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Car Ownership and Mode of Transport to Work in Ireland*

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Abstract: Rapid economic and demographic change in Ireland over the last decade, with associated increases in car dependence and congestion, has focused policy on encouraging more sustainable forms of travel. In this context, knowledge of current travel patterns and their determinants is crucial. In this paper, we extend earlier Irish research to examine the joint decision of car ownership and mode of transport to work. We employ cross-section micro-data from the *2006 Census of Population* to estimate discrete choice models of car ownership and commuting mode choice for four sub-samples of the Irish population, based on residential location. Empirical results suggest that travel and supply-side characteristics such as travel time, costs, work location and public transport availability, as well as demographic and socio-economic characteristics such as age and household composition have significant effects on these decisions.

I INTRODUCTION

As a result of rapid economic and demographic change over the last decade, and the resulting increase in car ownership, Ireland has experienced many of the problems associated with increasing car dependence. Over the period 1996-2006,[1] the population of Ireland grew by 16.9 per cent while the

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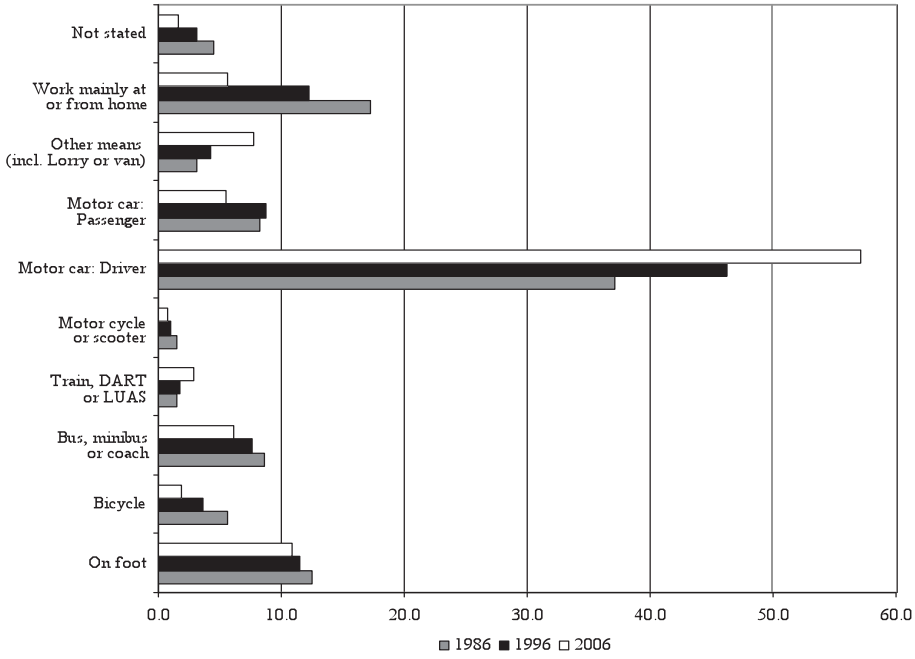
[1] Economic activity has contracted sharply since late 2007. Unemployment reached 12.0 per cent in the second quarter of 2009 (Central Statistics Office, 2009a), a return to net emigration is forecast for 2009 and 2010 (Barrett *et al*., 2009) and new car registrations fell by 63.6 per cent between March 2008 and March 2009 (Central Statistics Office, 2009b).

numbers in employment increased by 47.6 per cent, largely due to increases in the rate of female participation in the labour force and inward migration. In terms of the implications for transport, the most striking is the increase in new vehicle registrations, which increased by over 60 per cent over the period (Central Statistics Office, 2007). Data for journeys to work, school and college confirm this shift towards the private car; the proportions driving to work increased from 46.3 per cent in 1996 to 57.1 per cent in 2006 (see Figure 1), while the proportion of primary school students travelling as car passengers increased from 35.8 per cent in 1996 to 55.0 per cent in 2006, overtaking the proportions walking (24.3 per cent), which has traditionally been the primary means of transport to school for this age-group (Central Statistics Office, 2004). The resulting levels of congestion impact on all those using the road and public transport network; in the Dublin area, average journey speeds in the morning peak for car and bus[2] decreased by 12.4 per cent and 6.2 per cent respectively between 2003 and 2004 (Dublin Transportation Office, 2005).

Figure 1: *Mode of Transport to Work, 1986, 1996 and 2006 (Percentage of all Commuters*



Source: CSO Census Interactive Tables (www.cso.ie).

[2] Bus speeds on Quality Bus corridor routes (that is, routes with dedicated road space for buses) only.

There are also wider economic impacts, with carbon dioxide emissions from transport increasing by 88.7 per cent between 1996 and 2006 (Lyons et al., 2008).

Environmental considerations imply a need to reverse or at the very least to halt this shift in favour of the private car. Current policy focuses on a variety of measures that seek to limit or redirect travel demand in the short to medium term and encourage alternative more sustainable land-use strategies in the longer term (see Department of Transport, 2008a, 2008b; Dublin Transportation Office, 2001, 2006a, 2006b; European Commission, 2007; Fitz Gerald *et al.*, 2008; Morgenroth and Fitz Gerald, 2006). Investment in public transport and measures which seek to use existing infrastructure more efficiently such as improved cycle and bus lanes, parking restrictions, road pricing, carpooling etc. are all considered necessary if a shift away from the private car towards more sustainable methods of transport such as walking, cycling and public transport is to be achieved. Current initiatives include the provision of tax relief for the purchase of public transport tickets and bicycles for commuting trips with more severe measures such as urban road pricing or the introduction of a carbon tax proposed but yet to be implemented.

In this context, knowledge of the factors influencing the demand for passenger transport is crucial. In this paper we concentrate on transport demand for a specific journey purpose, namely the journey to work, and examine the influence of demographic, socio-economic and supply-side factors on choice of mode of transport for the journey to work in Ireland in 2006 using discrete choice econometric methodologies. We extend previous Irish research to incorporate the endogeneity of the car ownership decision by estimating a joint model of car ownership and mode of transport to work. The *2006 Census of Population* also contains detailed information on home and work location for the full population of working individuals, allowing us to consider the influence of proximity to rail connections for the first time. Section II discusses previous literature in the area, both international and Irish. Section III describes the data and provides some descriptive statistics, while Section IV describes the econometric methodology employed. Section V presents empirical results and Section VI concludes.

II PREVIOUS RESEARCH

Internationally, there is an extensive research literature on the determinants of various aspects of travel behaviour, and in particular commuting behaviour. Due to the nature of such decisions, and the data

available, discrete or qualitative choice methods such as multinomial or conditional logit[3] are typically employed. The models are grounded in consumer utility theory whereby the individual chooses among alternatives with the aim of maximising personal utility. Ben-Akiva and Lerman (1975) apply the multinomial logit methodology to the choice between a number of different alternatives for the journey to work in Washington, and find particularly significant effects for lifecycle and public transport availability. Aside from modal choice, the multinomial logit methodology has been extensively applied to other transport decisions such as the number of cars to own (Alperovich *et al.,* 1999; Bhat and Pulugurtha, 1998 and Cragg and Uhler, 1970); choice of car type (Lave and Train, 1979 and McCarthy, 1996); tourist destination (Eymann and Ronning, 1997) and choice of departure time (McCafferty and Hall, 1982). A number of studies have analysed mode choice for other journey purposes, using a variety of methods (see Cohen and Harris, 1998) for trips to visit friends and relatives, Domencich and McFadden (1975) for shopping trips, Ewing *et al*. (2004) for mode choice for the journey to school and McGillivray (1972) for other journey purposes including personal business, visiting friends and relations, shopping and other recreation).

Asensio (2002); De Palma and Rochat (2000); Dissanayake and Morikawa (2005); Thobani (1984) and Train (1980) all use the nested multinomial logit methodology to estimate modal choice for the journeys to work in Barcelona, Geneva, Bangkok, Karachi and San Francisco respectively. The nested multinomial logit model overcomes the restrictive requirement of the multinomial logit methodology to have distinct and independent alternatives. More recent versions of the nested multinomial logit model (such as the generalised or cross-nested logit) have been developed to incorporate situations in which correlations exist between alternatives across nests as well as alternatives within nests, thus allowing for the incorporation of related decisions such as car ownership or residential/employment location (see for example, Vega and Reynolds-Feighan, 2008 and Salon, 2009).[4]

Much of the early research on Irish travel patterns was carried out in the context of research on the sustainability of residential and commercial development (see for example, MacLaran and Killen, 2002; McCarthy, 2004

[3] The multinomial logit and conditional logit models differ in the type of explanatory variables that can be included; the conditional model can support individual-specific as well as alternative-specific variables while the multinomial logit can support only the former (Stata, 2007).

[4] De Donnea (1971); Lave (1970) and Madan and Groenhout (1987) all use the binary logit methodology but the ability of the conditional, multinomial and nested logit methods to incorporate more than two categories of the dependent variable means that they are favoured in applied work relating to modal choice. Bhat and Pulugurtha (1998) and Hausman and Wise (1978) estimate multinomial probit models, but the computational complexity of this model means that it is rarely applied.

and Williams and Shiels, 2000). The interactions between commuting and the housing and labour markets have been analysed by Morgenroth (2002) who used gravity models to analyse the determinants of inter-county commuting flows and Keane (2001) who similarly related commuting to issues of job search and the development of local labour market areas. Horner (1999) and Walsh *et al*. (2005) described patterns of travel to work using earlier versions of the Census of Population (CoP) data employed in this paper. Both papers highlighted a substantial phenomenon of long-distance commuting.

Research on the travel behaviour of individuals using disaggregated data has been increasing in recent years in Ireland, in part due to the increased availability of detailed micro-data on commuting behaviour from the Census of Population. Nolan (2003) examined the income and socio-economic determinants of household car ownership, car use and public transport use in the Dublin area, using micro-data from the 1987, 1994 and 1999 Irish Household Budget Surveys. McDonnell *et al.* (2006) focused on the determinants of bus use in a particular QBC (quality bus corridor) catchment area in Dublin. They found that the key to attracting commuters to bus was shorter journey times at peak times, even in high income areas. Vega and Reynolds-Feighan (2006) estimated a simultaneous model of residential location and mode of transport to work in the Dublin area using data from the *2002 Census of Population*, and found significant effects for alternative-specific characteristics such as travel time, as well as individual socio-economic characteristics. In a later paper, using the same data, Vega and Reynolds-Feighan (2008) concentrated on four employment sub-centres in the Dublin area, and found that the spatial distribution of employment exerted a large and significant influence on modal choice for the journey to work. Commins and Nolan (2008), using the same data employed in this paper (i.e. the *2006 Census of Population*), examined choice of mode of transport for the journey to work in the Greater Dublin Area, but assumed that residential location and household car ownership status were exogenous.

III DATA

The data employed in this paper are micro-data from the Place of Work Census of Anonymised Records (POWCAR) from the *2006 Census of Population* (CoP). The CoP is carried out every five years by the Central Statistics Office and includes all individuals present in the country on the last Sunday in April. For the first time, the micro-data for 2006 constitute the entire population of working individuals aged 15+ years surveyed at home in private households. In total 1,834,472 individuals are included in the micro-

data file. After excluding individuals working from home, those with a mobile place of employment and where "other means"[5] and lorry/van were recorded, the final sample for estimation is 1,564,330 individuals. Due to the substantial difference in population density and public transport provision across different areas of Ireland, we further divide the sample into four sub-samples; Dublin city and county (494,370 individuals), Dublin commuter belt (i.e. the surrounding counties of Kildare, Meath and Wicklow; 187,779 individuals), other urban areas (377,649 individuals) and rural areas (504,532 individuals).[6] Table 1 defines the four sub-samples, and provides some details on public transport availability and transport characteristics in each area.

Each individual observation contains information on demographic and socio-economic characteristics such as age; gender; household type; housing tenure; marital status; education level; socio-economic group and industrial group; as well as variables relating to county and electoral division (ED[7]) of residence, county, ED and geo-code of place of work, distance travelled, time of departure and mode of transport for the journey to work. Mode of transport refers to the usual mode of transport for the outward journey to work. Where more than one mode of transport is used, the mode of transport used for the greater part of the journey (by distance) is recorded. Household car ownership refers to the number of cars or vans available for use by the household. All variables are self-reported. The CoP does not contain information on income or prices.

Our joint model of household car ownership and mode choice for the journey to work consists of six alternatives; two car ownership levels (no car or at least one car) and three modes of transport to work (walk/cycle, bus/train and motorcycle/car driver/car passenger). See Section IV for further details on methodology. Table 2 presents car ownership and modal shares for 2006, and indicates that the majority of workers travelled by car in each of the four areas, followed by walking/cycling and public transport. However, it is clear that the range of options available to those in the Greater Dublin Area (i.e. Dublin city and county and commuter belt) is wider, with public transport really only attracting a significant number of commuters here. The proportion of households with at least one car is considerably higher in rural areas than in Dublin city and county. Consequently, the distribution of individuals across all six alternatives is more dispersed for Dublin city and county than for the other areas, in particular, rural areas.

[5] These observations are excluded as the modelling approach requires that alternatives be distinct and independent.

[6] To ease the computational burden, we take a 10 per cent random sample in each case.

[7] The electoral division (ED) is the smallest administrative area for which population statistics are published. There are 3,440 EDs in the state.

Table 1: *Sub-Sample Definitions and Selected Characteristics*

	Dublin City and County	*Commuter*	*Other Urban*	*Rural*
Definition	Dublin County Borough, Fingal, South Dublin, Dun Laoghaire-Rathdown	Kildare, Meath and Wicklow	Cork, Galway, Limerick and Waterford cities and EDs with residential density of 150 persons per km^2 or greater	EDs with residential density of fewer than 150 persons per km^2
Resident working population	494,370	187,779	377,649	504,532
Population density	4,097*	598	1,610	46
Average kilometres to work	10	21	11	18
Median kilometres to work	7	16	5	12
Public transport options	Extensive bus service; suburban coastal light rail line (DART); four radial suburban heavy rail lines (Commuter); two radial tram lines (LUAS)	Inter-urban bus and rail services; four radial suburban heavy rail lines (Commuter)	City bus services in cities with inter-urban bus and rail services; one suburban rail line in Cork	Inter-urban bus and rail services

Note: The samples exclude those who stated that they work at home, travelled by "other" means (including lorry or van), or did not answer the question (see also Section III).

Source: 2006 POWCAR.

*Despite having the highest population density in the country, Dublin is a low density city by European standards (see European Environment Agency, 2006).

Table 2: *Household Car Ownership and Mode of Transport to Work, 2006 (Full Population of Working Individuals 15+ Years; Percentage)*

	Dublin City and County	*Dublin Commuter Belt*	*Other Urban*	*Rural*
No household car	*14.5*	*4.7*	*12.0*	*2.8*
On foot or bicycle	6.9	2.7	8.1	1.7
Bus, train or LUAS	6.8	1.2	2.0	0.3
Motorcycle, scooter, car driver or passenger	0.8	0.8	1.9	0.8
At least one household car	*85.5*	*95.3*	*88.0*	*97.2*
On foot or bicycle	11.8	7.2	14.0	4.9
Bus, train or LUAS	17.0	9.2	3.2	1.3
Motorcycle, scooter, car driver or passenger	56.7	78.9	70.8	91.0
Total	100.0	100.0	100.0	100.0

Note: The samples exclude those who stated that they work at home, travelled by "other" means (including lorry or van), or did not answer the question (see also Section III).
Source: 2006 POWCAR.

Independent variables are individual as well as alternative-specific. While (self-reported) travel times for the individual's chosen mode are available in POWCAR, travel times for alternative modes are not. To estimate travel times for the non-chosen modes, we apply the method employed by De Palma and Rochat (2000). For alternatives not chosen, average travel times by mode are inserted. Alternative formulations of the travel time variable (using simple average travel times by mode) give similar results.[8] Cost information is not available in POWCAR. We construct a simple alternative-specific (monetary) cost per kilometre variable using information on public transport fares and car operating costs (including fuel). We assume zero costs for the walking and cycling modes (in common with others in the literature (see also Hole and FitzRoy, 2005).[9]

Individual-specific independent variables include the age of the individual (classified using a nine-category variable representing five-yearly age groups) and gender (with males regarded as the reference category). We also include a

[8] See the Appendix for discussion of alternative formulations of the travel time variable.
[9] Further details on the construction of the time and cost variables are available from the authors.

seven-category household composition variable to identify households with children, single parent households, other households etc. This is important as POWCAR does not include household identifiers, meaning that we cannot link household members. Individuals that are married[10] are indicated by a binary variable for marital status, as are individuals with third level education as their highest level of education completed. The socio-economic group of the individual is represented by a nine-category variable that identifies individuals in each socio-economic group, with those in the highest socio-economic group (employers and managers) regarded as the reference category. We include an eight-category indicator for industrial group, in an attempt to proxy job characteristics such as flexibility in working hours, provision of company vehicles etc. Individuals working in the commercial sector, the largest industrial group, are regarded as the reference category.

We also include dummy variables for those living and working in densely populated EDs (i.e. with 150 persons or more per square kilometre). This provides a crude proxy for public transport availability and parking provision with the expectation that those living and working in densely populated areas will have better public transport options and/or poorer parking availability than those living and working in less densely populated areas. We also construct a rail availability index based on ED-level data. This is a binary variable, which identifies individuals who live and work in EDs with 75 per cent of addresses within two kilometres of a rail station (for the Dublin city and county and commuter samples, the cut-off is 100 per cent due to the smaller size of the EDs). Using ArcGIS software, data from the An Post Geodirectory, matched with a dataset of rail station geo-locations, is employed for this estimation. The An Post Geodirectory is a complete database of the geographical locations of all addresses in Ireland, which we use to calculate the distance from each address to its nearest rail station. We then calculate the proportion of addresses in each ED which are within two kilometres of a station, in order to construct our index.[11] Potentially important omitted variables include cycle lane facilities,[12] bus service availability and more general indicators of public transport quality and frequency. Variable definitions and summary statistics are presented in Table 3.

[10] Co-habitation is not recorded in the Census.
[11] See Mayor *et al*., 2008 for further details.
[12] See Ewing *et al*., 2004 for a discussion of the effect of footpaths and cycle lanes on choice of mode of transport to school in Florida.

Table 3: *Variable Definitions and Summary Statistics, 2006 (Independent Variables)*

	Definition	*Dublin City and County*	*Commuter*	*Other Urban*	*Rural*
Age 25-29 years	=1 if aged 25-29 years	19.2	15.3	17.9	12.8
Age 30-34 years	=1 if aged 30-34 years	16.1	16.5	15.5	14.9
Age 35-39 years	=1 if aged 35-39 years	12.1	14.8	12.6	14.6
Age 40-44 years	=1 if aged 40-44 years	10.8	12.7	11.6	13.8
Age 45-49 years	=1 if aged 45-49 years	9.9	11.0	10.3	12.3
Age 50-54 years	=1 if aged 50-54 years	8.7	8.8	8.1	10.1
Age 55-59 years	=1 if aged 55-59 years	6.1	5.8	6.0	6.8
Age 60+ years	=1 if aged 60+ years	4.4	3.6	3.9	3.8
	(Reference category = aged 15-24 years)	12.7	11.5	14.1	10.9
Female	=1 if female	48.9	49.4	49.5	53.9
	(Reference category = male)	51.1	50.6	50.5	46.1
Lone parent with at least one resident child under 19 years	=1 if lone parent with children under 19 years	4.0	3.7	5.0	3.8
Lone parent with resident children but none under 19 years	=1 if lone parent with children over 19 years	3.9	3.1	3.5	4.1
Couple with at least one resident children under 19 years	=1 if couple with children under 19 years	32.7	44.4	35.4	48.7
Couple with resident children but none under 19 years	=1 if couple with children over 19 years	12.1	11.8	10.5	13.4
Couple with no resident children	=1 if couple with no resident children	18.1	19.7	17.5	17.2
Other households	=1 if other household types				
	(Reference category = single households)	19.8	10.8	18.5	6.7
		9.4	6.5	9.6	6.1
Ever married	=1 if married, separated/divorced, widowed	50.5	62.3	53.5	66.6
	(Reference category = single)	49.5	37.7	46.5	33.4
Third level	=1 if highest level of education completed is third level				
	(Reference category = less than third level)	55.0	47.0	46.3	41.9
		45.0	53.0	53.7	58.1
Higher professional	=1 if higher professional	12.4	7.9	9.2	6.5
Lower professional	=1 if lower professional	17.0	16.6	15.9	17.9
Non-manual	=1 if non-manual	31.3	30.5	31.0	29.9
Manual skilled	=1 if manual skilled	7.2	9.4	10.0	11.5

Table 3*: Variable Definitions and Summary Statistics, 2006 (Independent Variables) (contd.)*

	Definition	*Dublin City and County*	*Commuter*	*Other Urban*	*Rural*
Semi-skilled	=1 if semi-skilled	7.7	10.1	13.9	13.5
Unskilled	=1 if unskilled	2.6	2.6	3.4	2.9
Own account, farmers etc.	=1 if own account workers, farmers, agricultural workers	1.3	2.4	1.8	3.4
Other	=1 if all other gainfully occupied and unknown	0.2	0.2	0.2	0.2
	(Reference category = employers and managers)	20.3	20.3	14.6	14.2
Agriculture, forestry etc.	=1 if agriculture, forestry or fishing	0.3	1.3	0.6	2.2
Manufacturing	=1 if manufacturing, mining, quarrying, turf production, electricity, gas or water	10.5	17.7	19.9	20.1
Construction	=1 if construction	3.7	5.6	5.0	5.8
Transport	=1 if transport, storage or communications	7.4	5.0	4.9	3.9
Public administration	=1 if works in public administration or defence	8.0	7.7	6.4	6.8
Health, education, social	=1 if works in health, education or social work	19.5	19.5	21.8	25.5
Other	=1 if other	9.9	9.6	11.6	9.2
	(Reference category = commerce)	40.7	33.6	29.8	26.5
Population density (home)	=1 if population density of home ED is >=150 per km^2	98.4	63.0	*	*
Population density (work)	=1 if population density of work ED is >=150 per km^2	97.5	80.4	83.6	53.9
Rail available	=1 if lives and works in an ED where 100 per cent of addresses are within 2 kilometres of a rail station	35.0	3.8		
	(Reference category = does not live and work in such an ED)	65.0	96.2		
Rail available	=1 if lives and works in an ED where 75 per cent of addresses are within 2 kilometres of a rail station			19.4	2.0
	(Reference category = does not live and work in such an ED)			80.6	98.0

Note: The samples exclude those who stated that they work at home, travelled by "other" means (including lorry or van), or did not answer the question (see also Section III).

*As the urban and rural samples are defined on the basis of population density above and below 150 persons per km^2 (see Section III), the population density (home) variable drops out of the analysis in these two sub-samples.

IV METHODOLOGY

In this application, an individual chooses among six discrete alternatives (representing two car ownership alternatives and three mode of transport alternatives). We specify a conditional logit model, a particular type of discrete choice econometric method. The conditional logit model extends the multinomial logit model to include variables that describe the attributes of the choices (such as travel time), as well as variables that describe the attributes of the individuals (such as age or gender). Assume each individual i faces a choice between a set of J alternatives ($J = 1, 2, \ldots, J$), with the attributes of the choices described by z_{ij} and the characteristics of the individual described by x_i. The model is based on McFadden's random utility framework (see McFadden, 1974), in which each individual i aims to maximise their utility. The (unobserved) utility of each alternative is assumed to be a linear function of various independent variables and an error term as follows:

$$U_{ij}^{*} = x_i' \alpha_j + z_{ij} \beta + \varepsilon_{ij} \tag{1}$$

where U_{ij}^{*} is the unobserved utility individual i derives from alternative j, x_i is the vector of individual-specific independent variables, α_j is the vector of estimated parameters for the individual-specific variables, z_{ij} is the vector of alternative-specific variables, β is the vector of alternative-specific parameters and ε_{ij} is the error term. An individual i chooses alternative j if it gives the highest utility among all possible alternatives. The distributional assumptions concerning the random error component ε_{ij} determine the form of the model. The most common assumption is that the error terms are independently and identically distributed with a Type 1 Extreme Value (or Weibull) distribution, which results in the following probability of individual i choosing alternative j:

$$Pr\left(y_i = j\right) = \frac{\exp\left(x_i \alpha_j + z_{ij} \beta\right)}{\sum_{k=1}^{K} \exp\left(x_i \alpha_k + z_{ik} \beta\right)} \tag{2}$$

Conditional logit regression methods (using the *asclogit* command in STATA 10) are used to obtain estimates of the parameters α_j and β. The conditional logit model reduces to the multinomial logit model when all independent variables are individual-specific. As with the multinomial logit, a restrictive feature of the conditional logit model is the assumption of 'Independence from Irrelevant Alternatives' (IIA). The property implies that

the relative probabilities between a pair of alternatives are specified without reference to the nature of the other alternatives in the choice set. Hausman and Small-Hsiao tests of the IIA property have been developed for the multinomial logit and conditional logit models, but are prone to errors (see for example, Scott Long and Freese, 2006).[13] To test the appropriateness of the conditional logit methodology, we follow Salon (2009) and also estimate a nested logit model.

In order to estimate the conditional logit models, the data must be constructed in such a way that there are J observations for each individual i. As there are 35,528, 13,896, 26,899 and 35,292 individuals in our sample with complete information on all variables of interest respectively, this results in respective sample sizes of 213,168, 83,376, 161,394 and 211,752. Estimation results are presented in terms of odds ratios, with values greater than unity indicating an increased probability of observing the alternative in question, and values smaller than unity a reduced probability of observing the alternative in question (in comparison with the base alternative).

It is possible that each individual does not have access to the full range of alternatives, particularly in rural areas where public transport options may just not be available. We therefore estimate a second specification of the model with a restricted choice set. We consider walking and cycling to be unavailable for those travelling over ten kilometres to work and public transport to be unavailable for those living in EDs with fewer than 100 per cent of addresses within two kilometres of a rail station (see also Ewing *et al.*, 2004 and Hole and FitzRoy, 2005).[14] As very few individuals who travel by motorised means to work (motorcycle or car) live in households without a car, we also consider the case when this alternative is dropped from the model.[15] Reference to these results is made in Section V.

[13] To test the appropriateness of the conditional logit methodology, we follow Salon (2009) and also estimate a nested logit model. Results from the nested logit models are available on request from the authors. The assumption of independent alternatives is rejected for all samples. However, the majority of the inclusive values are greater than one, indicating that the estimated models are inconsistent with random utility maximisation. In addition, the nested logit models that are estimated here are also subject to restrictive assumptions in that they do not allow for alternatives to belong to more than one nest. Cross nested logit models would be more appropriate in this application; this is the subject of further research. For these reasons, we present results, and base our discussion, on results from the conditional logit models, while recognising their limitations.

[14] In the absence of more detailed information on public transport availability, access to rail services at the ED level is used here to proxy, albeit imperfectly, public transport availability.

[15] Results from these various robustness checks are available from the authors.

V EMPIRICAL RESULTS

Tables 4, 5, 6 and 7 present estimation results for the conditional logit models of car ownership and mode choice for each of the four sub-samples. Our travel cost variable is necessarily a crude approximation of the monetary costs associated with the various transport modes, but nonetheless, our results indicate that travel cost exerts a negative and significant effect for residents of the commuter counties, other urban areas and rural areas (as expected). The effect of travel cost is insignificant for residents of Dublin city and county. The cross elasticties[16] of travel time are highest for the car-motorised means alternatives, suggesting that an increase in travel time for this alternative is associated with proportionately large increases in the probability of other alternatives being chosen (e.g. in the commuter belt around Dublin, an increase of 1 per cent in travel time for those owning cars and choosing motorised means to work leads to a decline of 0.3 per cent in the probability of choosing that alternative, and a 1.3 per cent increase in the probability of the other alternatives).

The results for the individual-specific variables for Dublin city and county (Table 4), suggest that age has a significant influence on individuals' car ownership and mode choice decisions, with older age groups being significantly less likely to choose all car ownership-mode alternatives in comparison with the base alternative of owning a car and travelling by motorised means (motorcycle, car passenger or car driver) to work. Compared with the base alternative, females are significantly less likely to choose the no car-walk or cycle, no car-public transport and car-walk or cycle options. However, females in Dublin city and county are significantly more likely to choose the car-public transport option than males, perhaps reflecting competing demands on the household car which favour males and the significantly lower probability of females cycling to work which has been observed in other studies (see Commins and Nolan, 2008 and Pooley and Turnbull, 2000). Household composition also proves to be a significant determinant of car ownership and transport mode choice for the journey to work. Households with children are less likely to choose any of the no-car-owning alternatives, compared with single adult households. However, contrary to prior expectations, all other households are more likely to own a car but to walk, cycle or take public transport, than own a car and take motorised means to work, compared with single person households. This may suggest that car ownership is of more importance for non-work trips, particularly when there are children in the household. It may also reflect the

[16] Time and cost elasticities are available on request from the authors.

fact that our measure of car ownership refers to the number of cars or vans available for use by the *entire* household, rather than the individual commuter; as such, individuals in larger households face competition for the household car for the journey to work. Married individuals are significantly less likely to choose all other alternatives over the base alternative.

While higher education levels are negatively associated with the no-car-owning alternatives, those with a third level education in Dublin also have an increased probability of opting for public transport, despite owning a car. These divergent effects may suggest that the income effects associated with higher education, which are observed through the greater probability of car ownership, are counteracted by a greater awareness of the detrimental environmental effects of car driving among the higher educated, who choose more environmentally friendly modes of transport for commuting purposes. Socio-economic group, used as a proxy for household resources, is similarly significant. Those in lower socio-economic groups are more likely to choose any of the non-car owning alternatives, and more likely to walk, cycle or take public transport if they own a car, as expected. This may be picking up the effects of income, with the highest socio-economic group, employers and managers, more likely to own a car and drive to work than all other socio-economic groups. Compared to the commercial sector, all other industrial groups are less likely to choose the no-car alternatives. Most industries are also less likely to walk, cycle or take public transport in combination with car ownership. This may reflect the nature and locations of work in other industries, such as agriculture and construction, which may have a greater need for car ownership and use. Those in the commercial sector would be expected to have more regular working hours and greater access to public transport, thus making them more likely to walk, cycle or travel by public transport than other industrial groups. An exception is public sector workers, who are more likely to own a car but take public transport to work. Despite a recent survey which highlighted the high degree of free car parking available to public servants (i.e. those working in public administration) in the Dublin area,[17] other characteristics of these occupations such as the availability of subsidised public transport fares and/or their more regular working hours may make them more amenable to public transport.

Public transport availability is evidently an important consideration, as shown by the highly significant rail proximity variable. Those living and working in parts of Dublin city and county which are well serviced by rail are significantly more likely to choose all car ownership-mode combinations other

[17] The survey by the Dublin City Business Association suggested that up to 60 per cent of car parking spaces in Dublin city centre were used by public servants, the majority of whom have free parking (*The Irish Times*, June 16, 2008).

Table 4: *Dublin City and County (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Individual-specific variables					
Age 15-24 years	ref	ref	ref	ref	ref
Age 25-29 years	0.77***	0.68***	0.62**	0.66***	0.61***
Age 30-34 years	0.46***	0.44***	0.66*	0.61***	0.48***
Age 35-39 years	0.40***	0.40***	0.55**	0.51***	0.38***
Age 40-44 years	0.30***	0.31***	0.40***	0.50***	0.38***
Age 45-49 years	0.32***	0.36***	0.28***	0.55***	0.35***
Age 50-54 years	0.23***	0.29***	0.26***	0.46***	0.33***
Age 55-59 years	0.18***	0.27***	0.40***	0.43***	0.31***
Age 60+ years	0.15***	0.21***	0.21***	0.32***	0.33***
Male	ref	ref	ref	ref	ref
Female	0.67***	0.74***	0.57***	0.84***	1.14***
Single Person	ref	ref	ref	ref	ref
Lone parent with at least one resident child under 19 years	0.38***	0.33***	0.37***	0.82	1.06
Lone parent with resident children but none under 19 years	0.32***	0.49***	0.59*	1.06	1.91***
Couple with at least one resident child under 19 years	0.09***	0.11***	0.12***	1.07	1.40***
Couple with resident children but none under 19 years	0.11***	0.12***	0.15***	1.23**	2.16***
Couple with no resident children	0.49***	0.45***	0.27***	1.40***	1.82***
Other households	0.88	0.91	0.56***	2.42***	2.20***
Single	ref	ref	ref	ref	ref
Ever married	0.81***	0.74***	0.67**	0.79***	0.74***
Less than third level	ref	ref	ref	ref	ref
Third level	0.90	0.75***	0.57***	1.05	1.16***
Employers and managers	ref	ref	ref	ref	ref
Higher professional	1.70***	1.05	1.36	1.77***	1.23***
Lower professional	1.98***	1.65***	1.98**	1.64***	1.48***
Non-manual	3.67***	2.76***	3.06***	1.85***	1.67***

Table 4: *Dublin City and County (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger) (contd.)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Manual skilled	2.80***	1.90***	7.10***	1.58***	1.23**
Semi-skilled	6.08***	4.05***	6.69***	2.40***	1.41***
Unskilled manual	15.18***	11.20***	10.73***	3.99***	2.37***
Own account, farmers, agricultural workers etc.	0.84	0.68	1.65	0.77	0.65**
Other gainfully occupied and unknown	0.38	1.23	3.65	1.21	0.85
Agriculture, forestry and fishing	1.76	1.49	2.92	0.97	0.74
Manufacturing	0.67***	0.74***	0.96	0.62***	0.45***
Construction	0.62***	0.68***	0.60	0.35***	0.43***
Commerce	ref	ref	ref	ref	ref
Transport, storage and communications	0.68***	0.92	0.68	0.65***	0.82***
Public administration and defence	1.02	1.06	0.59	1.10	1.21***
Education, health and social work	0.79***	0.64***	0.76	0.71***	0.41***
Other industries	1.54***	1.43***	1.64**	0.98	0.79***
Population density (home)	2.76*	2.75**	1.13	1.23	1.57***
Population density (work)	1.14	0.97	0.49**	1.32	2.39***
Living and working in an ED with less than 100 per cent of addresses within 2 kilometres of a rail station	ref	ref	ref	ref	ref
Living and working in an ED with 100 per cent of addresses within 2kilometres of a rail station	3.72***	2.12***	1.50***	2.47***	1.66***
Alternative-specific variables					
Travel time			0.95***		
Travel cost			1.00		
Number of Observations			213,168		
Number of Individuals			35,528		
Log-Likelihood			–32,862.54		

*** Significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

than owning a car and travelling by motorised means, with the results for those choosing the no car-walking, cycling and public transport alternatives particularly significant. For instance, in comparison with living in a car-owning household and choosing a motorised means of transport to work, those living and working in areas with all addresses within 2 kilometres of a railway station are over two times as likely to choose the no car-public transport option, and over 3.7 times more likely to choose the no car-walking or cycle option. Population density at home and work displays effects that are generally consistent with expectations; for example, those living and working in densely populated areas are significantly more likely to choose the car-public transport option.

Results for the sample of those living in the commuter belt counties of Kildare, Meath and Wicklow (see Table 5) are broadly in line with those observed for Dublin city and county, with age, household composition, living and working in densely populated areas, and access to rail having the highest significance. These variables all have the same signs as previously outlined, with younger people, those working in densely populated areas and those living and working near a railway station significantly more likely to choose all car ownership-mode combinations over owning a car and travelling by motorised means to work. Individuals in lower socio-economic groups are also still more likely than those in the highest socio-economic group to choose any of the no-car alternatives or the car-walk or cycle alternative. Due to the smaller number of observations in this sample, the significance levels of some variables such as gender, marital status and industrial group fall. Once again, those working in public administration and defence are significantly more likely to choose the car-public transport option.

The results for other urban and rural areas (Tables 6 and 7 respectively) differ in some respects to the samples outlined above, partly due to smaller sample sizes and reduced significance levels. However, the main drivers of car ownership levels and transport mode choice are still clearly evident, in the significance of age, gender, household composition and socio-economic group. The results for the rail availability and work population density variables indicate some differences in comparison with the results for Dublin city and county and the commuter counties. For example, rail availability is less significant for the other urban and rural samples, reflecting the relatively poor availability of rail connections suitable for commuting outside the Greater Dublin Area.[18] While those working in densely populated areas

[18] Rail availability exerts a negative effect on the probability of choosing the public transport alternatives in the urban sample; why this is the case is unclear. It could reflect the fact that rail services in urban areas are generally only attractive for those undertaking inter-urban trips, and as such, are less attractive for the majority of commuters.

are significantly more likely to choose the car-public transport option in both urban and rural areas, those working in densely populated areas are significantly less likely to choose the walking or cycling alternatives in the rural sub-sample. Why this is the case is not entirely clear, although it is possible that conditions for walking and cycling in rural areas are so poor (no cycle lanes, poor lighting, lack of a continuous footpath etc.) as to make these alternatives unpopular even for those working in densely populated areas.

Comparing the results across the four sub-samples indicates differences in the effects of some variables, most notably for education, industrial group and work location population density. While in all cases the probability of choosing a no car alternative is lower among those with a third level education, the possible preference for more environmentally friendly modes of transport among higher educated car owners in Dublin city and county and the commuter counties is not reflected in other parts of the country (where the car-public transport alternative is significantly *less* likely to be chosen). Explaining these divergent effects is difficult although it is possible that education in the Dublin city and county or commuter samples may be correlated with other factors such as work or home location, which may not have been picked up by the aggregated nature of the dummy variables. The effect of workplace population density also differs across the four areas. In general, those resident in rural areas behave differently to those resident in the other three areas of the country; for example, while those working in areas with high population density are significantly more likely to choose the car-walk or cycle option in Dublin city and county, the commuter counties and other urban areas, rural residents who work in densely populated areas are significantly *less* likely to choose this option. The relative quality of walking and cycling facilities in rural areas may explain this counterintuitive result.

Some of our models are fitting better than others, in part due to amount of variation across alternatives and the quality of independent variables available to us. For example, the Dublin city and county sample has the highest significance levels for all variables, followed by the commuter counties. These areas are better serviced by public transport, and have lower car ownership levels, meaning that individuals are more likely to choose from a wider variety of alternatives than the other urban and rural areas. Finally, the small proportion of individuals choosing the no car-motorised means option leads to less significant results, although consistent with expectations (e.g. non-single households are significantly less likely to choose the no car-motorised option, perhaps reflecting competing household demands such as the presence of school-age children which would make car-sharing more attractive).

Table 5: *Commuter Counties – Kildare, Meath, Wicklow (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Individual-specific variables					
Age 15-24 years	ref	ref	ref	ref	ref
Age 25-29 years	0.96	0.77	1.14	0.65***	0.63***
Age 30-34 years	0.74	0.56*	0.75	0.39***	0.51***
Age 35-39 years	0.54**	0.27***	0.63	0.45***	0.43***
Age 40-44 years	0.92	0.35**	0.71	0.55***	0.37***
Age 45-49 years	0.66	0.69	0.29*	0.47***	0.40***
Age 50-54 years	0.39**	0.42*	0.45	0.44***	0.38***
Age 55-59 years	0.76	0.67	0.37	0.50***	0.32***
Age 60+ years	0.56	0.17**	0.19	0.62**	0.30***
Male	ref	ref	ref	ref	ref
Female	0.82	0.68**	0.43***	1.04	0.98
Single Person	ref	ref	ref	ref	ref
Lone parent with at least one resident child under 19 years	0.31***	0.49**	3.36**	0.88	0.88
Lone parent with resident children but none under 19 years	0.48**	0.60	0.82	2.34**	2.07***
Couple with at least one resident children under 19 years	0.06***	0.06***	0.17***	1.96**	1.31
Couple with resident child but none under 19 years	0.08***	0.07***	0.17***	2.15***	1.76***
Couple with no resident children	0.19***	0.24***	0.24***	2.08***	1.48***
Other households	0.97	0.68	1.74	5.10***	1.86***
Single	ref	ref	ref	ref	ref
Ever married	0.92	0.75	0.49**	1.06	0.79**
Less than third level	ref	ref	ref	ref	ref
Third level	0.58***	0.81	0.34***	0.85*	1.52***
Employers and managers	ref	ref	ref	ref	ref
Higher professional	0.77	1.79	3.31	1.63**	1.13
Lower professional	0.69	1.88*	2.31	0.99	0.99
Non-manual	2.29***	3.03***	3.57**	1.87***	1.10

Table 5: *Commuter Counties – Kildare, Meath, Wicklow (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Manual skilled	1.66	1.73	4.48**	1.22	0.49***
Semi-skilled	4.11***	3.28***	8.05***	2.03***	0.87
Unskilled manual	3.91***	6.67***	9.88***	3.93***	1.09
Own account, farmers, agricultural workers etc.	1.64	1.00	8.92***	1.66**	0.55
Other gainfully occupied and unknown	12.23***	1.00	24.57***	2.49**	0.97
Agriculture, forestry and fishing	0.94	1.00	1.91	2.06**	0.38
Manufacturing	0.77	0.66	1.63	0.64***	0.31***
Construction	0.36**	0.23**	1.17	0.43***	0.41***
Commerce	ref	ref	ref	ref	ref
Transport, storage and communications	0.62	0.80	0.47	0.52**	1.30*
Public administration and defence	0.75	0.58	0.76	0.64**	1.62***
Education, health and social work	0.82	0.49**	0.75	0.78*	0.51***
Other industries	1.35	1.26	1.47	1.09	0.67***
Population density (home)	1.28	5.09***	1.70**	1.62***	1.62****
Population density (work)	1.62**	1.32	0.46***	1.11	4.10***
Living and working in an ED with less than 100 per cent of addresses within 2kilometres of a rail station	ref	ref	ref	ref	ref
Living and working in an ED with 100 per cent of addresses within 2kilometres of a rail station	4.85***	1.72	1.94	2.60***	2.78***
Alternative-specific variables					
Travel time			0.95***		
Travel cost			0.89***		
Number of Observations			83,376		
Number of Individuals			13,896		
Log-Likelihood			–6,928.3		

*** Significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

Table 6: *Other Urban Areas (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Individual-specific variables					
Age 15-24 years	ref	ref	ref	ref	ref
Age 25-29 years	0.72***	0.73**	0.81	0.68***	0.60***
Age 30-34 years	0.47***	0.61***	0.78	0.54***	0.53***
Age 35-39 years	0.39***	0.39***	0.80	0.54***	0.56***
Age 40-44 years	0.40***	0.42***	0.76	0.65***	0.53***
Age 45-49 years	0.43***	0.45***	0.43***	0.64***	0.49***
Age 50-54 years	0.53***	0.24***	0.73	0.64***	0.36***
Age 55-59 years	0.34***	0.65*	0.56*	0.60***	0.42***
Age 60+ years	0.21***	0.36***	0.52*	0.46***	0.38***
Male	ref	ref	ref	ref	ref
Female	0.64***	0.80**	1.00	0.98	1.15
Single Person	ref	ref	ref	ref	ref
Lone parent with at least one resident child under 19 years	0.45***	0.39***	0.65*	0.72**	1.16
Lone parent with resident children but none under 19 years	0.49***	0.47***	0.54**	1.66***	2.12***
Couple with at least one resident children under 19 years	0.09***	0.08***	0.19***	1.05	1.18
Couple with resident child but none under 19 years	0.07***	0.11***	0.09***	1.35***	2.16***
Couple with no resident children	0.27***	0.29***	0.28***	1.31***	1.85***
Other households	0.88	1.05	0.90	2.95***	3.09***
Single	ref	ref	ref	ref	ref
Ever married	1.03	0.91	0.69***	0.92	0.68***
Less than third level	ref	ref	ref	ref	ref
Third level	0.69***	0.86	0.63***	0.84***	1.01
Employers and managers	ref	ref	ref	ref	ref
Higher professional	0.71*	0.73	0.70	1.16	1.66**
Lower professional	1.18	1.44	1.57	1.03	1.61**
Non-manual	3.17***	3.33***	2.32***	1.91***	2.33***

Table 6: *Other Urban Areas (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger) (contd.)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Manual skilled	3.51***	2.41***	4.83***	1.68***	2.15***
Semi-skilled	4.51***	4.19***	6.96***	2.09***	3.08***
Unskilled manual	10.43***	7.87***	14.10***	3.13***	3.01***
Own account, farmers, agricultural workers etc.	0.66	0.88	0.56	0.99	1.03
Other gainfully occupied and unknown	3.96**	12.94***	8.35***	2.54*	4.39*
Agriculture, forestry and fishing	2.53**	2.42	4.00***	0.99	0.88
Manufacturing	0.86*	1.36**	1.02	0.66***	0.60***
Construction	0.53***	0.58*	1.16	0.52***	0.51***
Commerce	ref	ref	ref	ref	ref
Transport, storage and communications	0.30***	1.18	0.50**	0.76**	0.81
Public administration and defence	0.42***	0.55**	0.56**	0.54***	0.56***
Education, health and social work	0.93	0.58***	0.46***	0.84***	0.50***
Other industries	1.83***	1.78***	1.21	1.46***	1.05
Population density (work)	1.12	1.14	0.55***	1.81***	1.30**
Living and working in an ED with less than 75 per cent of addresses within 2 kilometres of a rail station	ref	ref	ref	ref	ref
Living and working in an ED with greater than 75 per cent of addresses within 2 kilometres of a rail station	2.41***	0.47***	1.04	1.86***	0.56***
Alternative-specific variables					
Travel time			0.94***		
Travel cost			0.95***		
Number of Observations			161,394		
Number of Individuals			26,899		
Log-Likelihood			–17,329.8		

*** Significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

Table 7: *Rural Areas (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Individual-specific variables					
Age 15-24 years	ref	ref	ref	ref	ref
Age 25-29 years	1.18	1.36	0.88	0.79**	0.53***
Age 30-34 years	0.77	0.77	0.97	0.55***	0.46***
Age 35-39 years	0.59**	0.32*	0.68	0.68***	0.52***
Age 40-44 years	0.80	0.82	0.66	0.60***	0.56***
Age 45-49 years	0.62*	0.79	0.86	0.73**	0.45***
Age 50-54 years	0.58**	1.12	0.95	0.67***	0.66*
Age 55-59 years	0.51**	0.54	0.90	0.60***	0.83
Age 60+ years	0.26***	0.53	0.52	0.63***	0.62
Male	ref	ref	ref	ref	ref
Female	0.81*	0.57*	0.97	0.93	1.55***
Single Person	ref	ref	ref	ref	ref
Lone parent with at least one resident child under 19 years	0.44***	0.22**	0.71	0.62**	3.27***
Lone parent with resident children but none under 19 years	0.35***	0.51	0.53***	1.09	4.30***
Couple with at least one resident children under 19 years	0.05***	0.02***	0.06***	0.82	3.60***
Couple with resident child but none under 19 years	0.07***	0.07***	0.06***	0.90	3.75***
Couple with no resident children	0.21***	0.08**	0.11***	0.95	4.09***
Other households	1.11	25	0.76	2.23***	5.32***
Single	ref	ref	ref	ref	ref
Ever married	1.07	0.91	0.76	0.85*	0.39***
Less than third level	ref	ref	ref	ref	ref
Third level	0.59***	0.39**	0.40***	0.93	0.70***
Employers and managers	ref	ref	ref	ref	ref
Higher professional	0.78	1.00	0.70***	0.57***	1.27
Lower professional	1.07	0.83	3.61***	0.55*	1.08
Non-manual	3.59***	4.16**	3.35***	1.19*	1.52**

Table 7: *Rural Areas (Odds Ratios – Reference Choice is Car Owner and Motorcycle, Car Driver or Car Passenger) (contd.)*

	No Car			*One or More Cars*	
	On Foot or Bicycle	*Bus or Train*	*Motorcycle, Car Driver, Car Passenger*	*On Foot or Bicycle*	*Bus or Train*
Manual skilled	3.66***	2.54	7.32***	1.12	2.03***
Semi-skilled	4.53***	5.01***	8.18***	1.11	1.28
Unskilled manual	6.67***	4.19*	11.45***	2.09***	1.75*
Own account, farmers, agricultural workers etc.	1.47	1.90	3.48**	1.72***	1.02
Other gainfully occupied and unknown	3.03	1.00	6.89*	0.48	1.82
Agriculture, forestry and fishing	4.64***	4.23**	2.37**	0.89	1.35
Manufacturing	0.89	0.89	1.04	0.75***	0.37***
Construction	0.74	0.55	1.17	0.41***	0.36***
Commerce	ref	ref	ref	ref	ref
Transport, storage and communications	0.36**	0.25	0.25**	0.94	1.67**
Public administration and defence	0.38**	0.82	0.44*	0.63**	1.34
Education, health and social work	0.92	1.16	0.77	0.86	0.76*
Other industries	2.64***	1.28	1.53*	1.47***	1.10
Population density (work)	0.41***	0.98	0.45***	0.34***	2.29***
Living and working in an ED with less than 75 per cent of addresses within 2 kilometres of a rail station	ref	ref	ref	ref	ref
Living and working in an ED with greater than 75 per cent of addresses within 2 kilometres of a rail station	4.21***	3.59**	1.31	1.76***	1.46
Alternative-specific variables					
Travel time			0.95***		
Travel cost			0.94***		
Number of Observations			211,752		
Number of Individuals			35,292		
Log-Likelihood			–8,775.6		

*** Significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

Nonetheless, the results from all four samples give a clear indication that the dominant socio-economic influences on car ownership and modal choice are age, gender, household composition and socio-economic group, regardless of household location. Regional characteristics, such as work and home location are also significant. The strong effects of travel time, along with the positive results for rail availability, suggest some scope for policy intervention. The impact of rail proximity on the probability of travel by public transport suggests that there would be positive effects from the provision of better quality public transport. It would be interesting to test the relative popularity of bus and rail services, given international evidence on potential for rail services (which are not subject to congestion in the same way as bus services) to divert significant amounts of commuters away from motorised means (see for example, Webster and Bly, 1980). A change in the relative time or monetary costs of public transport relative to driving a car are also likely to make these more sustainable modes more attractive to commuters. Faster or cheaper public transport journeys, or relatively more expensive car trips, perhaps through the introduction of road pricing or carbon taxes have the potential to induce modal shifts. However, influencing behaviour that is associated with individual or household characteristics is more challenging.

We also estimated alternative models for each of the four sub-samples, based on a restricted choice set. In rural areas in particular, it is questionable whether all alternatives are available to all commuters. To restrict the choice set, we exclude walking and cycling as an alternative where the individual travels more than ten kilometres to work, and exclude public transport as an alternative where the individual lives in an area with poor rail availability. The results[19] are largely consistent with those from the unrestricted models, although significance levels fall.

Finally, we also estimated a simple joint residential location-car ownership-mode choice model for the Dublin city and county sample.[20] Our analysis thus far has assumed that residential location is exogenous, but of course, an individuals' mode of transport to work (or preferred mode of transport to work) may also influence their residential location. We estimated a model with twelve alternatives, comprising two residential locations (Dublin city centre and not), two car ownership levels (no car and one or more cars) and three modes of transport (walk/cycle, public transport and motorised means). Most of the variables have similar effects on the joint residential location-car ownership-mode decision, with age, gender, household composition, socio-economic group, rail availability and working densely populated

[19] Results are available on request from the authors.
[20] Results are available on request from the authors.

areas having particularly consistent effects. The divergent effects of education found for the joint car ownership-mode choice model, where those with a third level education are significantly more likely to choose the car-walk or cycle and car-public transport options, is replicated here, where those with a third level education are significantly *more* likely to choose the outside city centre-car-public transport option (with no significant difference in the effect of education on the car-public transport option, however).

VI SUMMARY AND CONCLUSIONS

Despite the limitations associated with using Census of Population data to examine modal choice decisions (see Section III), the results highlight the importance of individual demographic and socio-economic characteristics, travel times and costs, as well as regional and travel variables such as rail availability and home and work location in explaining the joint car ownership-mode of transport decision in Ireland.

In the Greater Dublin Area, those working in densely populated areas are significantly more likely to choose the car-walk or cycle and car-public transport options, indicating the effect of public transport availability and city centre parking difficulties and restrictions. The significant positive results observed for public transport use by those working in densely populated areas also add weight to the argument for the development of more concentrated employment districts, to reverse the trends of employment suburbanisation and urban sprawl, which increase car dependence. In addition, in comparison with those with poor rail availability, those living and working in EDs with good rail facilities are in general significantly more likely to choose all options in favour of owning a car and travelling by motorised means to work. This reflects the importance of public transport provision in influencing modal choice. In other urban and rural areas, rail availability and home and work location exert less significant effects, although the results are similar in effect and indicate the importance of public transport provision and parking restrictions on modal choice decisions.

The importance of household or family interactions in determining travel behaviour is confirmed by the significance of age, gender, household type and marital status. Non-single households are significantly less likely to choose the no car options, while females are also significantly less likely to choose these options (but are significantly more likely to choose the car-public transport option). Individual modal choice decisions are often made with reference to other members of the household, in particular with regard to the needs and schedules of school-age children and/or the availability of the

household car. In recent years, the proportion of schoolchildren being driven to school has increased substantially, and while the results here are static, the results for household type and marital status to some extent reflect this situation with individuals in households with young children in particular being significantly less likely to choose the no car options.

Of course, the research is subject to a number of caveats. We assume that residential location (and indeed work location) is exogenous but it is possible that individuals make their housing and work location decisions on the basis of (preferred) travel arrangements. We have however made an attempt to estimate a joint residential location-car ownership-mode choice model for the Dublin city and county sample and obtained results which are consistent with expectations (e.g. those living and working near railway stations are significantly more likely to choose all residential location-car ownership-mode options over living outside the city centre, owning a car and travelling by motorised means to work). A further limitation of this analysis concerns the nature of the data available; in particular, information on alternative characteristics such as in-vehicle time, waiting time, and public transport frequency is simply not available. Our data is also lacking any information on other household members' travel patterns, such as the necessity of dropping children to school, which may influence the car ownership and mode choice decision of an individual. Other potentially important omitted variables include information on the provision of bus services at a detailed regional level and the provision of other services such as cycle lanes, park and ride facilities and dedicated road space for buses.

While necessarily crude, our travel time and cost measures indicate the importance of alternative-specific factors in influencing travel behaviour. A change in the relative time or monetary costs of public transport relative to driving a car are likely to make these more sustainable modes more attractive to commuters. For example, in rural areas, increasing the cost of a commuting journey for those who have a car and drive to work by 1 per cent reduces the probability of that alternative being chosen by approximately 0.06 per cent (and increases the probability of alternatives being chosen by 0.7 per cent), while the respective changes for a similar increase in travel time are approximately 0.09 per cent and 1.1 per cent.[21] Faster or cheaper public transport journeys, or relatively more expensive car trips, perhaps through the introduction of road pricing or carbon taxes have the potential to induce modal shifts. The results, while subject to concerns over the reliability of our time and cost measures, suggest that travel time in general exerts a stronger influence on individual travel behaviour. In this context, measures which seek

[21] Full details on time and cost elasticities are available on request from the authors.

to make more sustainable modes of transport more comparable with the private car in terms of journey times (e.g., dedicated cycle and bus lanes, more frequent public transport services etc.) may be just as important as monetary incentives in inducing individuals to travel by more sustainable forms of transport.

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APPENDIX
COMPUTING INDIVIDUAL TRAVEL TIMES

In POWCAR, individuals record the travel time (in minutes) of their chosen mode. Travel times for alternative, non-chosen modes of transport are therefore not available. To compute travel times for the non-chosen modes, a number of methods have been suggested in the literature. Here we investigate three such methods and compare the estimated parameters.

The first method uses a simple individual-specific average travel time for the non-chosen modes. The second uses a method suggested by De Palma and Rochat (2000), whereby the missing travel times for alternative modes are replaced with the average travel time for these modes. The third follows the approach adopted by Hole and FitzRoy (2005), where the travel times for the alternative modes are calculated by regressing travel time on distance for each mode and using the estimated regression equations to calculate travel times for the non-chosen modes for all individuals in the sample.

The estimated odds ratios using the three different formulations of the travel time variable are presented in Table A1 below. As expected, the results from the average and De Palma and Rochat methods are very similar. The results from the Hole and FitzRoy method are smaller in all cases, although still highly significant. For the remaining independent variables, the estimated results are very similar using the three different formulations of the travel time variable.

All measures are potentially subject to selection bias, as the records of those who choose a particular mode are used to infer values for those who do not choose that mode. This is a common problem in analyses of this type (see discussion in De Palma and Rochat, 2000). However, as the De Palma and Rochat method makes the best use of the available data (by using the actual travel time for the chosen mode), we regard the estimates from the De Palma and Rochat method as most robust.

Table A1: *Odds Ratios on Travel Time Variables*

	DUBCC	*COMMUTER*	*URBAN*	*RURAL*
Average	0.95 ***	0.93 ***	0.94 ***	0.93 ***
De Palma and Rochat	0.95 ***	0.95 ***	0.94 ***	0.95 ***
Hole and FitzRoy	0.78 ***	0.75 ***	0.83 ***	0.75 ***