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Simulating Demand for Electrical Vehicles using Revealed Preference Data

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Abstract: We have modelled the market for new cars in Ireland with the aim of quantifying the values placed on a range of observable car characteristics. Mid-sized petrol cars with a manual transmission sell best. Price and perhaps fuel cost are negatively associated with sales, and acceleration and perhaps range are positively associated. Hybrid cars are popular. The values of car characteristics are then used to simulate the likely market shares of three new electrical vehicles. Electrical vehicles tend to be more expensive even after tax breaks and subsidies are applied, but we assume their market shares would benefit from an "environmental" premium similar to those of hybrid cars. The "environmental" premium and the level of subsidies would need to be raised to incredible levels to reach the government target of 10% market penetration of all-electric vehicles.

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1. Introduction

The Irish government provides incentives for purchase of electrical vehicles in pursuit of climate and energy targets, following the directions set out in the EU Climate and Energy Package and the Renewable Energy Directive (2009/28/EC). Ireland has set as own target that 10% of all vehicles will be electric by 2020.[1]

Electrical vehicles reached the Irish market in 2008. In that first year just five electrical cars were sold, and by 2011 that number was only up to 44 units. Considering the ambitious plans for the electrification of Irish motoring through government policy such as grants and favourable taxation since 2008, these sales are disappointing. Leaving aside the question of whether national targets for electrical vehicles are a good or bad idea, we attempt to cast light on whether electrical vehicles will succeed in gaining the level of market share specified in government objectives without further intervention. By using automobile differentiated product-level characteristics (with price one of them) and unit sales, this article estimates a demand system for the Irish automobile market. The estimated demand coefficients are then used to simulate the demand from the introduction of new electrical vehicles in the economy.

Using a Lancastrian model of demand (Lancaster (1971, 1991)), the vehicle is considered as a bundle of differentiated attributes rather than a homogeneous single product. Market shares of new electrical vehicles can be simulated by multiplying each of their characteristics (e.g. price, range, etc.) by the marginal valuation of the same or similar attributes in existing cars. One difficulty in simulating the introduction of a new model in the characteristics space is that some of its observable attributes may not have existed before. This possible limitation in the dimensions of the characteristics space makes any evaluation of the product introduction harder, for no marginal valuation is available for the innovative attributes of the innovative model. Thanks to the availability of hybrid automobiles we do not have to worry much about this issue.

Public policy may affect the uptake of electrical vehicles. The effects of different pricing scenarios on electric vehicles' market shares are presented. The current policy whereby electrical vehicles benefit from a grant and do not incur a Vehicle Registration Tax (VRT) is taken as the base scenario. Two other scenarios are shown: one that removes the grant and

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[1] These EU targets are the 20-20-20 targets and include a 20% reduction in EU greenhouse gas levels on 1990 levels, 20% of energy from renewable resources and 20% improvement of energy efficiency, all by 2020.

a second that both removes the grant and imposes VRT. A further possible avenue for public policy intervention is through informational advertising; that is, to raise ecological awareness through an energy efficiency campaign and thus to stimulate demand for electric vehicles indirectly. The effect of varying levels of ecological awareness on the base results is illustrated.

The paper continues as follows. Section 2 examines the existing literature in the areas of consumer vehicle choice and electric vehicles. The methodology and data used are detailed in Sections 3 and 4. The results are presented in Section 5. Section 6 provides a discussion and conclusion.

2. Previous research on the Car Market

There has been much written on the car market and consumer choice but there is little literature specific to electrical cars. Nolan (2010) gives a recent review of research in the car ownership area.

Emissions have been the focus of a number of Irish papers relating to the car market. O'Gallachoir *et al.* (2009) utilise new car data from 2000 to 2006 and show how purchasing trends over this period counter the efficiency benefits of improved engine performance. The paper also examines the 2008 vehicle registration and motor tax reforms that were put in place to change these trends; it is discovered that the resultant drop in emissions is not from a shift to smaller cars but to diesel cars. Hennessy and Tol (2011) confirm these results using data over a longer time period. Analysing the impact of Irish government policy on car ownership, following the 2008 tax reforms, they note the shift from petrol to diesel cars led to a decrease in carbon emissions but an increase in car usage, due to cheaper operating costs of diesel. The net decrease in emissions is small and the government is not on track to meet emission targets. Furthermore the increasing stock and preference for larger cars suggest emissions will increase over the next 15 years.

A number of studies focus on assessing governmental policies or aims in relation to electrification of the car fleet. Mandell (2009) describes different policy instruments used to incentivise the purchase of low emission cars and draws attention to Sweden where a subsidy was offered. The programme, due to run to 2010, was replaced with a five year exemption from motor tax in 2009 owing to the surprisingly large number of sales qualifying for the subsidy. California and France both pursued policies promoting electrical vehicles in the nineties; two very different approaches were followed, compared by Calef and Goble (2007), but neither resulted in substantial number of electric vehicles on the roads. Carlsson and Stenman (2003), in a cost benefit analysis for Sweden using American data, find that while electric cars are privately profitable they are not socially profitable. This result arises from the heavy subsidies and, often overlooked, lost tax revenues. Excluded from the result are the external costs of electricity production as well as the social costs associated with publically provided rapid charging, both of which would further widen the gap between

private and social benefits. It is also emphasised that, while privately financially profitable, this does not mean electric cars are more attractive than other cars as characteristics such as acceleration, engine power, range, and battery power matter.

Another approach by Brandon *et al.* (2011) involves behaviour analysis in examining the adoption of electric, hydrogen fuel cells and hybrid vehicles in the UK. Car type, car size and distance driven can be regarded as behavioural variables, depending on car user choices. Policy, such as fuel and car taxation, alters car users' choices but evidence on these influences is often incomplete. Unintended responses and rebound effects can complicate analysis and make forecasting future policy difficult.

Our paper takes into account the effect of consumers' ecological awareness on their demand for electrical vehicles. Energy efficiency campaigns as a form of advertising have been studied and can be classified as Demand Side Management (DSM) or Market Transformation (MT) (Birner and Martinot, 2005, Blumstein *et al.*, 2000). Birner and Martinot (2005) find that increased awareness of energy savings potential can impact markets on the supply side even before formal project implementation. Blumstein *et al.* (2000) point to the more technical meaning of MT that has developed, a policy objective of promoting social, technology and economic change towards greater energy efficiency. Gillingham, Newell and Palmer (2006) review DSM programmes in the United States and conclude that the most effective policies are the ones that offer incentives to buy energy-efficient durable goods.

Energy efficiency campaigns can take the form of generic advertising. Its impact is studied by Chakravarti and Janiszewski (2004), revealing that, while the goal is to increase primary demand of a product without influencing market share of any producer, often brand-level demand is affected. Brand differentiation can be strengthened or weakened by generic advertising through decreasing access to non-advertised product attributes and as such increasing price responsiveness. It is concluded that generic advertising should be used to suggest product appropriateness such as awareness advertising in immature commodity markets while concentrating on usage situation in more mature markets.

Many studies refer to the importance of substitution patterns in understanding car choice. The car ownership decision, because of its discrete nature, is often examined using discrete choice models. Brownstone and Train (1999) demonstrate the importance of mixed logit and probit models for new product forecasting in allowing for realistic substitution patterns. Applying standard logit models to Californian survey data on households' choices among fuel type, they find that the new electric car in the model will draw evenly from all sizes of cars, while mixed logits and probit show more substitution from smaller cars than larger cars. Axsen *et al.* (2009) and Dissanayake and Morikawa (2010) use multinomial and nested logit models with stated preference, revealed preference and a combination of both approaches to model vehicle choice. Both papers find the combined stated preference and revealed preference nested logit model generated the most reliable estimates.

Random coefficients logit models feature in the literature and are useful in attempting to include consumer heterogeneity evident in car choice decisions. Taking the traditional logit model as a starting point, Berry, Levinsohn and Pakes (1995) are the forerunners in using a random coefficients logit model in this area. With more realistic substitution patterns this model produces higher cross price elasticities as cars become more similar. Having realistic price elasticities is important, because demand elasticities play a crucial role in policy analysis. Petrin (2002) builds on the Berry, Levinsohn and Pakes (1995) approach and augments market level data with consumer demographics. Applying this approach to the automobile market, substitution patterns reflect consumer heterogeneity and more appropriate demand elasticities are estimated. A further extension of the random coefficient logit model is undertaken by Berry, Levinsohn and Pakes (2004) where observable and unobservable individual characteristics are enriched with a dataset on second choice information. Although we recognize the potential benefits of a random coefficient model in estimating richer substitution patterns, our paper employs the simplified logit methodology suggested in Berry (1994), for our interest in the estimation does not go beyond the requirement of an unbiased estimation of the demand coefficients.

3. Data employed

Car data used in the analysis is collected from a variety of sources. The price and unit sales are taken from the Society of Irish Motoring Industry (SIMI). SIMI compiles statistics for new vehicle purchases as well as second hand purchases. The dataset on new cars is supplemented with data on car model characteristics compiled from specialised press (mostly www.motorcheck.ie and www.carzone.ie). The electrical cars' characteristics are taken from the manufacturers' specifications as listed on their websites.[2]

The dataset contains 31 car companies and 127 car brands; for example *Alfa Romeo* is a company, *159* is a brand. Cars are considered at the model variation level; for example, *Alfa Romeo 159 1.9 JTD SPORTIVO 16V 2006* is an observation. It is an unbalanced panel of 4835 car variations recorded yearly during the period 2004-2008, for a total of 9485 observations when other characteristics such as engine size and number of doors are included. Table 1, below, illustrates how the dataset is comprised at the company, brand and model variation level.

Table 1: Number of companies, brands and model variation by year

	2004	2005	2006	2007	2008	Total
Companies	24	24	27	29	31	31
Brands	82	89	99	113	124	127
Models	1254	1559	1769	2051	2134	4835

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[2] www.nissan.ie, www.mitsubishi-motors.ie, www.renault.ie

Table 2 defines the variables drawn from the variety of sources.

Table 2: Variable descriptions

Variable	Description
Market Share	Market share (logged), the dependent variable, is calculated from number of unit sales for each model of car over number of total unit sales
Price	The average of the recommended retail price for January, July and December of each year, in euro thousands[3]
Cost	Expected fuel cost (logged) using discount rate of 5% in the low discount scenario and 9% in high discount scenarios[4]
Range	Kilometres possible with one full fuel tank in city driving conditions[5]
Warranty	Categorical variable from 1 to 4 of warranty duration
Acceleration	Seconds 0-100km/h
Cardoor	Number of doors in car
Year	Dummy variable for each year of new car
Petrol fuel	Dummy variable: 1 for petrol; 0 for diesel
Manual transmission	Dummy variable: 1 for manual; 0 for automatic
Hybrid	Dummy variable: 1 for hybrid; 0 otherwise
CO2 Tax Band A	Dummy variable:1 for band A, i.e. CO2 0:120g/km; 0 otherwise
CO2 Tax Band B	Dummy variable:1 for band B, i.e. CO2 121:140g/km; 0 otherwise
CO2 Tax Band C	Dummy variable: 1 for band C, i.e. CO2 emissions 141:155g/km; 0 otherwise
CO2 Tax Band D	Dummy variable:1 for band D, i.e. CO2 emissions 156:170g/km; 0 otherwise
CO2 Tax Band E	Dummy variable:1 for band E, i.e. CO2 emissions 171:190g/km; 0 otherwise
CO2 Tax Band F	Dummy variable:1 for band F, i.e. CO2 emissions 191:225g/km; 0 otherwise
CO2 Tax Band G	Dummy variable:1 for band G, i.e. CO2 emissions >225g/km; 0 otherwise

Descriptive statistics for the variables used in the paper are shown in Table 3 below. *Market Share* is the dependent variable and we express it in log terms. The *Price* variable is scaled to euro thousands. There is a broad array of prices in the dataset with the *Price* variable ranging from €9,500 to €316,000 per vehicle, with most of the observations clustered in the lower end. The majority of the cars included have four or five doors and have a manual transmission. There are very few hybrid cars in our dataset, as evident from the mean of the *Hybrid* dummy. *Warranty* captures the maximum mileage allowed for a car to remain in warranty; this is high for the vast majority of cars with many offering unlimited mileage warranty for a fixed time period. The CO_2 band variables represent carbon emissions, with most cars in the dataset coming under *CO_2 Band F.* This is probably driven mainly by the prevalence of cars with relatively large engines.

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[3] Real price with 2011 as base year.
[4] Discount rates based on Ramsey equation from the Ramsey growth model (Morgenroth, 2011).
[5] The quotient of fuel tank size and fuel consumption.

Table 3: Summary statistics

Variable name	Mean	Std Dev	Min.	Max.
Market Share (log)	-9.331	1.815	-11.682	-3.053
Price	35.285	20.384	9.519	315.990
Car door	4.218	0.872	2	5
Range	5.631	1.434	2.322	11.6
Acceleration	10.619	2.193	4.4	18.2
CO_2 Band A	0.103	0.304	0	1
CO_2 Band B	0.025	0.157	0	1
CO_2 Band C	0.074	0.261	0	1
CO_2 Band D	0.166	0.372	0	1
CO_2 Band E	0.167	0.373	0	1
CO_2 Band F	0.206	0.405	0	1
CO_2 Band G	0.185	0.388	0	1
Cost LD[6] (log)	5.871	1.151	0	7.066
Cost HD[7] (log)	6.072	1.035	0	7.063
Hybrid	0.001	0.036	0	1
Manual transmission	0.699	0.458	0	1
Warranty	3.746	0.654	2	4

The three electrical car models used for the purpose of this paper are *Nissan Leaf, Mitsubishi iMiEV* and *Renault Fluenze Z.E.* These are not included in the data described for estimation but are used later for simulating the demand for these vehicles. While displaying similar characteristics to conventional fuel cars of comparable size within the dataset, they differ notably in purchase price, range and emissions. Battery cost places them above average price relative to non electrical vehicles. Range is much lower; the average maximum of the electrical models is 170 kilometres while the mean range of the cars in the dataset is 563 kilometres. Petrol or diesel fuelled cars' pollutants include CO_2, nitrates and particulates. Emissions from electrical vehicle use are zero. Hybrid vehicles are included in the dataset. They combine internal combustion engines and electric battery power to achieve efficiencies in fuel and CO_2 emissions. As such, hybrids have lower CO_2 emissions than petrol vehicles of similar engine size but nevertheless higher than the non-emitting electrical cars.

4. Estimation

This paper estimates the demand for automobiles based on a set of observable vehicle characteristics, including annual fuel costs. We first estimate demand by OLS. Then we employ a 2SLS estimator and correct for the price endogeneity induced by the correlation between unobserved automobile characteristics and price. The comparison between the OLS and 2SLS estimates gives us an idea of the estimation bias.

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[6] Low discount rate of 5% (Morgenroth, 2011)
[7] High discount rate of 9% (Morgenroth, 2011)

The dependent variable is defined as $\ln\dfrac{s_{jt}}{s_{0t}}$, the natural log of the ratio between the market share of the car j in year t and the share of households that do not buy a car, which we term the "outshare", in the same year. The market share s_{jt} is the ratio between the unit sales of the car model variation j and the total unit sales in the market. The outside share in period t, s_{0t}, is the proportion of households who choose not to buy a new car and it is given by the ratio between total unit sales in the period and the number of households in Ireland in the period.[8] The procedure used to derive the demand specification with this dependent variable is detailed in Berry (1994).

Initially an OLS model is run. It can be seen that this model has explanatory power, returning significant coefficients; however, it is expected a problem of price endogeneity exists. It is likely there is at least one unobserved characteristic that proxies for quality, that is positively correlated with the price, and ignoring this will make the price estimate inconsistent. Due to the combination of positive correlation and negative price effect, it is believed the bias causes an understatement of the absolute value of the price coefficient.

Including brand dummies, a second OLS model is run. The additional controls used should capture any brand effects that vary within brands. In addition to improving the explanatory power of the model, brand dummies are expected to reduce the price endogeneity. In order to deal with the endogeneity issue, a 2SLS estimator is used. The 2SLS estimator requires an exogenous variable to instrument price. We combine the Berry *et al.* (1995) instruments with the Hausman *et al.* (1994) instrument. The former include the sum of acceleration and fuel CO_2 emissions for the subset of car models produced by the same company, as well as the sum of the fuel cost characteristic over the entire production set of the other companies. Hausman *et al.* (1994) suggest that the prices in one market segment are used to instrument prices in other market segments. Manufacturer specific characteristics are the same but the different market segments attract consumers with different characteristics, giving a suitable instrument. The instrument was created by first identifying the market segment of each car and, based on the manufacturer (*Audi, Toyota* etc.), the average price of cars marketed by the same manufacturer were calculated.[9] This is illustrated in Table 4.

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[8] Demographic projections come from the "low growth" macroeconomic scenario in Bergin *et al.* (2010).
[9] Seven market segments were identified: city, compact, convertible, executive, medium, MPV, and SUV.

Table 4: Examples of the Instrumental Variable

Car	Market segment	Manufacturer	Instrumental Variable
Alfa Romeo 159 1.9 JTD SPORTIVO 16V 2006	Executive	Alfa Romeo	Average price of Alfa Romeo cars in the sample in market segment city, compact, convertible, medium, MPV, SUV
MAZDA2 1.25 5DR COMFORT SE 2007	Compact	Mazda	Average price of Mazda cars in the sample in market segment city, convertible, executive, medium, MPV, SUV

Similarly to the OLS estimator, the 2SLS estimator is estimated both with and without brand dummies. We run the four estimates (two OLS and two 2SLS) with two different versions of fuel as explanatory variable. The first version includes fuel as a dummy variable (1 for petrol) while the second one incorporates the annual cost of fuel. This cost variable was constructed using the average kilometres driven per year, sourced from Sustainable Energy Authority Ireland (2011), and the estimated price of fuel, using petrol price data from Statistical Reports of the Revenue Commissioners and diesel price data from IEA Energy Prices and Taxes. The cost variable was discounted based on the expected single owner lifetime of a car. We followed the assumption in Buchanan (2000) that the average car "purchase life" is 5 years. In Buchanan's report on motoring taxation costs, vehicle mileage is used to estimate cost in a similar fashion to this paper, except that it adds additional detail on fuel taxes. The cost variable is more relevant than a fuel dummy variable when simulating demand for electrical vehicles, as discussed later.

Since our goal in modelling car purchase demand is to simulate the demand for new electrical vehicles, particular attention is paid to including explanatory variables that the previous literature suggests to be especially relevant to electrical vehicles such as range, acceleration and carbon emissions. The simulation is done by taking the estimated coefficients of the models, presented in Section 5, and applying them to three of the electrical vehicles that are for sale in Ireland in 2012. A list of the variables used and their descriptive statistics are included in Section 4.

5.   Results

5.1 Car purchasing decision

Two series of the models are run; the first, summarized in Table 5 and shown in full in Appendix 1, includes fuel as a dummy variable and the other, Table 6 and Appendix 2, replaces the fuel variable with an annual fuel cost variable.

Table 5: Car purchasing decision with ln(sjt/s0t) as the dependent variable

Variables	OLS(1)		OLS(2)		2SLS(1)		2SLS(2)	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Price	-0.008	0.004**	-0.008	0.003**	-0.005	0.006	-0.045	0.022**
Petrol fuel	0.274	0.109**	0.079	0.114	0.288	0.110**	0.008	0.103
Range	0.109	0.046**	0.038	0.039	0.116	0.048**	0.005	0.041
Acceleration	0.072	0.029**	0.088	0.032**	0.082	0.035**	0.007	0.063
Hybrid	2.800	0.312***	2.499	0.268***	2.781	0.319***	2.688	0.300***
Manual trans.	0.451	0.082***	0.507	0.080***	0.478	0.078***	0.282	0.170*
Warranty	-0.301	0.071***	0.062	0.073**	-0.306	0.074***	-0.005	0.075
CO_2 Band A	-0.141	0.123	-0.122	0.091	-0.125	0.127	-0.338	0.157**
CO_2 Band B	-0.243	0.193	-0.222	0.166	-0.230	0.198	-0.468	0.244**
CO_2 Band C	0.030	0.174	0.036	0.155	0.039	0.176	-0.179	0.167
CO_2 Band D	0.012	0.160	0.124	0.134	0.025	0.168	-0.109	0.175
CO_2 Band E	Ref.		Ref.		Ref.		Ref.	
CO_2 Band F	-0.076	0.097	-0.060	0.088	-0.054	0.105	-0.296	0.153*
CO_2 Band G	-0.285	0.099**	-0.294	0.084**	-0.279	0.100**	-0.356	0.110**
2 door	Ref.		Ref.		Ref.		Ref.	
3 door	-0.247	0.226	-0.300	0.227	-0.200	0.243	-0.570	0.348
4 door	0.538	0.210**	0.538	0.195**	0.556	0.207**	0.484	0.330
5 door	0.217	0.197	0.29	0.190	0.250	0.203	0.213	0.307
2004	Ref.		Ref.		Ref.		Ref.	
2005	-0.267	0.052***	-0.213	0.058***	-0.271	0.053***	-0.160	0.060***
2006	-0.402	0.075***	-0.320	0.072***	-0.410	0.075***	-0.184	0.101*
2007	-0.517	0.081***	-0.438	0.078***	-0.530	0.083***	-0.239	0.130*
2008	-0.592	0.088***	-0.532	0.083***	-0.607	0.089***	-0.299	0.154*
BrandDummy	No		Yes		No		Yes	

Note: Clustered standard errors. Significance: * p<0.10, ** p<0.05, *** p<0.01. 'Ref.' denotes reference category.

Focussing on the first series of models displayed in Table 5, market share as expected decreases as price rises across the four models. The coefficient is statistically significant with the exception of the 2SLS model without brand effects, however the magnitude is very small with a thousand euro price increase lowering market share (relative to the outside option) by less than 1% in the OLS models, all else qual. The magnitude is larger in the 2SLS model with brand effect controls with a 4.5% drop in market share for a thousand euro price increase. This effect is more in line with expectations. Petrol cars are preferred to diesel in all models, but the effect is not significant when brands are controlled for. The data in use are prior to the 2008 tax changes that saw a shift towards diesel cars as detailed in Hennessy and Tol (2011).

Range is an important variable to consider when examining electrical vehicles. Most such vehicles currently offered for sale have ranges lower than those available for petrol vehicles. In our historical models, where the data contain no electrical vehicles, range has a positive but small effect on market share. It is significantly different from zero in the OLS model and the 2SLS model, when the brand dummies are not included. However range loses its significance when the brand effects are controlled for. We had expected the coefficients on range to be larger. It may be that the marginal cost of supplying range in a petrol vehicle (i.e. increasing the size of the petrol tank) is not high compared to the cost of improving other attributes of the vehicle. Manufacturers may then choose the ranges of vehicles to be generous relative to the requirements of most consumers, reducing the magnitude and level of significance of the estimated coefficients.

A higher acceleration rate positively affects the car purchase decision as does a manual transmission. These coefficients are statistically significant in both the OLS models and the 2SLS model without brand control, transmission is also statistically significant in this model controlling for the brand effects. The carbon dioxide emissions variables show cars in all bands have lower demand relative to the omitted band E. This negative effect is greater for cars with very low or very high emissions. It seems likely that this pattern is not driven by consumers' attitudes towards CO_2 emissions *per se*, but rather by their preference for midsize cars over very large or very small cars.

The dummy variable for hybrid comes in statistically significant at the 1% level across the models, and has an extremely high magnitude suggesting that a hybrid car would increase (relative to the outside option) market share by 280% for OLS and 2SLS models without brand effects, 250% for OLS model including such effects and almost 270% for the brand controlled 2SLS model, all else equal. There are very few hybrids in the sample, just 12 car models, and the positive coefficients indicate that at least some car buyers have strong environmental motives. The data are not sufficient to show whether these motives may be extrapolated to the wider car buying public or whether they are particular to a small group.

We run each of the four models a second time including *Lncost*, a variable capturing the expected annual fuel cost, in place of the fuel dummy variable. This gives similar results as displayed in Appendix 2. In line with expectations, higher expected lifetime fuel cost has a negative effect on consumer demand. The variable is logged therefore it can be read as an elasticity. The cost coefficient is statistically significant in the models not controlling for brand effects. The lack of significance when brand dummies are controlled for may be due to some degree of multicollinearity between brand dummies and running cost.

Dummy variables for the year of sale and car brand are included to control for time- or brand-specific effects on market share that are not related to the vehicles' characteristics.

Table 6: Car purchasing decision with annual fuel cost included

Variables	OLS(1) Coef.	OLS(1) Std. Err.	OLS(2) Coef.	OLS(2) Std. Err.	2SLS(1) Coef.	2SLS(1) Std. Err.	2SLS(2) Coef.	2SLS(2) Std. Err.
Price	-0.007	0.003**	-0.007	0.003***	-0.007	0.007	-0.048	0.026*
Lncost	-0.592	0.239**	-0.358	0.241	-0.602	0.23	0.236	0.413
Range	0.052	0.047	0.010	0.040	-0.007	0.007	0.011	0.042
Acceleration	0.054	0.031*	0.077	0.035***	0.056	0.037***	0.009	0.060
Hybrid	2.905	0.358***	2.500	0.295***	2.902	0.362**	2.740	0.291***
Manual trans.	0.449	0.082***	0.501	0.079***	0.453	0.077***	0.278	0.178
Warranty	-0.298	0.073***	0.073	0.065	-0.299	0.074***	-0.005	0.076
CO_2 Band A	-0.241	0.119**	-0.173	0.092*	-0.24	0.120***	-0.312	0.133**
CO_2 Band B	-0.393	0.199*	-0.331	0.173*	-0.394	0.196	-0.384	0.201*
CO_2 Band C	-0.102	0.187	-0.033	0.168	-0.103	0.186	-0.141	0.154***
CO_2 Band D	-0.058	0.165	0.083	0.140	-0.057	0.168	-0.087	0.162***
CO_2 Band E	*Ref.*		*Ref.*		*Ref.*		*Ref.*	
CO_2 Band F	-0.087	0.094	-0.059	0.087	-0.083	0.101***	-0.312	0.169*
CO_2 Band G	-0.256	0.097***	-0.275	0.082***	-0.254	0.099***	-0.377	0.121***
2 door	*Ref.*		*Ref.*		*Ref.*		*Ref.*	
3 door	-0.291	0.218	-0.336	0.225	-0.283	0.239***	-0.561	0.340*
4 door	0.538	0.207**	0.547	0.196***	0.541	0.207	0.468	0.334
5 door	0.209	0.192	0.288	0.191	0.215	0.203***	0.207	0.311
2004	*Ref.*		*Ref.*		*Ref.*		*Ref.*	
2005	-0.275	0.052***	-0.216	0.058***	-0.276	0.052***	-0.155	0.061***
2006	-0.412	0.075***	-0.325	0.072***	-0.414	0.075***	-0.175	0.108
2007	-0.530	0.080***	-0.447	0.078***	-0.533	0.082***	-0.222	0.146
2008	-0.604	0.089***	-0.541	0.082***	-0.606	0.090	-0.28	0.174
BrandDummy	No		Yes		No		Yes	

Note: Clustered standard errors. Significance: * p<0.10, ** p<0.05, *** p<0.01. 'Ref.' denotes reference categories.

We now turn to the results from the 2SLS model using the cost variable. We focus on the annual cost as it is more appropriate than fuel type for simulating demand for electrical vehicles.

As expected market share decreases as price rises; it is statistically significant at the 10% level. All else equal, a thousand euro price increase would (relative to the outside option) lower market share by 4.8%. The annual fuel cost has an unexpected positive sign but is not statistically significant. Range has a small coefficient of 0.011 and is not statistically significant.

A higher acceleration rate is positively associated with the car purchase decision as does a manual transmission but these effects are not statistically different from zero. The dummy variable for hybrid comes in statistically significant and has an extremely high magnitude suggesting that a hybrid car would (relative to the outside option) increase market share by over 270%, *ceteris paribus*. The major impact of the hybrid dummy coefficient on car demand motivates the investigation of the effect of ecological awareness on the demand for electrical vehicles. The CO_2 emissions dummy variables are all negative and statistically significant but of a larger magnitude at the upper and lower levels, again suggesting that

they are picking up 'inverted U-shaped' preferences for car size. Midsize cars are preferred to very small or very large cars.[10]

5.2 Simulating demand for Electrical Vehicles

Demand for electrical vehicles is simulated using the results shown in Table 6 above and presented in full in Appendix 2. This model is more appropriate for simulating electric vehicle market shares because it includes a continuous variable for fuel cost rather than a dummy variable for the fuel used. The fuel dummy variable is not sensible in examining demand for electrical vehicles as they fit into neither petrol nor diesel category. By including the cost variable we can examine the cost of running an electrical car as a determinant of the consumer purchase decision. Furthermore using the 2SLS model the issue of endogeneity is addressed. The magnitude of the price variable is slightly larger in this model compared to the others discussed in this paper. We simulate demand in three different scenarios using the characteristics of three different electrical vehicles that are available on the Irish market in 2012:

Scenario 1:   Current recommended retail price (RRP) which includes a €5000 government
                grant and an exemption from Vehicle Registration Tax (VRT)
Scenario 2:   We remove the €5000 government grant
Scenario 3:   We remove the €5000 government grant and impose VRT.

In our simulations we implicitly assume that the new electrical cars do not displace existing vehicles and the prices of existing cars are unaffected by the entry of this new type of cars. By imposing this form of entry we avoid having to estimate a simultaneous equations model as in Berry Levinsohn and Pakes (1995), Nevo (2001) and Petrin (2002) or a demand equation model with a pricing equation derived from the equilibrium assumption. Electrical cars enter the market with their own sets of attributes, and based on the marginal valuations estimated for existing models we are able to predict their market shares at the expense of existing models. The competition from the new electrical cars is modelled entirely in the inside market.

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[10]   The size distribution of car supply matches the size distribution of car demand. What is referred to as a "mid-
        sized" car is essentially the car-size that commands the highest market share.

Table 7: Simulated Market Share of Electrical Vehicles

|	Scenario		
	1	**2**	**3**
Nissan Leaf	0.003	0.002	0.002
Mitsubishi iMiEV	0.002	0.002	0.001
Renault Fluence ZE	0.005	0.004	0.003
Total	**0.010**	**0.008**	**0.004**

Table 7 illustrates demand for electrical vehicles simulated under three different pricing scenarios. Market shares are very low; electrical vehicles would garner just 1% of all new cars sold under the current pricing scenario. As public subsidies are reduced and removed, therefore raising prices, the demand lessens further. Although the simulated market shares here are close to those of individual models of some conventional cars they are low relative to government targets to reach a total car stock comprised of 10% of electrical vehicles by 2020. The slow uptake by consumers is not unusual for new technology on the market. Shepherd *et al.* (2012) point to the importance of word of mouth in new technology uptake and specifically conclude that more research into awareness campaigns and marketing of electrical vehicles would be useful.

Raising Ecological Awareness

Electrical vehicle sales may be boosted by raising ecological awareness and appealing to environmental motives of potential buyers. The model of the demand for automobiles contains a dummy variable for hybrid vehicles. This may capture buyers' desire for an environmentally friendly car. In Table 7 we therefore assumed that this dummy applies to all-electric vehicles as well. However, all-electric cars are greener than hybrid cars. To see how sensitive the results are to the strength of this effect, we arbitrarily increase the dummy. In addition to the default level, four further levels are examined; moderate, medium, medium/high and intense, increasing the dummy by 10, 20, 30 and 50 per cent respectively. These simulations are presented in Figure 1 and Table 8.

With greater ecological awareness comes a greater demand for electrical vehicles. However, even at the "intense" level of ecological awareness, the total demand is only 3.9 per cent of vehicles at the current subsidy policy, dropping to 3.0 and 2.4 per cent as the subsidy is reduced by first the grant and then further reduced by the removal of the VRT exemption. This falls far short of the government target of a 10% market penetration.

Figure 1: Simulated Market Share of Electrical Vehicles; Three Pricing Scenarios, 5 Ecological Awareness Levels, Increased Grant
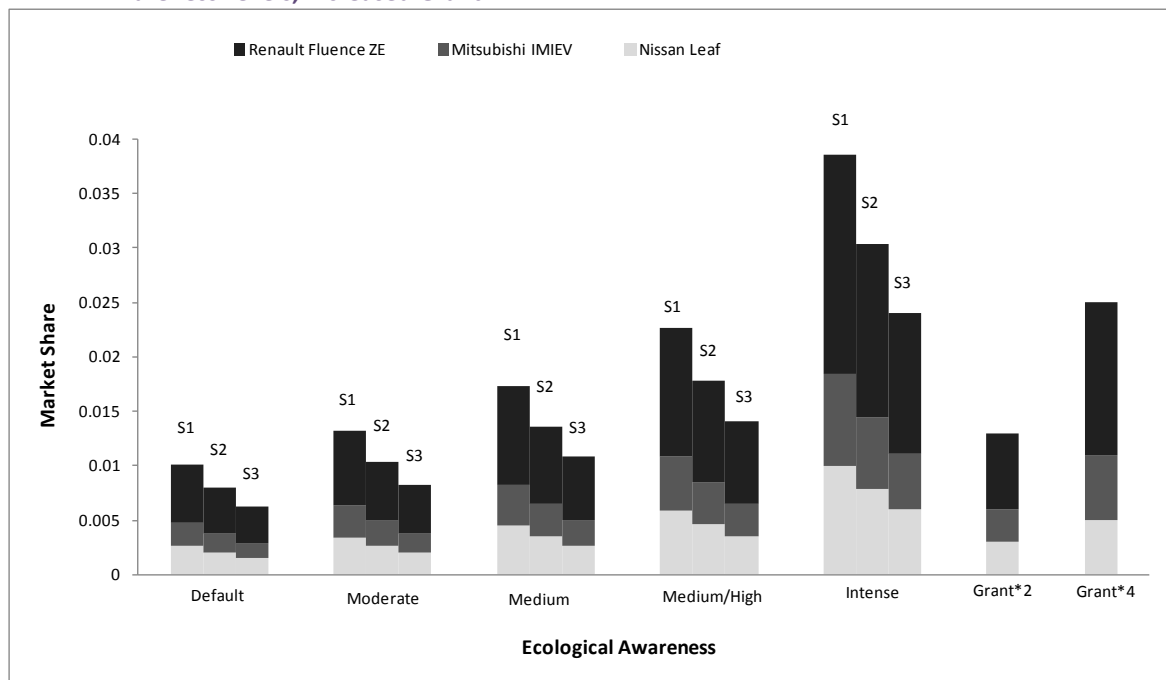
Increasing Subsidy

Electrical vehicle sales are encouraged through the government grant previously outlined. Table 8 shows our assumptions of subsidies; double and quadruple the current level. With the extremely large subsidies total demand remains low, 2.5 per cent for a grant of €20,000. Further simulation shows that a €50,000 subsidy would be needed to bring the total demand to the 10% government target of market penetration.

Table 8: Simulated Market Share of Electrical Vehicles; Three Pricing Scenarios, 5 Ecological Awareness Levels, Increased Grant

Ecological Awareness	Nissan Leaf			Mitsubishi IMIEV			Renault Fluence ZE			Total Electrical Cars		
	Current RRP	excl. grant	excl. grant & impose VRT	Current RRP	excl. grant	excl. grant & impose VRT	Current RRP	excl. grant	excl. grant & impose VRT	Current RRP	excl. grant	excl. grant & impose VRT
Default	0.003	0.002	0.002	0.002	0.002	0.001	0.005	0.004	0.003	0.010	0.008	0.006
Moderate	0.003	0.003	0.002	0.003	0.002	0.002	0.007	0.005	0.004	0.013	0.010	0.008
Medium	0.005	0.004	0.003	0.004	0.003	0.002	0.009	0.007	0.006	0.017	0.014	0.011
Medium/High	0.006	0.005	0.004	0.005	0.004	0.003	0.012	0.009	0.008	0.023	0.018	0.014
Intense	0.010	0.005	0.008	0.006	0.008	0.007	0.020	0.016	0.013	0.039	0.030	0.024
Grantx2	0.003			0.003			0.007			0.013		
Grantx4	0.005			0.006			0.014			0.025		

6. Conclusions

We have modelled the market for new cars in Ireland with the aim of estimating the values placed on a range of car characteristics. The values of car characteristics are then used to simulate the likely market shares of three new electrical vehicles for which characteristics have been published. The electrical vehicles modelled here have much lower range than comparable petrol vehicles, but because range is assigned a low marginal (and often insignificant value in the existing market), this factor has little effect on their predicted market shares. Electrical vehicles also tend to be more expensive even after tax breaks and subsidies are applied, but we assume their market shares would benefit from an "environmental" premium. The level of this premium is assumed to be the same as the market share uplift currently enjoyed by hybrid cars.

The net effect of applying these characteristics leads to simulated market shares that are broadly in line with individual models of fossil fuelled cars. Strengthening or weakening electrical vehicle subsidies has a relatively limited impact on predicted market shares due to the modest price coefficients in the model. Even with subsidies in place, however, the market shares are very low relative to government targets for electrical vehicle penetration, because these targets are defined in terms of the stock of vehicles. It would take extremely high new car penetration rates for the share of the total car stock made up of electrical vehicles to reach 10% by 2020.

However, there are also reasons to think that market shares might be higher in practice. Electrical vehicles will benefit from government information and advertising campaigns on environmental benefits and energy efficiency. Arbitrarily increasing the hybrid premium, so it becomes an electrical vehicle premium, increases total demand for electrical vehicles. However, even large increases are not enough to reach government targets for market penetration. Assuming higher subsidy levels shows the same effect: increased demand but still remaining too low to meet government targets. Our simulation shows a subsidy greater than the current RRP is needed to reach these targets.

These shares might be overestimates or underestimates. First, would the hybrid premium continue at its current value as the market expanded significantly? It is possible that the willingness to pay the observed hybrid premium is restricted to only a fixed portion of the car buying public. Another factor that could point towards overestimation is that very few electrical cars have been sold in Ireland to date. Given existing data, we cannot tell whether this is because the models on the market have less desirable bundles of characteristics than the models simulated here or because it takes time for information about the environmental benefits of new vehicles or the attributes of new brands generally to influence the market. Another issue is that our results place little weight on the effects of lower range on electrical vehicle demand. In effect, we are predicting these effects far out of sample. It is plausible that the range discount could be stronger than predicted based on historical data.

Furthermore the simulations are based on the marginal valuations as estimated before the introduction of the electrical cars. We rely on the assumption that apart from ecological awareness, all other marginal valuations (preferences) will remain unchanged; that is, the experience of owning and using electric cars will not be so different from petrol cars as to produce a structural change in consumer preferences.

Acknowledgements

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Appendix 1: Car purchasing decision with ln(sjt/s0t) as the dependent variable

Variables	OLS(1)		OLS(2)		2SLS(1)		2SLS(2)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Price	-0.008	0.004**	-0.008	0.003**	-0.005	0.006	-0.045	0.022**
Fuel	0.274	0.109**	0.079	0.114	0.288	0.110***	0.008	0.103
Range	0.109	0.046**	0.038	0.039***	0.116	0.048**	0.005	0.041
Acceleration	0.072	0.029**	0.088	0.032***	0.082	0.035**	0.007	0.063
Hybrid	2.800	0.312***	2.499	0.268***	2.781	0.319***	2.688	0.300***
Transmission	0.451	0.082***	0.507	0.080***	0.478	0.078***	0.282	0.170*
Warranty	-0.301	0.071***	0.062	0.073***	-0.306	0.074***	-0.005	0.075
CO_2 Band A	-0.141	0.123	-0.122	0.091	-0.125	0.127	-0.338	0.157**
CO_2 Band B	-0.243	0.193	-0.222	0.166	-0.230	0.198	-0.468	0.244**
CO_2 Band C	0.030	0.174	0.036	0.155	0.039	0.176	-0.179	0.167
CO_2 Band D	0.012	0.160	0.124	0.134	0.025	0.168	-0.109	0.175
CO_2 Band F	-0.076	0.097	-0.060	0.088	-0.054	0.105	-0.296	0.153*
CO_2 Band G	-0.285	0.099***	-0.294	0.084***	-0.279	0.100***	-0.356	0.110***
3 door	-0.247	0.226	-0.300	0.227	-0.200	0.243	-0.570	0.348
4 door	0.538	0.210**	0.538	0.195***	0.556	0.207***	0.484	0.330
5 door	0.217	0.197	0.29	0.190	0.250	0.203	0.213	0.307
2005	-0.267	0.052***	-0.213	0.058***	-0.271	0.053***	-0.160	0.060***
2006	-0.402	0.075***	-0.320	0.072***	-0.410	0.075***	-0.184	0.101*
2007	-0.517	0.081***	-0.438	0.078***	-0.530	0.083***	-0.239	0.130*
2008	-0.592	0.088***	-0.532	0.083***	-0.607	0.089***	-0.299	0.154*
Audi			0.731	0.093***			1.102	-0.323***
BMW			1.035	0.128***			1.716	-0.502***
Chevrolet			1.598	0.160***			0.976	-0.39***
Chrysler			1.125	0.166***			1.211	0.150***
Citroen			0.399	0.159**			0.294	0.176*
Daihatsu			1.132	0.242***			0.585	0.431
Dodge			1.156	0.249***			0.805	0.213***
Fiat			1.297	0.174***			1.001	0.229***
Ford			1.043	0.128***			0.921	0.138***
Honda			2.053	0.237***			1.914	0.242***
Hyundai			3.842	0.419***			3.451	0.546***
Jaguar			1.092	0.185***			2.933	1.109***
Kia			2.248	0.140***			1.772	0.316***
Land Rover			2.713	0.179***			2.998	0.257***
Lexus			2.202	0.166***			2.492	0.243***
Mazda			1.418	0.315***			1.129	0.279***
Mercedes			1.401	0.189***			2.040	0.604***
Mitsubishi			1.343	0.235***			0.993	0.347***
Nissan			1.632	0.219***			1.258	0.263***
Opel			0.832	0.178***			0.723	0.187***
Peugeot			0.667	0.231***			0.277	0.328
Renault			1.487	0.152***			1.263	0.188***
Saab			0.311	0.074***			0.536	0.166***
Seat			1.349	0.192***			1.004	0.267***
Skoda			0.386	0.199*			-0.065	0.325
Subaru			1.308	0.233***			0.900	0.305***
Suzuki			2.695	0.192***			2.121	0.389***
Toyota			1.870	0.141***			1.642	0.208***
Volkswagen			1.024	0.222***			0.926	0.181***
Volvo			0.498	0.111***			0.871	0.261***
R-squared	0.112		0.157		0.112		0.094	
Observations	9485		9485		9485		9485	

Notes: Clustered standard errors; *** p<0.01, ** p<0.05, * p<0.1; 2 door omitted; 2004 omitted; CO2 Band E omitted; Alfa Romeo omitted.

Appendix 2: Car purchasing decision with annual fuel cost included

Variables	OLS(1) Coef.	OLS(1) Std. Err.	OLS(2) Coef.	OLS(2) Std. Err.	2SLS(1) Coef.	2SLS(1) Std. Err.	2SLS(2) Coef.	2SLS(2) Std. Err.
Price	-0.007	0.003**	-0.007	0.003***	-0.007	0.007	-0.048	0.026*
Lncost	-0.592	0.239**	-0.358	0.241	-0.602	0.23	0.236	0.413
Range	0.052	0.047	0.010	0.040	-0.007	0.007	0.011	0.042
Acceleration	0.054	0.031*	0.077	0.035***	0.056	0.037***	0.009	0.060
Hybrid	2.905	0.358***	2.500	0.295***	2.902	0.362**	2.74	0.291***
Transmission	0.449	0.082***	0.501	0.079***	0.453	0.077***	0.278	0.178
Warranty	-0.298	0.073***	0.073	0.065	-0.299	0.074***	-0.005	0.076
CO2 Band A	-0.241	0.119**	-0.173	0.092*	-0.24	0.12***	-0.312	0.133**
CO2 Band B	-0.393	0.199*	-0.331	0.173*	-0.394	0.196	-0.384	0.201*
CO2 Band C	-0.102	0.187	-0.033	0.168	-0.103	0.186	-0.141	0.154***
CO2 Band D	-0.058	0.165	0.083	0.140	-0.057	0.168	-0.087	0.162***
CO2 Band F	-0.087	0.094	-0.059	0.087	-0.083	0.101***	-0.312	0.169*
CO2 Band G	-0.256	0.097***	-0.275	0.082***	-0.254	0.099***	-0.377	0.121***
3 door	-0.291	0.218	-0.336	0.225	-0.283	0.239***	-0.561	0.340*
4 door	0.538	0.207**	0.547	0.196***	0.541	0.207	0.468	0.334
5 door	0.209	0.192	0.288	0.191	0.215	0.203***	0.207	0.311
2005	-0.275	0.052***	-0.216	0.058***	-0.276	0.052***	-0.155	0.061***
2006	-0.412	0.075***	-0.325	0.072***	-0.414	0.075***	-0.175	0.108
2007	-0.530	0.08***	-0.447	0.078***	-0.533	0.082***	-0.222	0.146
2008	-0.604	0.089***	-0.541	0.082***	-0.606	0.090	-0.28	0.174
Audi			0.744	0.091***			1.101	0.332***
BMW			1.022	0.119***			1.743	0.564***
Chevrolet			1.575	0.148***			0.984	0.405**
Chrysler			1.200	0.163***			1.186	0.151***
Citroen			0.418	0.16***			0.27	0.198
Daihatsu			1.106	0.278***			0.596	0.415
Dodge			1.166	0.219***			0.739	0.270***
Fiat			1.268	0.162***			1.029	0.219***
Ford			1.062	0.120***			0.891	0.18***
Honda			2.076	0.219***			1.919	0.236***
Hyundai			3.915	0.447***			3.357	0.579***
Jaguar			1.047	0.178***			3.051	1.283**
Kia			2.213	0.151***			1.773	0.326***
Land Rover			2.788	0.186***			2.954	0.243***
Lexus			2.199	0.158***			2.531	0.283***
Mazda			1.442	0.309***			1.119	0.284***
Mercedes			1.380	0.189***			2.081	0.656***
Mitsubishi			1.318	0.245***			1.024	0.329***
Nissan			1.622	0.199***			1.264	0.272***
Opel			0.837	0.178***			0.712	0.198***
Peugeot			0.699	0.214***			0.256	0.358
Renault			1.513	0.133***			1.255	0.203***
Saab			0.291	0.043***			0.525	0.165***
Seat			1.325	0.184***			0.989	0.291***
Skoda			0.349	0.219			-0.073	0.325
Subaru			1.375	0.241***			0.804	0.405**
Suzuki			2.669	0.174***			2.133	0.395***
Toyota			1.880	0.132***			1.647	0.204***
Volkswagen			1.043	0.219***			0.891	0.200***
Volvo			0.540	0.115***			0.836	0.246***
R-squared	0.112		0.158		0.112		0.085	
Observations	9485		9485		9485		9485	

*Notes: Clustered standard errors; *** p<0.01, ** p<0.05, * p<0.1; 2 door omitted; 2004 omitted; CO2 Band E omitted; Alfa Romeo omitted.*

Year	Number	Title/Author(s) ESRI Authors/Co-authors *Italicised*
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