggest a greater degree of homogeneity amongst household groups. This effect was also observed in the petrol results but not to such an extent. For the variables representing car possession, the insignificance of the 2 and 3+ dummies in the 2009/10 results could be because there are more 1 car households with diesel cars thus equalising differences in diesel use across 1 car households, 2 car households and 3+ car households.

Another observation from comparing the 2004/05 and 2009/10 results is that the 2009/10 elasticities tend to be smaller compared to the 2004/05 values. This is particularly the case for the location variables and the possession of zero cars dummy. It was previously stated that locational differences for diesel use are a lot more pronounced compared to petrol but it would appear that this effect is diminishing. For example, a household living in Dublin in 2004/05 has a negative diesel elasticity equal to -2.853 whereas in 2009/10 this value increased to -1.823. It is worth pointing out that this is mainly coming from an increase in the probability of participation which would give a clear indication of increased penetration of diesel use into urban locations. Further evidence for the general increase in diesel use can be seen in the estimates for the possession of zero cars dummy. These values are also increasing which at first may seem strange for a household with no cars but it could be that this is reflecting increased diesel usage from private vehicles that are not recorded by households in the HBS as cars, such are vans or lorry's or even mini-buses. The public transport variable in contrast decreases in size (or becomes more negative) between the 2004/05 and 2009/10. A similar result was found in the petrol and data and was assumed to be related to the downturn in the economy resulting in increased numbers of householders availing of public transport.

A discussion surrounding the effect of income (or total household expenditure) has been set aside until now as it is a particularly important determinant of petrol and diesel expenditures. The total income elasticity for petrol in 2009/10 equals 0.828 while for diesel it is equal to 1.162. Petrol can therefore be classed as a necessity good while diesel as a luxury good. This supports the view expressed in the introduction of petrol being the more conventional fuel for

**Table 7: Estimated Elasticities – Diesel Expenditures, 2004/05 and 2009/10 HBS**

| | 2004/05 | | | 2009/10 | | |
|---|---|---|---|---|---|---|
| | $P[y_i > 0 \mid x]$ | $E[y_i \mid x, y_i > 0]$ | E[yi \| x] | $P[y_i > 0 \mid x]$ | $E[y_i \mid x, y_i > 0]$ | E[yi \| x] |
| *Location:* | | | | | | |
| BMW Rural (ref) | | | | | | |
| BMW Urban | -1.283*** | 0.003 | -1.279*** | -0.468*** | -0.132*** | -0.600*** |
| Mid-South Rural | -0.602** | -0.057* | -0.659*** | -0.252*** | -0.085*** | -0.337*** |
| Mid-South Urban | -1.711*** | -0.238*** | -1.949*** | -0.960*** | -0.237*** | -1.197*** |
| Dublin | -2.342*** | -0.311*** | -2.653*** | -1.448*** | -0.375*** | -1.823*** |
| *Lifecycle of HOH:* | | | | | | |
| Single, <44, No Children (ref) | | | | | | |
| Single, <44, Children | -1.693*** | -0.353*** | -2.046*** | -0.149 | -0.051 | -0.200 |
| Single, 45-64, No Children | -0.649** | -0.117 | -0.766** | 0.224*** | 0.121*** | 0.345** |
| Single, >45, Children | -1.345** | -0.256** | -1.602** | -0.272 | -0.035 | -0.307 |
| Single, >65, No Children | -1.043*** | -0.193*** | -1.236*** | 0.109 | 0.046 | 0.155 |
| Married, <44, No Children | -1.042** | -0.253*** | -1.295*** | 0.244 | 0.020 | 0.264 |
| Married, <44, Children | -0.933*** | -0.237*** | -1.170*** | 0.257 | -0.035 | 0.222 |
| Married, 45-64, No Children | -0.656** | -0.171*** | -0.826** | 0.361** | 0.039 | 0.401** |
| Married, >45, Children | -0.926** | -0.242*** | -1.169*** | 0.402 | 0.009 | 0.412 |
| Married, >65, No Children | -0.664* | -0.205*** | -0.869** | 0.206 | -0.022 | 0.184 |
| *Sex of HOH:* | | | | | | |
| Male | 0.062 | 0.009 | 0.071 | 0.500*** | -0.042* | 0.458 |
| Female (ref) | | | | | | |
| *Education of HOH:* | | | | | | |
| No education or Primary education (ref) | | | | | | |
| Secondary education | 0.096 | -0.038 | 0.058 | -0.081 | 0.019 | -0.063 |
| Third Level education | -0.086 | -0.032 | -0.118 | 0.004 | -0.004 | -0.001 |
| *Public Transport Dummy:* | | | | | | |
| Zero Public Transport Spend (ref) | | | | | | |
| Positive Public Transport Spend | -0.418*** | -0.001 | -0.419*** | -0.485*** | -0.122*** | -0.607*** |
| *Number of cars possessed:* | | | | | | |
| None | -1.443*** | -0.226*** | -1.669*** | -0.434*** | -0.055* | -0.489*** |
| One (ref) | | | | | | |
| Two | 0.695*** | 0.086*** | 0.782*** | 0.036 | -0.033 | 0.003 |
| Three + | 1.052*** | 0.165** | 1.217*** | 0.412 | 0.013 | 0.425 |
| *Number of Workers:* | | | | | | |
| None (ref) | | | | | | |
| One | -0.211 | 0.159*** | -0.052 | 0.326*** | 0.050* | 0.376** |
| Two | -0.434 | 0.203*** | -0.231 | 0.390*** | 0.083*** | 0.473*** |
| Three + | -2.010 | 0.279*** | -1.731 | 0.196 | 0.083 | 0.280 |
| | | | | | | |
| Number of Equivalent Adults | 0.650*** | 0.162*** | 0.813*** | 0.549*** | 0.072** | 0.621*** |
| Natural Log of Total Household Expenditure | 0.732*** | 0.349*** | 1.081*** | 0.813*** | 0.349*** | 1.162*** |

*** p-value < 0.01, **p-value < 0.05, *p-value <0.10

short to mid-range journeys and diesel being the luxury fuel used by householders who take longer journeys. These values are a little bit higher than estimates from the literature although one should bear in mind the differences in methodologies and data. Schmalensee and Stoker (1999) for example calculated a range of income elasticities equal to 0.12 to 0.23, while Kayser (2000), Asensio et al. (2002) and Johansson-Stenman (2002) report estimates equal to 0.49, 0.51 and 0.46 respectively. If one take estimates based on the conditional expectation however (0.506 for petrol and 0.349 for diesel) the values are more in line with what has been found in the literature. Comparing the overall income elasticity estimates with the corresponding 2004/05 values we see that the income elasticity for both fuels has increased over the period with a more substantial increase for petrol compared to diesel. The general rule of thumb is for income elasticities to decrease as income increases so the opposite effect has occurred here in line with the downturn in the economy. The downturn in the economy has had a greater effect on petrol purchases for the simple reason that petrol is used by a greater proportion of households.

Even though income is excluded from the participation equation, an elasticity on the probability of participation can still be calculated. As can be seen from the formula for the marginal effect on the probability of participation (equation 6) even if $\alpha_j = 0$, a value for the second part of this equation can still be calculated. This elasticity can then be referred to as an elasticity on the probability of a positive expenditure given that income is assumed to influence the expenditure hurdle only. The difference in contribution to the overall elasticity between the probability of a positive expenditure and the conditional elasticity for petrol and diesel is very evident. For petrol, the probability elasticity is smaller relative to the conditional elasticity. For diesel, it is the opposite case. To investigate this further, table 8 provides estimates for the overall income elasticities and income elasticities calculated at the average household income of each income quartile.

As can be seen from the table the probability petrol elasticity estimates are only sizeable and significant for the first income quartile. So for the 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ income quartiles, changes in income have little or no effect on the probability of a positive expenditure in the petrol market and instead only affect the level of expenditure on petrol. For diesel the probability of a positive expenditure is much larger and while it decreases from the 1$^{st}$ to 4$^{th}$ quartile it is still large in magnitude and outweighs the conditional elasticity even for the 4$^{th}$ income

quartile. Another interesting feature of the diesel estimates is the fact that the conditional elasticities are very uniform across the income distribution. So the effect on diesel expenditures for a change in income (and conditional on its purchase) is the same for low income, middle income and high income households. Furthermore, there is very little change in the size of these elasticities between 2004/05 and 2009/10. Thus the effect that income has on diesel (for those households purchasing diesel) is stable across time and is stable across households with different income levels. What is driving the variation in the overall unconditional diesel income elasticity is thus the effect that income has on the probability that a household will have a positive diesel expenditure.

**Table 8: Estimated Income Elasticities by Income Quartile – Petrol and Diesel Expenditures, 2004/05 and 2009/10 HBS**

| | 2004/05 | | | 2009/10 | | |
|---|---|---|---|---|---|---|
| | $P[y_i > 0 \mid x]$ | $E[y_i \mid x, y_i > 0]$ | E[yi \| x] | $P[y_i > 0 \mid x]$ | $E[y_i \mid x, y_i > 0]$ | E[yi \| x] |
| *Petrol:* | | | | | | |
| 1st Quartile | 0.218 | 0.551 | 0.769 | 0.400 | 0.644 | 1.044 |
| 2nd Quartile | 0.046 | 0.416 | 0.462 | 0.132 | 0.501 | 0.634 |
| 3rd Quartile | 0.011ns | 0.373 | 0.384 | 0.066 | 0.443 | 0.509 |
| 4th Quartile | -0.014ns | 0.342 | 0.328 | 0.019ns | 0.393 | 0.412 |
| Overall | 0.208 | 0.442 | 0.651 | 0.321 | 0.506 | 0.828 |
| *Diesel:* | | | | | | |
| 1st Quartile | 0.969 | 0.381 | 1.350 | 1.260 | 0.373 | 1.632 |
| 2nd Quartile | 0.599 | 0.352 | 0.951 | 0.830 | 0.355 | 1.186 |
| 3rd Quartile | 0.470 | 0.338 | 0.809 | 0.649 | 0.343 | 0.992 |
| 4th Quartile | 0.361 | 0.324 | 0.685 | 0.479 | 0.326 | 0.805 |
| Overall | 0.732 | 0.349 | 1.081 | 0.813 | 0.349 | 1.162 |

ns = not significant at the 5% level of significance

## 6: CONCLUSIONS

The objective of this study is to examine the determinants of household transport expenditures in Ireland using a large micro data set, the Irish Household Budget Survey. The current body of research into this area using micro data in particular is limited which is surprising given its importance in the context of developing sustainable and environmentally friendly forms of transport. This study is also unique in that it analyses both petrol and diesel household expenditures for the first time. In the past petrol cars has been very much the transport fuel of choice for households with diesel cars making up only a very small proportion of the overall stock. However recent changes in legislation have caused a shift in preferences from petrol to diesel which makes this research into the determinants of both fuels very timely.

The study finds that households living in urban areas, households that spend money on public transport and households that do not possess a car will spend less on both petrol and diesel. A number of previous researchers (see for example Kayser, 2000) have highlighted the differing effects that changes in transport prices has on households living in rural areas with no public transportation versus households living in urban areas with public transportation. This is something worth noting for Irish policy makers given that petrol and diesel prices in Ireland are heavily taxed as well as being influenced to a large extent by fluctuations in global oil prices. In contrast, households in possession of higher number of cars, households with more occupants working or just generally with more occupants and households with higher level of household spending will spend more on petrol and diesel (with slightly differing effects for the number of cars possessed on diesel and equivalent adults on petrol). These factors illustrate the strong link between purchasing power and petrol/diesel use in that all of the factors are correlated to a large extent with levels of household income.

Another major contribution of the study is the methodology that was utilised. The double hurdle has been applied in a number of differing contexts but this is its first application to petrol and diesel expenditures. The results arising from the analysis would indicate that it provides a number of additional insights especially in terms of the effect that the explanatory variables have on the probability of participation and the level of expenditure. Not only were some estimated effects found to be different across participation and consumption but significant differences were also found across the two fuels examined. This was particularly the case for the estimated income elasticities. While overall income elasticities showed petrol to a necessity and diesel and luxury the contribution to this overall effect was quite the opposite for both fuels. For petrol a change in income has a small effect for low income households or insignificant effect for high income households on the probability of a positive expenditure but a much larger effect for all households on the conditional level of spending. In contrast, for diesel a change in income has a much larger effect on the probability of a positive expenditure especially for households on lower incomes and a much smaller effect on the conditional level of spending. The latter is found to be uniformly the case across all households.

In making inferences about the level of future petrol and diesel use, the analysis is complicated slightly by the fact that period examined 2004/05 to 2009/10 corresponded to a

downturn in the Irish economy (and many other economies as well). The current prospects are however that the economy is recovering and incomes are rising. In this scenario our model would predict some increase in participation in the petrol market, especially for those on low incomes, but the main effect will be on the level of petrol expenditures. In contrast increases in income will see large increases in the number of households moving from zero diesel expenditures to positive diesel expenditures. The level of diesel expenditures will also increase but not to the same extent as petrol. These findings support previous research by Hennessy and Tol (2011a,b) on the effect of the change in VRT. Their projections suggest that the switching from petrol cars to diesel cars will continue at a steady pace. In fact, the latest figures for new private cars licenses from the CSO show that over 2.5 times more diesel cars were licensed in 2013 compared to petrol cars. The gradual increase in diesel cars will leave to an improvement in the efficiency of the car stock which in turn should have a positive effect on emissions. Hennessy and Tol (2011a,b) caution however that this is dependent on the average amount of vehicle kilometres travelled remaining relatively constant.

**REFERENCES**


Aristei D. and L. Pieroni (2008). "A double-hurdle approach to modelling tobacco consumption in Italy" *Applied Economics* 40(19): 2463-2476.

Asensio J., A. Matas and J-L Raymond (2002) “Petrol expenditure and redistributive effects of its taxation in Spain” *Transportation Research Part A* 37: 49–69.

Atkinson A. B., J. Gomulka and N. H. Stern (1984). Household Expenditure on Tobacco 1970-80: Evidence from the Family Expenditure Survey. London School of Economics ESRC Programme on Taxation, Incentives and the Distribution of Income, Discussion Paper 57.

Banks J., R. Blundell and A. Lewbel (1997). "Quadratic Engel Curves and Consumer Demand" *Review of Economics and Statistics* 79(4): 527-539.

Bjorner T. (1999) “Demand for car ownership and use in Denmark: a micro econometric model.” *International Journal of Transport Economics* 26 (3): 377–395.

Blaylock J. R. and W. N. Blisard (1993). "Women and the Demand for Alcohol: Estimating Participation and Consumption" *Journal of Consumer Affairs* 27(2): 319-334.

Blundell R., J. Ham and C. Meghir (1987). "Unemployment and Female Labour Supply" *The Economic Journal* 97: 44-64.

Blundell R. and C. Meghir (1987). "Bivariate alternatives to the Tobit model" *Journal of Econometrics* 34(1–2): 179-200.

Carroll J., S. McCarthy and C. Newman (2005). "An Econometric Analysis of Charitable Donations in the Republic of Ireland" *The Economic and Social Review* 36(3): 229-249.

Caulfield B. (2012). "An examination of the factors that impact upon multiple vehicle ownership: The case of Dublin, Ireland" *Transport Policy* 19(1): 132-138.

Central Statistics Office. 2013. Household Budget Survey 2009/10. Stationery Office. Dublin. Ireland.

Central Statistics Office, 2012. Transport Omnibus 2011, Stationery Office, Dublin. Ireland

Commins N. and A. Nolan (2010) “Car ownership and mode of transport to work in Ireland.” *Economic and Social Review* 41: 43-75.

Cragg J. G. (1971). "Some Statistical Models for Limited Dependent Variables with Application to the Demand for Durable Goods" *Econometrica* 39(5): 829-844.

Crowley F., J. Eakins and D. Jordan (2012) “Participation, Expenditure and Regressivity in the Irish Lottery: Evidence from Irish Household Budget Survey 2004/2005” *The Economic and Social Review* 43(2): 199-225.

Deaton A. and J. Muellbauer (1980). "An Almost Ideal Demand System" *The American Economic Review* 70(3): 312-326.

De Jong G. C. (1990). "An indirect utility model of car ownership and private car use" *European Economic Review* 34(5): 971-985.

Environmental Protection Agency (2013) Ireland’s Greenhouse Gas Emission Projections 2012-2030. Wexford. Ireland.

García J. and J. M. Labeaga (1996). "Alternative Approaches to Modelling Zero Expenditure: An Application to Spanish Demand for Tobacco" *Oxford Bulletin of Economics and Statistics* 58(3): 489-506.

Greening L. A., H. T. Jeng, J. P. Formby and D. C. Cheng (1995). "Use of region, life-cycle and role variables in the short-run estimation of the demand for gasoline and miles travelled" *Applied Economics* 27(7): 643-656.

Heckman J. J. (1979). "Sample Selection Bias as a Specification Error" *Econometrica* 47(1): 153-161.

Hennessy H. and R.S.J Tol (2011a) “The Impact of Government Policy on Private Car Ownership in Ireland” *The Economic and Social Review* 42 (2): 135–157.

Hennessy H. and R.S.J Tol (2011b) “The impact of tax reform on new car purchases in Ireland” *Energy Policy* 39: 7059–7067.

Howley M. and M. Holland. (2013) Energy in Ireland 1990 – 2012. Energy Policy Statistical Support Unit, Sustainable Energy Authority of Ireland.

Humphreys B.R., Lee Y.S. and B.P. Soebbing (2010) “Consumer behaviour in lottery: the double hurdle approach and zeros in gambling survey data” *International Gambling Studies* 10(2): 165-176.

Johansson-Stenman O. (2002) “Estimating individual driving distance by car and public transport use in Sweden.” *Applied Economics* 34: 959–967.

Jones A. (1989). "A double-hurdle model of cigarette consumption" *Journal of Applied Econometrics* 4(1): 23-39.

Jones A. (1992). "A Note on Computation of the Double-Hurdle Model with Dependence with an Application to Tobacco Expenditure" *Bulletin of Economic Research* 44(1): 67-74.

Kayser H. (2000) “Gasoline demand and car choice. Estimating gasoline demand using household information.” *Energy Economics* 22: 331–348.

Labandeira X., J. M. Labeaga and M. Rodríguez (2006). "A Residential Energy Demand System for Spain" *The Energy Journal* 27(2): 87-111.

Mannering F. and C. Winston (1985) “A dynamic empirical analysis of household vehicle ownership and utilisation.” *The Rand Journal of Economics* 16 (2): 215–236.

McDonald J. F. and R. A. Moffitt (1980). "The Uses of Tobit Analysis" *The Review of Economics and Statistics* 62(2): 318-321.

Manzan S. and D. Zerom (2010). "A Semiparametric Analysis of Gasoline Demand in the United States Reexamining The Impact of Price" *Econometric Reviews* 29(4): 439-468.

Mutlu S. and A. Gracia (2006). "Spanish food expenditure away from home (FAFH): by type of meal" *Applied Economics* 38(9): 1037-1047.

Newman C., M. Henchion and A. Matthews (2001). "Infrequency of purchase and double hurdle models of Irish households' meat expenditure" *European Review of Agricultural Economics* 28(4): 393-419.

Newman C., M. Henchion and A. Matthews (2003). "A double-hurdle model of Irish household expenditure on prepared meals" *Applied Economics* 35(9): 1053-1061.

Nicol C. J. (2003). "Elasticities of demand for gasoline in Canada and the United States" *Energy Economics* 25(2): 201-214.

Nolan A. (2003) "The determinants of urban households' transport decisions: a microeconometric study using Irish data." *International Journal of Transport Economics* 30 (1): 103–132.

Nolan A. (2010) "A dynamic analysis of household car ownership." *Transportation research Part A: Policy and Practice* 44: 446-455.

Pudney S. (1989) Modelling Individual Choice: The Econometrics of Corners, Kinks and Holes. Blackwell Publishing. Massachusetts, USA.

Rogan F., E. Dennehy, H. Daly, M. Howley and B.P. Ó Gallachóir (2011) "Impacts of an emission based private car taxation policy – First year ex-post analysis" *Transportation Research Part A* 45 583–597.

Schmalensee R. and T. M. Stoker (1999). "Household Gasoline Demand in the United States" *Econometrica* 67(3): 645-662.

Tobin J. (1958). "Estimation of Relationships for Limited Dependent Variables" *Econometrica* 26(1): 24-36.

Wadud Z., D. J. Graham and R. B. Noland (2010). "Gasoline Demand with Heterogeneity in Household Responses" *The Energy Journal* 31(1): 47-74.

West S. E. and R. C. Williams (2004). "Estimates from a consumer demand system: implications for the incidence of environmental taxes" *Journal of Environmental Economics and Management* 47(3): 535-558.

Yatchew A. and J. A. No (2001). "Household Gasoline Demand in Canada" *Econometrica* 69(6): 1697-1709.

Yen S. T. and H. H. Jensen (1996). “Determinants of Household Expenditures on Alcohol " *Journal of Consumer Affairs* 30(1): 48-67.

Yen S. T. and A. M. Jones (1997). "Household Consumption of Cheese: An Inverse Hyperbolic Sine Double-Hurdle Model with Dependent Errors" *American Journal of Agricultural Economics* 79(1): 246-251.

Yen S. T. and S. Su (1995). "Modeling U.S. Butter Consumption with Zero Observations" *Agricultural and Resource Economics Review* 24(1): 47-55.

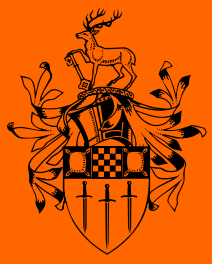
**Surrey Energy Economics Centre (SEEC)**

**School of Economics**

**University of Surrey**

**Guildford**

**Surrey GU2 7XH**



SURREY

ENERGY

ECONOMICS

DISCUSSION PAPER

SERIES

**For further information about SEEC please go to:**

**www.seec.surrey.ac.uk**