ESTIMATING THE INCOME AND SOCIO-ECONOMIC DETERMINANTS OF THE DEMAND FOR TRANSPORT USING HOUSEHOLD MICRO-DATA

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DECLARATION

I declare that this thesis, submitted to Trinity College Dublin for the degree of Doctor in Philosophy (Ph.D.), has not been submitted as an exercise for a degree at this or any other university. All research contained herewith is entirely my own.

I also authorise the Library of Trinity College Dublin to lend or copy this thesis upon request.

Date 16th April 2003

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SUMMARY

The purpose of this thesis is to examine the income and socio-economic determinants of transport demand, using Dublin as a case study.

Chapter 1 sets the context by discussing the problem of excessive car use in urban areas and the increasing movement away from earlier policies that were primarily concerned with expanding road capacity towards a more integrated solution encompassing investment in public transport and measures such as improved cycle and bus lanes, parking restrictions and road pricing. In this context, the need for a better understanding of the income and socio-economic factors influencing the demand for urban transport is highlighted.

Chapter 2 discusses previous literature relevant to the analyses in this thesis. The discussion is grouped into the three broad areas that form the basis of the core chapters, namely car ownership and use (Chapter 5), public transport use (Chapter 6) and modal choice (Chapter 7). Chapter 3 motivates the use of Dublin as a case study by documenting the rapid economic and demographic changes that have occurred in Dublin over the last fifteen years and assesses the implications for patterns of travel to work, school and college. Chapter 4 introduces the two micro-data sets that are employed in this thesis, namely the 1987/1988, 1994/1995 and 1999/2000 Household Budget Surveys and the 1996 Census of Population. Issues such as sample sizes and the choice of dependent and independent variables are discussed and broad relationships between the dependent and independent variables are presented. This chapter also describes the procedure whereby information from the 1994/1995 Household Budget Survey is used to supplement the data from the 1996 Census of Population, which is used in Chapter 7.

In Chapter 5, the factors influencing variations in household car ownership and use are examined. Using Household Budget Survey data from 1987/1988, 1994/1995 and

1999/2000, binary probit models of car ownership and Tobit models of car use, as proxied by petrol expenditures, are estimated for each individual year. In an attempt to identify changes in the relationships over the period 1987-2000, the models are also estimated for the pooled sample. Where appropriate, adjustments are made to the models to account for heteroscedastic and/or non-normal errors. The results highlight the significance of income and socio-economic characteristics in determining variations in household car ownership and use, with the income elasticities suggesting that car ownership has changed from being a luxury to a necessity over the period 1987-2000. In comparison, the demand for car use may be consistently classified as a necessity.

Chapter 6 extends the analysis in Chapter 5 to incorporate household decisions about bus and taxi use. Using per capita bus and taxi fare expenditures to proxy bus and taxi use, Tobit models are estimated for each individual year and for the pooled sample. Once again, adjustments to the models to account for heteroscedastic and/or non-normal errors are considered. The results indicate clear differences in the effect of the income and socio-economic characteristics on bus and taxi use for households with differing levels of car ownership. In addition, the fact that household characteristics such as income and gender exert differing effects on bus and taxi use highlights the need to analyse public transport at more disaggregated levels.

Chapter 7 estimates multinomial logit models of the modal choice decisions of workers and students in an attempt to ascertain whether the factors influencing overall levels of transport use found in Chapters 5 and 6 are any different to those influencing travel for two specific purposes, i.e., the journeys to work and school/college. A new development is the extension of the analysis to incorporate the journey to school/college, a journey purpose overlooked in previous applications. In addition, the availability of data on distance and area of residence, which are not available for the analyses in Chapters 5 and 6, enables the quantification of the influence of these important factors on modal choice.

Chapter 8 provides an overview of the thesis, summarises the main findings, discusses policy implications and presents issues for future research.

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CHAPTER 1

INTRODUCTION

1.1 Setting the Context

Over the last twenty years, the demand for passenger transport worldwide has increased greatly. While car ownership and use have grown rapidly over this period, walking, cycling and using public transport have declined in popularity with the end result that passenger transport is increasingly dominated by the private car. For example, data for the UK indicate that while the number of journeys per person per year grew by 12.4 per cent between 1975 and 1998, the number of car journeys increased by 47.8 per cent in comparison to the number of journeys on foot, by bicycle and by public transport (bus and train) which declined by 11.4 per cent, 46.7 per cent and 27.6 per cent respectively [UK DETR (2001f)]. This shift towards the private car is increasingly regarded as unsustainable on economic, environmental and social grounds, and in particular for urban areas where the primary consequences of increasing car use, namely congestion, pollution, community severance, sprawl and peripheral development and inaccessibility due to car dependence, are particularly severe [see OECD (1995)].

There is therefore a perceived need to reverse or at the very least to halt this shift in favour of the private car. In the past, the dominant strategy was to "predict and provide", i.e., to respond to the projected increase in travel demand by increasing capacity, principally on the road network [Madden (2001) and Hey and Sheldrake (1997)]. The failing of continued investment in infrastructure is that it often gives rise to latent demand so that the alleviation of congestion is considerably less than originally envisaged [Madden (2001)]. Recent thinking has moved away from the emphasis on increasing road capacity towards a variety of measures that seek to limit or redirect travel demand in the short- to medium-term and alternative more sustainable land-use strategies in the longer term [Madden (2001), Dublin Transportation Office (2000), Department of the Environment and Local Government (1999), Pucher and Lefevre (1997) and O'Sullivan (1991)]. 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 and tolling 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.

In this context, a knowledge of the factors influencing the demand for transport is crucial. Button (1993) identifies a number of factors, namely income, price, price of alternatives and tastes and preferences[1], which influence the demand for transport. The contribution of income and socio-economic characteristics, which are outside of the control of the government or transport operators, are increasingly regarded as important determinants of transport demand [see Johansson-Stenman (2002), Bergantino (1997) and Webster and Bly (1980)]. Indeed, the OECD cites changes in the socio-economic characteristics of the

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[1] Button (1993) interprets tastes and preferences to include primarily the socio-economic characteristics of the decision-maker [see also Section 2.2].

population such as increasing average incomes and car ownership rates, the reduction in average household size, the increased participation by women in the labour force, changing lifestyles and changing settlement structures as the primary causes of the shift towards the private car in urban transport [1995]. An understanding of the income and socio-economic influences on transport demand is important for a number of reasons:

- Forecasting

With rapidly changing economic and demographic structures in many urban areas, a knowledge of the influence of income and socio-economic factors on the various components of transport demand (such as car ownership and use) is necessary for forecasting future levels of transport demand and for planning accordingly.

- Targeting

An understanding of the way in which income and socio-economic factors influence the demand for transport may assist in the identification of categories of traveller that need to be targeted if a shift in modal split away from the private car towards walking, cycling and using public transport is to be achieved.

- Assessing

With the increasing popularity of measures that aim to redirect the demand for transport towards more sustainable modes, a detailed knowledge of the effects of income and socio-economic characteristics on transport demand is useful for assessing the distributional impacts of these measures (e.g. road pricing, tolling).

The increasing availability of micro-data in recent years has enabled researchers to focus on the income and socio-economic determinants of transport demand. The primary advantage of cross-sectional micro-data over aggregate time-series data, for example, is the ability to incorporate a much wider variety of socio-economic characteristics, such as household size and composition, gender, age and level of education, as explanatory factors.[2] The demand for transport at the cross-sectional level may be analysed on a number of different levels such as expenditure, modal split, journey purpose, number of trips *etc.* but the majority of studies concentrate on three areas: (i) car ownership and use, (ii) public transport use and (iii) modal choice for specific journeys, principally the journey to work. It is these three areas that form the core of the thesis in Chapters 5, 6 and 7 respectively and recent approaches to analysing the demand for car ownership and use, public transport use and modal choice are discussed in Chapter 2.

Dublin[3] displays all the features of a rapidly growing urban area struggling with the economic, environmental and social consequences of excessive car use. Indeed, Dublin has experienced a more rapid descent into transport chaos than many other urban areas by virtue of spectacular rates of economic growth in the 1990s and the increase in travel demand that accompanied this rapid economic and demographic change. Over the period 1986-2002, the population of Dublin has grown by 9.9 per cent while the numbers in employment have increased by 61.5 per cent, much of which was due to rapidly increasing rates of female participation in the labour force [see Tables 3.1 and 3.3]. As a consequence, the number of peak hour trips in Dublin has increased by 64.5 per cent between 1991 and 1997 while the number of off-peak trips has increased by 67.3 per cent

[2] In addition, the larger sample sizes that characterise micro-data sets allow for a richer econometric specification and generally involve less multicollinearity among the explanatory variables [McCarthy (1996)].
[3] The terms "Dublin" or the "Dublin area" throughout this thesis refer to four local authority regions of Dublin County Borough, Dun Laoghaire-Rathdown, Fingal and South Dublin [see Figure 3.1].

over the same period, with car journeys accounting for over 70 per cent of these trips and increasing continuously [Dublin Transportation Office (2000)]. Data for journeys to work, school and college confirm this shift towards the private car with the proportions driving their car to work increasing from 38.1 per cent in 1986 to 50.3 per cent in 2000 with a consequent decline in the proportions cycling (from 8.5 per cent to 3.7 per cent) and using the bus to travel to work (from 20.5 per cent to 16.1 per cent) [see Table 3.10]. The trend towards the private car is also evident in the shift towards transporting children to school by car as the proportions of primary and secondary school students travelling to school as passengers in a car in Dun Laoghaire-Rathdown are now greater than the proportions walking, which has traditionally been the primary means of transport to school [see Tables 3.17, 3.19, 3.21 and 3.23].

As in many other urban areas, responses to increasing levels of car use in Dublin have primarily focused on the implementation of major infrastructural projects, especially in light of generous EU funding and budget surpluses in the 1990s. The earlier attempts to tackle the transport problems in Dublin almost exclusively focused on the need for expanding capacity, principally on the road network in and around the city [see the Dublin Transportation Strategy of 1972 and the Dublin Rail Rapid Transit Study of 1975]. From 1980 onwards with the Transport Consultative Commission Report on Public Transport, there has been a growing recognition that short-term low cost measures to curb car use, such as bus lanes and parking restrictions, could also have a significant role to play in alleviating traffic congestion. Their importance has been further strengthened with delays in major infrastructural projects in the 1990s and early 2000s, such as the LUAS light rail project and the Port Tunnel. Both the Dublin Transportation Office and the Department of Public Enterprise now explicitly recommend an integrated solution to the urban transport problem, encompassing a variety of measures such as investment in public transport, improved cycle and bus lanes, park and ride facilities, parking restrictions in the city centre, road pricing and tolling [see Dublin Transportation Office (2000) and Department of Public Enterprise (1999)]. The success of the Quality Bus Corridors (QBCs) introduced by Dublin Corporation highlight the significant change in behaviour that can be achieved when restrictions on car use and a corresponding improvement in the bus service are implemented.[4]

1.2 Aims of the Thesis

In light of the growing interest in measures aimed at limiting or redirecting the demand for transport towards more sustainable modes, this thesis is concerned with assessing the income and socio-economic influences on transport demand and examining the extent to which these influences changed over the period 1987-2000, using Dublin as a case study. While Button (1993) identifies price in addition to income and tastes and preferences as important determinants of the demand for transport, the nature of the data precludes an examination of the influence of price on transport demand in this thesis.

In addition to chapters reviewing previous literature, discussing travel patterns in Dublin and describing the micro-data sets that are employed in this thesis, the thesis comprises

[4] Dublin Bus (2002) claim that there has been a 243 per cent increase in peak hour passengers on the Stillorgan QBC and a 24 per cent, 44 per cent and 39 per cent increase in peak hour passengers on the Tallaght, Malahide and Rathfarnham QBCs respectively over the period 1995-1999. The much higher increase for the Stillorgan QBC reflects the substantial increase in bus capacity that accompanied the introduction of the QBC on this route [Department of Public Enterprise (1999)].

three core chapters. Chapter 5 examines the demand for car ownership and use at the household level in Dublin using data from the 1987/1988, 1994/1995 and 1999/2000 Irish Household Budget Surveys. The income and socio-economic influences on household car ownership and use are examined separately for each year using binary probit and Tobit econometric methodologies. The models are then estimated using pooled data from the three surveys to identify changes in the relationships between household car ownership and use and the socio-economic factors over the period 1987-2000. Chapter 6 extends the analysis in Chapter 5 to consider household decisions about public transport use, distinguishing separately bus use and taxi use, which in most studies are analysed jointly. In a new development, bus and taxi fare expenditures are used to proxy bus and taxi use and Tobit models are estimated. In addition, the variations in bus and taxi use are examined based on the car ownership status of the household, to identify if there are any significant differences in the effects of the socio-economic variables depending on the car ownership status of the household. As in Chapter 5, changes over time in public transport use are analysed using the pooled data.

In Chapter 7, the transport decisions of Dublin individuals are analysed for specific journey purposes, namely, the journey to work and the journey to school/college. Combining micro-data from the 1996 Irish Census of Population with Household Budget Survey data for 1994/1995, the socio-economic influences on choice of mode of transport for the journeys to work and school/college are examined using the multinomial logit econometric methodology.

This is the first time that micro-data have been used to analyse the demand for transport in Ireland, whether car ownership and use, public transport use or modal choice decisions for specific journey purposes. While previous research has examined transport expenditures [see Section 2.4], this is the first time that expenditure data have been used to proxy bus and taxi use separately. In addition, while most studies of modal choice concentrate on the journey to work [see Section 2.5], this thesis also examines the modal choice decisions of students using micro-data for the first time.

1.3 Structure of the Thesis

Chapter 2 discusses previous research related to the estimation of the demand for transport using micro-data. The studies are grouped into three areas, i.e., car ownership and use, public transport use and modal choice decisions. These groups broadly correspond to the subjects of Chapters 5, 6 and 7 respectively. Chapter 3 briefly outlines the economic and demographic changes that have occurred in the Dublin area over the last fifteen years and their implications for travel patterns to work, school and college. Chapter 4 introduces the 1987/1988, 1994/1995 and 1999/2000 Household Budget Surveys, which are the datasets that are used in the analyses in Chapters 5 and 6 and the 1996 Census of Population, which is the dataset used in Chapter 7. In Chapter 5, the car ownership and use decisions of Dublin households are examined, while in Chapter 6 the public transport use decisions of these households are analysed. In Chapter 7, the modal choice decisions of Dublin workers and students are studied. Chapter 8 concludes by summarising the main findings, discussing policy recommendations and presenting areas for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As discussed in Chapter 1, in urban areas across the industrialised world, car ownership and use have grown rapidly over the last few decades. In contrast, the proportions walking, cycling and using public transport have either fallen or remained stable with the end result that urban travel has become increasingly dominated by the private car. This shift towards the car is increasingly seen as unsustainable on economic, environmental and social grounds. A growing interest in the role of measures that seek to redirect transport demand towards more sustainable modes rather than traditional "predict and provide" responses to the problem of excessive car use in urban areas necessitates a more thorough examination of the factors underlying the demand for transport. The increasing availability of micro-data has enabled researchers to examine the influence of a range of factors such as income, price and socio-economic characteristics on the demand for transport, analyses that were not possible using aggregated cross-section or time-series data. The influence of income and socio-economic characteristics is especially important; the shift away from walking, cycling and public transport towards car use was mainly the result of increasing average incomes and car ownership rates, the reduction in average household size, the increased participation by women in the labour force, changing lifestyles and changing settlement structures in urban areas [OECD (1995)].

In this thesis, the income and socio-economic factors influencing the demand for transport are analysed. In Chapters 5 and 6, household level data are used to analyse the determinants of a number of household transport decisions, namely car ownership, car use and public transport use. In Chapter 7, individual level data are employed to examine the socio-economic factors determining an individual's choice of mode of transport for the journey to work and school/college. The purpose of this chapter is to review previous literature relevant to the three issues examined in Chapters 5, 6 and 7, namely, car ownership and use, public transport use and modal choice respectively. Despite differences in data sources, time periods, econometric methodologies and dependent variables, a number of common results emerge. Section 2.2 briefly outlines basic principles in transport demand modelling. Section 2.3 discusses studies examining the issues of car ownership and use while Section 2.4 reviews previous research related to the demand for public transport. Section 2.5 examines studies concerned with estimating modal choice models, mainly for the journey to work. Section 2.6 summarises and concludes the chapter.

2.2 Transport Demand

This thesis concentrates on the microeconomic approach to transport demand modelling which attempts to explain transport behaviour at the individual or household level, using a wide range of variables as explanatory factors.[5] As outlined in Button (1993), standard

[5] Pollak and Heertje (1993) and Domencich and McFadden (1975) provide overviews of alternatives to the microeconomic approach, namely, four-stage transport models concerned with analysing trip generation, trip distribution, modal choice and route choice between different zones at a particular point in time and the activity based approach, which analyses travel behaviour in the wider context of an individual's or household's daily, weekly or monthly activity patterns.

economic theory postulates that the demand for any commodity is determined by four broad factors, i.e.,

$$D_T = f(Y, P_T, P_O, T) \qquad (2.1)$$

where D_T represents the demand for transport[6], Y represents income, P_T represents the price of the transport commodity desired, P_O represents the price of other transport goods and T represents tastes and preferences. The price of transport includes not only the money costs of transport such as public transport fares, motor expenses and car parking charges but also time costs.[7] Tastes and preferences are the final determinant of transport demand and encompass a wide variety of factors, principally the socio-economic characteristics of the individual, household or region in question.[8] Due to the nature of the data (discussed in greater detail in Chapter 4), this thesis concentrates on the income and socio-economic determinants of transport demand, as expressed in terms of car ownership and use, public transport use and modal choice for the journeys to work and school/college. As discussed in Chapter 1, an understanding of the income and socio-economic factors influencing individual and household transport behaviour is important for a number of reasons. The review of the literature therefore concentrates on previous studies analysing the demand for transport at individual or household level with specific emphasis on the impact of income and other socio-economic characteristics on these decisions.

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[6] D_T may be expressed in either discrete or continuous form. Examples of discrete demand include the choice of number of cars to own or choice of mode of transport to work while expenditure on transport is an example of a continuous transport demand variable.
[7] See Button (1993) for a discussion of the concept of "generalised cost" which incorporates factors other than the simple monetary cost of a trip such as access time, waiting time, in-vehicle time *etc.*
[8] Button (1993, pp.48) states that *"the economic meaning of "tastes" is seldom made clear, but in practice it seems to embrace all influences on demand not covered by the previous headings"*. In addition to the socio-economic characteristics of the decision-maker, factors encompassing service quality (frequency, punctuality, comfort, route penetration *etc.*) are often included as explanatory factors, particularly in explaining modal choice decisions.

2.3 Car Ownership and Use

2.3.1 Car Ownership

The microeconomic approach to car ownership demand modelling has its roots in studies based on aggregated data, which attempt to explain the general relationships between car ownership and variables such as population density and average incomes at regional or country level [see Button *et al.* (1993), Said (1992), Stanovnik (1990), McCarthy (1977), Buxton and Rhys (1972) and Fairhurst (1965)]. However, the nature of the data limits the number and type of independent variables that can be considered. A particular problem associated with aggregated data is that if a variable varies more within a region than it does between regions, the true effect of the variable will be difficult to determine [Fairhurst (1965)].

The increasing availability of micro-data in recent years has enabled researchers to overcome many of the problems inherent in aggregated data. It has allowed the formulation of more accurate models of car ownership at an individual or household level employing a wider range of socio-economic characteristics as independent variables [see Alperovich *et al.* (1999), Dargay and Vythoulkas (1999), McCarthy (1996), Lave and Train (1979), Cragg and Uhler (1970) and Bennett (1967)]. The discrete nature of the car ownership decision means that discrete choice econometric methodologies, such as binary and multinomial probit and logit, are often employed in modelling demand. Alperovich *et al.* (1999), Stanovnik (1990) and Cragg and Uhler (1970) employ binary and multinomial logit, binary probit and multinomial logit methodologies respectively to the demand for car ownership while McCarthy (1996) and Lave and Train (1979) use the multinomial logit methodology to model choice of car type. Bergantino (1997) and Blundell *et al.* (1993) examine budget shares allocated to private and public transport and total transport expenditures respectively while Bennett (1967) analyses expenditure on cars. More recently, the demand for car ownership at the micro-level has also been analysed in the context of other transport decisions such as car use and modal choice. Johansson-Stenman (2002), Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Berkowitz *et al.* (1990), De Jong (1990) and Mannering and Winston (1985) all model the joint decisions of car ownership and car use using a variety of econometric methodologies [see Section 2.3.2]. De Palma and Rochat (2000), Thobani (1984) and Train (1980) examine the joint decisions of car ownership and mode of transport to work [see Section 2.5 for further discussion of car ownership-modal choice studies].

Income is the most consistently important socio-economic factor found to have a positive relationship with car ownership, with the majority of the earlier studies reporting income elasticities that are in excess of unity [Blundell *et al.* (1993), Button *et al.* (1993), Stanovnik (1990), Thobani (1984), McCarthy (1977), Buxton and Rhys (1972), Bennett (1967) and Fairhurst (1965)]. There is some evidence to show that the income elasticity of car ownership demand has declined over time with more recent studies reporting income elasticities that classify the private car as a necessity rather than a luxury [see Johansson-Stenman (2002), Dargay (2001) and Dargay and Vythoulkas (1999)].[9] Dargay (2001) finds evidence for a "hysteresis" effect, with the income elasticity found to be higher for increasing income than for falling income. In other words, the acquisition of a

[9] In addition, Bergantino (1997) reports an income elasticity of private transport of 1.02 but the value of this elasticity is not significantly greater than unity at the one per cent level of significance, leading to the conclusion that private transport cannot be classified as a luxury good.

car is seen as a luxury but once acquired, the car becomes a necessity so that disposing of a car is more difficult. She cites this as a particular problem in attempting to reduce the car dependence of the population. Some studies also find that the relationship between income and car ownership is non-linear [Cragg and Uhler (1970) and Bennett (1967)], while others find that income elasticities of car ownership decline in magnitude as the number of cars per household increases [Dargay (2001), Dargay and Vythoulkas (1999) and Train (1980)]. These results suggest that the effect of income on household car ownership is not constant, with the effect being more pronounced at lower levels of car ownership and income.

Other variables found to have a significant effect on car ownership include general household characteristics such as the number of adults, children and workers in the household and household location. Economies of scale associated with increasing household size are evident in the results of Alperovich *et al.* (1999), who find a non-linear relationship between the size of the household and the probability of car ownership, and Bergantino (1997) who reports a negative relationship between the number of adults in the household and the share of total expenditure allocated to transport.[10] Johansson-Stenman (2002), Dargay and Vythoulkas (1999) and Bergantino (1997) find a positive relationship between the number of children in the household and the probability of car ownership, average car ownership levels and the share of expenditure on private transport respectively. The positive effect of the number of children in the household on the probability of car ownership may reflect the fact that

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[10] 68 per cent of total transport expenditure is allocated to private transport in the data utilised by Bergantino (1997).

households with children may have more diverse activity patterns than other household types. Asensio *et al.* (2001), De Palma and Rochat (2000), Alperovich *et al.* (1999), Bhat and Pulugurtha (1998) and Train (1980) find that the number of workers in the household positively affects the probability of car ownership. This reflects the fact that working households have more regular and rigid travelling needs than non-working households. Household location is often employed to proxy a number of different factors such as distance from the city centre, population density and the quality and quantity of public transport alternatives. The results consistently indicate that, in comparison with rural and/or suburban residents, urban dwellers are less likely to own cars [see Johansson-Stenman (2002), Dargay and Vythoulkas (1999), Bhat and Pulugurtha (1998) and Bennett (1967)].[11] Asensio *et al.* (2001) and Alperovich *et al.* (1999) similarly find that as population size increases, the probability of car ownership falls while McCarthy (1977) and Buxton and Rhys (1972) find that car ownership rates decline as population density increases. Based on a sample of urban residents, Train (1980) finds that those living in the city centre are significantly less likely to own cars than those living in suburban areas.

Head of household (HOH)[12] characteristics such as gender, age, education and occupation are also commonly employed. The results for age of HOH often conflict. Johansson-Stenman (2002), Asensio *et al.* (2001), Dargay (2001), Alperovich *et al.* (1999) and Bennett (1967) find that car ownership probability, while increasing with age,

[11] Bergantino (1997) also find that urban dwellers spend less on private transport.
[12] While it may be argued that the term "head of household" has become less meaningful over time, it is still taken as the unit of analysis in proxying such characteristics of the household as age, gender and educational level. See also Section 4.2.3.

declines in magnitude once the HOH reaches 40 years, 35-55 years, 50 years, 45 years and retirement age respectively. On the other hand, Buxton and Rhys (1972) and Cragg and Uhler (1970) find that as the age of the HOH increases, the probability of car ownership declines.

2.3.2 Car Use

In contrast to the large number of studies analysing car ownership at both aggregated and disaggregated levels, a relatively small number of studies have examined the related issue of car use. Button *et al.* (1993), Hensher (1985) and Mannering (1983) examine car use independently of the car ownership decision, using mileage data. The latter two studies use household level data and differentiate households by number of cars owned, while the former study uses aggregated country-level data for a sample of low-income countries. Studies examining petrol expenditures include those by Asensio *et al.* (2001), Labeaga and Lopez (1997) and Archibald and Gillingham (1980) who utilise household micro-data, applying differing econometric methodologies such as OLS, IV and GMM estimation of an AIDS model and OLS respectively.[13] A number of the above studies [Hensher (1985), Mannering (1983) and Archibald and Gillingham (1980)] analyse the car use decisions of multi-car households in an attempt to quantify vehicle substitution effects, i.e., to account for the fact that there is an endogenous relationship between the level of use of each household vehicle [Hensher (1985)].

[13] Kayser (2000) and Schmalensee and Stoker (1999) also use petrol consumption as a proxy for car use, but analyse consumption in terms of gallons of petrol rather than expenditure.

A common approach taken in many studies is to analyse the car use decision simultaneously with the car ownership decision. Bjorner (1999) and De Jong (1990) use the Tobit Type II methodology to estimate the demand for car use conditional on the decision to own a car, while Berkowitz *et al.* (1990) and Mannering and Winston (1985) follow the approach initially outlined by Dubin and McFadden (1984) and estimate joint discrete-continuous models of vehicle holdings and use.[14] Johansson-Stenman (2002), Asensio *et al.* (2001) and Kayser (2000) estimate Heckman sample selection models of the joint demand for car ownership and car use.[15]

Similar independent variables to those used in explaining variations in car ownership levels are employed in determining the income and socio-economic influences on car use. A significant finding in many of the studies is the low positive income elasticity of car use, resulting in the classification of car use as a necessity [see Johansson-Stenman (2002), Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Schmalensee and Stoker (1999), Labeaga and Lopez (1997), De Jong (1990) and Archibald and Gillingham (1980)]. The consistent classification of car use demand as a necessity suggests that

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[14] Berkowitz *et al.* (1990) simultaneously estimate the demand for vehicle holdings (number and type) and vehicle usage (discretionary and non-discretionary use). There are therefore three household decisions under consideration: number and type of vehicle holdings, work use of vehicles and non-work vehicle use. The three decisions are nested: each decision is made sequentially with reference to the utility expected at subsequent stages of the decision process. Mannering and Winston (1985) apply the same methodology to a two stage decision: the number and type of cars to own at the first stage and how much to use the car(s) at the second stage.

[15] Kayser (2000) motivates the use of the Heckman sample selection methodology on the basis that households may have a positive demand for petrol but report no consumption because they do not own a car. However, both Asensio *et al.* (2001) and Johansson-Stenman (2002) favour an independent approach to estimating the demand for car ownership and use due to the insignificance of the Mill's ratio, which is an indicator of selection. In addition, Asensio *et al.* (2001) notes the difficulty in deciding on exclusion restrictions, i.e., variables that affect the probability of car ownership but do not affect the level of car use. See also Sections 5.2 and 5.4.2 for further discussion of the appropriate econometric methodology to use in modelling car use.

income is a more important factor in determining variations in car ownership than in car use. Archibald and Gillingham (1980) show that the income elasticity of car use is larger for households that own two or more cars while Asensio *et al.* (2001) and Hensher (1985) find that income elasticities of car use decline as the number of household cars increases. Kayser (2000) also finds evidence for a non-linear effect indicating that car use increases with increasing income but at a decreasing rate.

The number of adults in the household is often included to proxy the number of potential drivers in the household, which is included as an independent variable by Schmalensee and Stoker (1999) in addition to household size. The effect of children is generally found to be positive [Bjorner (1999)]. In common with the effect on car ownership, this may indicate the diversity of activities undertaken by households of this type as well as the fact that young children are unlikely to travel unescorted. Additional significant socio-economic characteristics include the number/presence of workers in the household [see Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Berkowitz *et al.* (1990), Mannering and Winston (1985) and Archibald and Gillingham (1980)] and the location of the household [see Johansson-Stenman (2002), Asensio *et al.* (2001), Bjorner (1999), Schmalensee and Stoker (1999), Berkowitz *et al.* (1990), Mannering and Winston (1985), Mannering (1983) and Archibald and Gillingham (1980)[16]]. In common with the effect of location on car ownership, residents of urban areas are found to use their cars significantly less than suburban or rural residents, reflecting perhaps the shorter distances

[16] All of these studies include dummy variables for urban vs. rural residence with Johansson-Stenman (2002), Asensio *et al.* (2001) and Bjorner (1999) including a number of dummy variables indicating large cities, intermediate cities and rural residence. Kayser (2000) also includes a dummy variable indicating whether public transport is available for the journey to work and finds that rural residence and availability of public transport significantly increase and decrease car use respectively.

for work and other journey purposes, car parking restrictions and the increased availability and feasibility of alternatives such as walking, cycling and public transport.

Johansson-Stenman (2002), Kayser (2000), Bjorner (1999), De Jong (1990), Mannering (1983) and Archibald and Gillingham (1980) all report that a female HOH exerts a significant negative effect on household car use. These results support the contention of Mannering (1983) that women choose frequencies and types of activities that require less vehicular travel than men. Once again, the effect of the age of the HOH is conflicting. Asensio *et al.* (2001), Bjorner (1999), De Jong (1990), Hensher (1985), Mannering (1983) and Archibald and Gillingham (1980) find that the age of the HOH has a consistently negative effect on car use, a finding that is in contrast to the positive, but declining effect of the age of the HOH on car ownership found in many of the car ownership studies. On the other hand, Puller and Greening (1999) and Mannering (1983) report a linear positive effect and Johansson-Stenman (2002), Schmalensee and Stoker (1999) and Kayser (2000) find evidence for a non-linear effect of age on car use, an effect that is positive but at a decreasing rate. Finally, Archibald and Gillingham (1980) find that households with more than one car consume significantly more petrol although they do note that petrol consumption per car is lower for multi-car households than it is for one-car households.

2.4 Public Transport Use[17]

In common with the earlier approaches to car ownership modelling, much of the emphasis in public transport demand modelling has been on models using aggregated

[17] By public transport we mean bus, train, tram, taxi *etc.*

data, usually time-series. For example, FitzRoy and Smith (1998, 1994) explain the growth in public transport trips in Freiburg and Zurich respectively as functions of income, population, public transport fares and various service aspects of the public transport system such as route coverage. At the micro-level, the demand for public transport is most often analysed in the context of modal choice [see Section 2.5], while comparatively little research has been undertaken using expenditure on transport as a proxy for (public) transport demand. Exceptions are Bergantino (1997), Melenberg and Van Soest (1996), Blundell *et al.* (1993), Hagemann (1981) and Bennett (1967), who all use household-level expenditure data. While Bergantino (1997) and Blundell *et al.* (1993) examine the budget shares allocated to private and public transport and total transport respectively, Melenberg and Van Soest (1996) and Hagemann (1981) estimate Tobit models of expenditure on holiday travel and Bennett (1967) estimates Tobit models of expenditure on cars. Johansson-Stenman (2002) similarly analyses the demand for public transport in Sweden using the annual number of public transport trips per person as the dependent variable by estimating Cragg and Heckman sample selection models.[18]

The effect of income on public transport demand is generally found to be positive, but less than unity. Bergantino (1997) finds that the income elasticity of public transport (0.99) is slightly less than that for private transport (1.02) and concludes therefore that public transport may be classified as a necessity. In common with the effect of income on car ownership, which was found to differ over income levels [see Dargay and Vythoulkas

[18] Johansson-Stenman (2002) motivates the use of the Cragg and Heckman sample selection methodologies by arguing that different variables may affect the probability of travelling by public transport and the number of trips, once the decision to use public transport has been taken. The Cragg methodology assumes that the two decisions are independent whereas the Heckman sample selection methodology assumes that the two decisions are related [see Section 6.4.1 for further discussion of these issues].

(1999)], Bergantino (1997) finds that the elasticity of total transport expenditure is not constant over different income levels, declining from a luxury to a necessity as income increases. In other words, as the income of the poor increases, the expenditure that they allocate to transport increases more than proportionately. Conversely, Blundell *et al.* (1993) report an income elasticity of total transport in excess of unity which is increasing over income levels, reflecting perhaps differences in the types of transport goods consumed by those of differing incomes, i.e., private motoring by those on high incomes and public transport by those on low incomes. Despite initial expectations that public transport would be an inferior good, FitzRoy and Smith (1994, 1998), in their time-series analyses of public transport trips in Zurich and Freiburg, report positive but inelastic income elasticities of 0.48 and 0.40 respectively. Webster and Bly (1980) summarise a number of cross-sectional studies using UK micro-data, which find that, for a given level of car ownership[19], a higher level of income leads to greater, but proportionately less, public transport use and expenditure, particularly for non-work journeys. In contrast to all of the above, Johansson-Stenman (2002) finds that the income of the individual exerts a negative effect on both the probability and number of public transport trips. However, the latter effect is insignificant and the former only marginally so.

Additional socio-economic characteristics found to be significant in explaining cross-sectional variations in public transport use include the number of adults, workers and children in the household. De Palma and Rochat (2000) find that increasing household

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[19] It is important to control for car ownership in examining the effect of income on public transport demand as income, in addition to the direct effect on public transport demand, has an indirect effect through its effect on car ownership. The two effects often conflict making it difficult to determine the true effect of income on public transport demand [see Webster and Bly (1980) and Jones and Tanner (1979)].

size reduces public transport demand (for the journey to work in households with cars) while Johansson-Stenman (2002) and Bergantino (1997) find negative effects of children on the probability of travelling by public transport and public transport expenditure respectively. As with the car ownership and use studies, household location is often included not only to proxy distance but also to proxy public transport availability [see Johansson-Stenman (2002), Berkowitz *et al.* (1990) and Bergantino (1997)]. Finally, HOH characteristics such as the age of the HOH are found to have negative effects on public transport demand by Berkowitz *et al.* (1990) but positive effects by De Palma and Rochat (2000) and Bergantino (1997). However, Johansson-Stenman (2002) finds that while age has an initially negative effect on the probability of making public transport trips, this decreases at a decreasing rate. He also finds that once a person has decided to use public transport, the annual number of public transport trips is positively, albeit at a decreasing rate, associated with age.

2.5 Modal Choice

Modal choice studies examine the choice between a number of competing modes of transport for a specific journey purpose. Examining transport behaviour for specific journey purposes enables researchers to determine if the factors influencing the demand for transport differ in their effect depending on journey purpose. For example, there is much evidence to show that price elasticities of public transport demand are lower for journeys to work than for leisure or shopping journeys [see Button (1993) and McGillivray (1972)]. The majority of studies discussed in this section concentrate on the journey to work because the data are more readily available and easier to collect as the journey is generally fixed by route, time and mode for the majority of workers [Domencich and McFadden (1975)]. In addition, while the journey to work only accounted for just over 15 per cent of total journeys per person in the UK in 2000 [see Table 7.1], for certain modes it is the major journey purpose (e.g. 50 per cent of rail journeys in the UK are work journeys [Pooley and Turnbull (2000)]). Domencich and McFadden (1975), in addition to examining mode of transport to work, also analyse choice of mode of transport for shopping trips, while McGillivray (1972) examines choice of mode of transport for a number of journey purposes including trips for work, for personal business, to visit friends and relations, shopping and other recreational purposes.

In modelling the choice of mode of transport, discrete choice econometric methodologies are commonly chosen due to the nature of the decision under analysis. Lave (1970), De Donnea (1971), Domencich and McFadden (1975) and Madan and Groenhaut (1987) use binary logit and probit models to examine choice of car versus public transport for the journey to work.[20] A number of studies expand the range of alternatives by using multinomial logit or nested logit models to examine the choice between a number of alternative modes of transport [see Ben-Akiva and Lerman (1975) for an application of the multinomial logit methodology and De Palma and Rochat (2000), Thobani (1984) and Train (1980) for applications using the nested multinomial logit methodology]. The nested multinomial econometric methodology is used in recognition of the fact that car ownership and modal choice are related decisions. De Palma and Rochat (2000) argue

[20] McGillivray (1972) uses discriminate analysis to examine modal split between car and public transport for a number of different journey purposes, namely, work, personal business, visiting friends and relations, shopping and other recreational purposes.

that the car ownership decision should be endogenous to the model structure. The nested multinomial methodology, in the context of modal choice, therefore assumes that two decisions are made simultaneously, namely, whether or not to own a car, and conditional on this choice, whether or not to use the car to travel to work.[21]

The majority of the modal choice studies concentrate on the impact of alternative-specific attributes on modal choice decisions. For example, De Palma and Rochat (2000) include alternative-specific variables relating to comfort, availability, travel time and cost in the second binary stage (car vs. public transport) of their nested multinomial logit model of choice of mode of transport to work, conditional on car ownership status. All of the above studies include income and a variety of other socio-economic characteristics as independent variables. However, the effect of income on modal choice is not consistent across the studies. Thobani (1984) and Train (1980) find that income is significant in explaining car ownership status but insignificant in explaining modal choice although the latter result may be due to the fact that income is also interacted with alternative-specific characteristics, such as cost, leading to possible multicollinearity problems. De Palma and Rochat (2000) and McGillivray (1972) also find an insignificant income effect on modal choice for the journey to work, while Madan and Groenhaut (1987) find that income is significant in explaining modal choice with income elasticities of car and public transport choice of 0.09 and –0.16 respectively. The low positive income elasticities reported by Madan and Groenhaut (1987), along with the insignificance of income in the other

[21] The use of the nested multinomial logit econometric methodology requires the existence of alternative specific characteristics that do not vary across the units of observation (e.g. individuals or households), such as fuel costs in the context of car use or journey time in the context of modal choice [see Greene (2000) and Ben-Akiva and Lerman (1975)]. Section 7.4 discusses the issue of the appropriate econometric methodology to use in modelling modal choice using Irish Census of Population data.

studies, may suggest that income is more important in determining variations in car ownership than in explaining differences in mode of transport for the journey to work.

As with the studies of car ownership and use and public transport use discussed in Sections 2.3 and 2.4, the number of adults, workers, drivers and children in the household are commonly employed as independent variables in explaining modal choice. De Palma and Rochat (2000) find a significant negative effect of household size on the probability of taking public transport to work, reflecting perhaps the returns to scale involved in household members travelling to work by car. Both Madan and Groenhaut (1987) and Ben-Akiva and Lerman (1975) include the number of cars per licensed driver as independent variables in an attempt to capture the effect of competition for the household car(s) on modal choice behaviour and find significant positive effects of the number of cars per licensed driver on the probability of taking the car to work. Madan and Groenhaut (1987) find that the number of cars per licensed driver is the most significant factor in explaining modal choice with the highest elasticity values of 0.15 and –0.27 for the choice of car and public transport respectively. Location variables are found to be significant by Berkowitz *et al.* (1990) who find that those living in big cities are more likely to take public transport to work. They explain this as being due to the parking and driving inconveniences associated with a big city. The effect of age on the probability of taking public transport to work is found to be positive by De Palma and Rochat (2000) and Lave (1970) but negative by Berkowitz *et al.* (1990). Berkowitz *et al.* (1990) explain this result by arguing that younger people have lower opportunity costs of time than older people, therefore, even though they own a car, they may be more likely to choose a slower alternative to work.

2.6 Summary

In this chapter, previous research examining the income and socio-economic determinants of a number of different transport decisions at the cross-sectional level was reviewed. While differences in data sources, time periods, econometric methodologies and dependent variables make conclusions more difficult, some consistent results do emerge. The review highlights the significance of income and socio-economic characteristics in determining household and individual transport behaviour. There is broad agreement that while car ownership may be considered a luxury (although there is some evidence to show that this positive income effect is declining over time), car use and public transport use may be considered necessities. Additional socio-economic characteristics such as household size, location and the gender and age of the HOH are also found to be particularly significant with the effects of some variables such as the age of the HOH found to have opposing effects on car ownership on the one hand and car and public transport use on the other. The next chapter introduces the subject of the subsequent econometric analyses, namely, the Dublin area. The changing economic and demographic profile of the Dublin area since 1986 is briefly described and the implications for patterns of travel to work, school and college are explored.

CHAPTER 3

ECONOMIC AND DEMOGRPAHIC PROFILE OF THE DUBLIN AREA AND IMPLICATIONS FOR TRANSPORT: 1986-2000

3.1 Introduction

Chapter 2 reviewed the literature related to the estimation of the demand for transport, paying particular attention to studies using micro-data to examine the influence of income and socio-economic factors on this demand. As discussed in Chapter 1, a knowledge of the income and socio-economic factors influencing the demand for urban transport is becoming more important in the context of the increasing popularity of measures which seek to re-direct the demand for transport towards more sustainable modes such as walking, cycling and public transport. In common with many other urban areas, Dublin has experienced all of the negative consequences of car dependence such as congestion, pollution, community severance, sprawl and peripheral development and inaccessibility due to car dependence. In addition, Dublin has experienced rapid rates of economic and demographic change over the last fifteen years and this has had major implications for travel in the Dublin area.

The purpose of this chapter is to briefly outline the changes that have occurred in the economic and demographic structure of the Dublin area since 1986 and to assess the implications for transport in the Dublin area.[22] Section 3.2 briefly outlines the trends in the economic and demographic factors that the OECD regards as the main causes behind the shift towards the private car in urban areas. Section 3.3 details the major implications that this changing economic and demographic structure has had for patterns of travel to work, school and college in the Dublin area over the period 1986-2000. Section 3.4 summarises and concludes the chapter.

3.2 Economic and Demographic Change

Over the last fifteen years, and in particular the last ten years, the Dublin area has changed dramatically in economic and demographic terms.

3.2.1 Population

As is evident from Table 3.1, the population of the Dublin area rose by 9.9 per cent between 1986 and 2002, with the majority of the increase occurring in the period 1996-2002. This figure masks considerable differences in the extent of population change within the Dublin area. While the population of Dublin County Borough (the inner city area) fell between 1986 and 2002, the population of Dublin County (encompassing the local authority regions of Dun Laoghaire-Rathdown, Fingal and South Dublin) increased consistently over the period 1986-2002 with the more suburban counties of Fingal and South Dublin recording the highest levels of population growth (41.7 per cent and 20.2

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[22] The published data from the Census of Population (COP) and the Quarterly National Household Survey (QNHS), which are both administered by the Central Statistics Office (CSO), are the primary data sources for this chapter. All data sources are referenced after the tables presented at the end of this chapter.

per cent respectively). With the exception of Dun Laoghaire-Rathdown, all three areas experienced the largest rates of population growth since 1996 with the much larger rates of growth in Fingal and South Dublin confirming the trend towards a dispersal of the population towards outlying areas of the Dublin area. While this thesis does not deal with the travel patterns of the entire Greater Dublin Area[23], which encompasses the neighbouring counties of Kildare, Meath and Wicklow, an examination of Table 3.1 confirms the shift in the distribution of the population of the Greater Dublin Area towards outlying areas, in particular over the period 1996-2002.

3.2.2 Employment

By far the most significant change in the Dublin area over the period 1986-2002 has been the spectacular increase in the numbers in employment. This has been driven by a number of factors including the increase in the size of the population (see Table 3.1) and a favourable demographic profile. From Table 3.2 it is evident that the proportion of the Dublin population that are of prime working age (25-64 years) has increased by 31.7 per cent over the period 1986-2001. However, the most important factor has been the sharp increase in the number of females entering the workforce. Table 3.3 indicates that while the numbers of males in employment in the Dublin area grew by 42.8 per cent over the period 1986-2002, the numbers of females in employment grew by 91.5 per cent over the same period. In both cases, the majority of the increase has taken place since 1996.

[23] Data limitations preclude the examination of the travel patterns of the entire Greater Dublin Area [see Section 4.2.1].

3.2.3 Education

Table 3.2 indicates that the proportion of the population aged 24 years and younger has been consistently falling over the period 1986-2001, with much larger decreases in the proportion of the population aged 14 years and younger. This has had implications for the numbers in education as presented in Table 3.4. The numbers of primary schoolchildren have fallen by 16.1 per cent over the period 1986-1996 and the number of secondary schoolchildren has increased marginally by 1.2 per cent. While data for the period 1996-2002 are not available, the data presented in Table 3.2 for the age structure of the population would indicate that the decline in the numbers in primary school has now been replicated for secondary school students. In contrast, the number of students entering third level education has increased dramatically, increasing by 85.1 per cent between 1986 and 1996. The figures in Table 3.2 would suggest, however, that this trend has not been maintained at the same level since 1996.

3.2.4 Household Size

As the number of households in the Dublin area has increased over the period 1986 to 1998, so the average size of these households has fallen accordingly [see Table 3.5]. The faster decrease in the average size of households reflects the fact that the population has been growing at a slower rate than that of household formation. While the population of the Dublin area increased by 9.9 per cent over the period 1986 to 2002, the number of households increased by 29.1 per cent over the period 1986 to 1998.

3.2.5 Income

Along with the increase in female participation in the workforce, the most significant change in the economic and demographic structure of Dublin over the last fifteen years, and over the last ten years in particular, has been the spectacular rates of economic growth. Data on disposable incomes per person confirm that the population of Dublin has become richer over the period 1991 to 1999 with an increase of 59.6 per cent in per capita disposable incomes over the period. In common with many of the other trends analysed in this chapter, much of that increase occurred in the latter half of the 1990s.

3.2.6 Car Ownership

Fuelled by the increase in incomes, the rate of car ownership has significantly increased in the Dublin area over the period 1986-2000, with the number of private cars nearly doubling over the period. The average rate of car ownership per household has subsequently increased by 49.3 over the same period to the point where the average number of private cars per household is one. In contrast to the trends in the other variables, the major changes in car ownership occurred before 1996, reflecting the low bases from which the subsequent growth occurred. While the rate of car ownership in Ireland is still considerably below that of other European countries, the number of private cars per 1,000 inhabitants has been increasing steadily towards the EU average of 460 in 1999 [see Table 3.7 and Table 3.3.1.2 in European Commission (2002)]. It is also significant that the rate of growth in the number of cars per 1,000 inhabitants in Dublin consistently exceeds that for the state as a whole.

3.3 Implications for Transport

3.3.1 General Transport Situation

All of the above factors have combined to increase substantially the demand for travel in the Dublin area in recent years and in particular over the 1990s, when the changes in the economic and demographic factors were most pronounced. The Dublin Transportation Office estimate that, over the period 1991 to 1997, the number of peak and off-peak trips in Dublin increased by 64.5 and 67.3 per cent respectively [2000]. In common with trends across all urban areas in the industrialised world, the majority of these trips are undertaken by car. They estimate that car journeys account for over 70 per cent of these trips and that this proportion is continuing to increase over time [Dublin Transportation Office (2000)]. While the numbers travelling by bus and train have been increasing since 1986, the increases are small in comparison to the growth in car ownership over the period [see Table 3.8]. Data on travel patterns to work, school and college, which are presented in Sections 3.3.2, 3.3.3 and 3.3.4 respectively, confirm the trend towards the private car for the ever increasing number of trips that are undertaken in the Dublin area.

3.3.2 Travel to Work[24]

Tables 3.9 and 3.10 illustrate the travel patterns of the total working population resident in the Dublin area expressed in terms of distance travelled to work and mode of transport to work respectively. Over the period 1986-2000, the numbers of employed people resident in the Dublin area increased by 55.5 per cent. From Table 3.9 it is evident that

[24] The COP asks respondents to state their distance travelled to work to the nearest mile with the collected data then presented in nine categories: 0, 1, 2, 3, 4, 5-9, 10-14, 15 and over and not stated. The data in the tables at the end of the chapter further aggregates these data into five categories: one mile or less (0+1), two to four miles (2+3+4), five to nine miles (5-9), ten miles or greater (10-14 + 15 and over) and not stated.

the proportions travelling four miles or less and ten miles or greater increased over this period, with the proportion travelling five to nine miles declining. The increase in the proportion travelling one mile or less to work may be accounted for by an increase in the numbers working from home although it is impossible to identify such workers from the data. Despite the increase in the share of workers travelling ten miles or more to work, the majority of commuters travel relatively short distances to work, with 59.1 per cent of the working population in 2000 travelling four miles or less to work compared with 35.3 per cent travelling distances greater than five miles.

In terms of mode of transport, the data in Table 3.10 illustrate that the largest increase in modal share occurred for the car driver category. While the numbers in employment increased by 55.5 per cent since 1986, the numbers driving to work more than doubled. This dramatic increase in the numbers driving cars to work has resulted in a situation where over 50 per cent of workers in the Dublin area now drive to work. In contrast, the proportions walking, cycling, using public transport and travelling as a passenger in a car either fell, remained stable or increased very slightly. The proportion of workers walking to work has remained relatively stable over the period 1986-2000, a trend that is mirrored by UK data which reports that there was little change in the proportions walking to work over the period 1991-1999 [UK DETR (2001c)]. Cycling, using the bus and travelling as a passenger in a car all declined in terms of modal share with cycling performing particularly poorly. In a period of increasing numbers at work, the absolute numbers cycling to work also declined. The private car remains the most popular mode of transport to work in the Dublin area (50.3 per cent), followed by travelling by bus (16.1 per cent) and walking (12.1 per cent).

It is important to realise that mode of transport is dependent to a large extent on the distance that the individual must travel to work. Table 3.11 illustrates these differences for 1986 and 1996.[25] While walking to work is the third most popular method of transport to work in 1996, for distances of one mile or less, 47.2 per cent of workers walk to work. For distances greater than two miles, the private car remains the most popular method of transport to work, with nearly 46 per cent of workers in 1996 travelling between two and four miles to work using their own cars. Examining the changes over time, it is evident that cycling as a mode of transport to work has declined in share across all distances. Using the bus to travel to work has also declined in share for all distances except one mile or less. The car passenger category has increased share at the shorter distances but decreased share at distances greater than five miles while the train has increased share over all distances of nine miles or less. The car driver category has increased share over all distances, which is all the more significant given that this increase has occurred from a high base in comparison with that for the train. However, the most significant finding is that the increase in the proportions driving to work occurred for all distances with nearly 20 per cent of those travelling distances of one mile or less driving their cars to work in 1996. This striking finding may be accounted for by people who need a car for work purposes, by those with access to free parking at work or by those who transport children to school or their way to work.

[25] The 2000 QNHS module on Travel to Work does not cross-reference distance and mode of transport for the Dublin area.

The above trends mask considerable differences across different areas of Dublin in the travel patterns of workers. Tables 3.12 and 3.13 illustrate the distances and modes of transport to work for each of the four local authority regions of Dublin over the period 1986-1996. In terms of distance travelled to place of employment, a common trend across all four areas is an increase in the proportion of workers who are travelling distances in excess of ten miles to work. The proportion travelling five to nine miles remained stable in Dublin County Borough and has declined slightly in the other three areas. The proportion travelling four miles or less increased in all areas with the exception of Dublin County Borough. The experience of Dublin County Borough is therefore different to the rest of the Dublin area with a clear increase in the average distance travelled to work. It must be remembered though that in 1996 the majority of the Dublin County Borough working population still travelled four miles or less to work (58.7 per cent), in contrast to the rest of the Dublin working population, in particular Fingal, in which 64.7 per cent of the population in 1996 travelled five or more miles to work. These differences may be due to the location of employment with the percentage share of employment located in central areas of Dublin decreasing from 70.3 per cent in 1987 to 61.5 per cent in 1999 and the percentage share of employment located in suburban areas consequently increasing from 29.7 per cent in 1987 to 38.4 per cent in 1999 [Morgenroth (2001)].

The figures for modal share also reveal some similarities between the travel behaviour of workers in each of the four regions. In all cases the proportion of the population cycling to work declined substantially and in all areas, despite an increase in the numbers at work, declined in absolute numbers also. The proportion of the population driving to work and taking the train to work increased in all areas. However, some differences exist between the various areas in their modal choice patterns. Firstly, while bus use (in terms of both modal share and absolute numbers) has declined in Dublin County Borough and Dun Laoghaire-Rathdown over time, it increased slightly in Fingal and South Dublin. Secondly, while the majority of workers in all areas drive their cars to work, the proportions doing so in each of the regions differs substantially. The proportions range from 56.6 per cent of all commuters in Dun Laoghaire-Rathdown in 1996 to 34.6 per cent in Dublin County Borough, with Fingal experiencing the largest increase in share over the period 1986-1996. This may be illustrated by the fact that in 1986 the proportions driving to work in Dun Laoghaire-Rathdown, Fingal and South Dublin were broadly similar at approximately 49 per cent, yet by 1996 the proportions range from 51.0 per cent in South Dublin to 56.6 per cent in Dun Laoghaire-Rathdown. Walking is a significant mode of transport in Dublin County Borough (in third place behind car and bus) yet is a lesser used mode in the other three areas. This is most obviously related to the shorter average distances to work in Dublin County Borough in comparison with the other three areas. Finally, the train is an increasingly popular option in Dun Laoghaire-Rathdown and Fingal but is an insignificant mode in South Dublin. This indicates the influence that the availability of a public transport mode running on dedicated lines has on public transport patronage, as South Dublin is poorly served with train services.

The data presented in Tables 3.14 and 3.15 highlight the fact that the travel patterns of males and females differ considerably. Male employment in the Dublin area grew by 9.7 per cent from 1986 to 1996 whereas female employment rose by 37.5 per cent. Men on average travel longer distances to work than women although over time the discrepancy in the average distance travelled to work is declining, with female workers experiencing faster rates of growth in the longer distances than their male counterparts. For example, in 1986 in the Dublin region, 58.6 per cent of females and 44.9 per cent of males travelled less than four miles to work compared with 1996 when the corresponding figures were 51.6 per cent and 42.7 per cent. Despite this trend, the majority of men in the Dublin area travel distances of five miles or greater to work. In contrast, the majority of women travel four miles or less to their place of employment.

Women drive and cycle to work in smaller proportions than men and consequently walk, travel as passengers in cars and use public transport (bus and train) in greater proportions than men. The UK National Travel Survey finds the same gender differences in commuting patterns [see UK DETR (2001b)]. The use of the bus as a mode of transport to work has changed considerably for females over the period. In 1986 the dominant mode of transport for female workers in Dublin was the bus although in 1996 commuting by bus was replaced by driving a private car as the dominant mode of transport to work. Over time there is some evidence to show that, as with distance, female travel patterns are beginning to resemble increasingly those of male workers, a result also found for the UK [UK DETR (2001b)]. Nonetheless in the Dublin area as a whole in 1996, the female proportions travelling by car (38.7 per cent) and bus (22.5 per cent) were substantially lower and higher respectively than the corresponding figures for male workers (50.1 per cent and 12.8 per cent).

3.3.3 Travel to School and College

The COP collects data on the travel patterns of three student types: primary schoolchildren aged 5-12 years, secondary schoolchildren aged 13-18 years and third level students aged 19 years and older. Accordingly, Tables 3.16 to 3.19 present the travel patterns of primary schoolchildren, Tables 3.20 to 3.23 present the travel patterns of secondary schoolchildren while Tables 3.24 to 3.27 detail the travel patterns of third level students. The 2000 QNHS only asked about patterns of travel to work and therefore, the latest available data on travel patterns to school and college refer to 1996.

Travel to Primary School

Tables 3.16 to 3.19 present the trends in the travel behaviour of schoolchildren aged 5-12 years and usually resident in the Dublin area in 1986 and 1996. Between 1986 and 1996, the number of primary schoolchildren declined by over 16 per cent. As for the category of those in employment, the proportion of schoolchildren travelling distances of five miles or greater to school increased over the time period. The absolute number of students travelling this distance increased also which makes the increase in the proportion all the more significant given the decline in the number of primary schoolchildren over the period. Even though the proportion of schoolchildren travelling one mile or less to school has fallen since 1986, nearly 60 per cent of all primary schoolchildren in 1996 lived within one mile or less of their school. In the UK in 1997/1999, 80 per cent of primary schoolchildren lived within two miles of their school [UK DETR (2001a)].

Given the high proportion of schoolchildren living so near their school, it is not surprising that the mode of transport used by the majority of Dublin primary schoolchildren is walking. There have been large decreases, however, in the proportion of schoolchildren walking and cycling to school, while the proportions using the bus and travelling as a passenger in a car increased, both in absolute and proportionate terms. Walking remains the most popular method of transport to school (49.8 per cent in 1996), followed by car passenger (27.6 per cent) and bus (12.2 per cent).

Taking a more detailed look at the four regions of Dublin in Tables 3.18 and 3.19, several trends emerge. In all areas the proportions travelling distances of five miles or more to school increased with the numbers travelling ten miles or greater also increasing, despite a decrease in the numbers at primary school. However, in all areas the majority of students still live within one mile or less of their school and this proportion varies from 53.9 per cent in Dun Laoghaire-Rathdown in 1996 to 62.1 per cent in South Dublin. In all areas the proportion of schoolchildren walking and cycling to school declined. With the exception of Dun Laoghaire-Rathdown, there was also an increase in the proportion of schoolchildren travelling to school by bus (which also increased in absolute terms). A final common trend across the four areas was a substantial increase in the proportion of schoolchildren being driven to school; all areas experienced an increase in absolute numbers also.

Despite these similarities, modal shares for travel to primary school still differ across the Dublin area. The proportion that walks to school ranges from 58.1 per cent in South

Dublin to 31.8 per cent in Dun Laoghaire-Rathdown. The proportion of students who travel to school as a passenger in a car ranges from 19.7 per cent in Dublin County Borough to 52.6 per cent in Dun Laoghaire-Rathdown. Some of these differences are certainly accounted for by differences in average distance to school (with South Dublin having the smallest and Dun Laoghaire-Rathdown having the largest proportions travelling five miles or more) but it is also possible that other factors may be influencing demand such as income and levels of female employment for instance. Dun Laoghaire-Rathdown exhibits significantly different travel patterns to the other three areas. In Dublin County Borough, Fingal and South Dublin, walking remained the most popular method of transport to school over the period 1986-1996, while in Dun Laoghaire-Rathdown, travelling as a passenger in a car is now the dominant mode of transport to school, compared with 1986 when walking was the most popular mode.

Travel to Secondary School

The student population of Dublin aged 13-18 years increased by just over 1 per cent in the ten years from 1986 to 1996. Tables 3.20 to 3.23 illustrate the trends in distance and mode of transport to school for students aged 13-18 years over the period 1986-1996. As with schoolchildren aged 5-12 years there has been a decrease in the proportion of students travelling one mile or less to school and an increase in the proportion travelling five miles or more to school. Nonetheless the majority of students (73.4 per cent in 1996) live within four miles of their school and 43.0 per cent live within one mile, findings very similar to those for the UK where 50 per cent of secondary school students in 1997/1999 lived within two miles of their school [UK DETR (2001a)].

In terms of mode of transport used to travel to school, both the bus and car passenger categories recorded an increase in the percentage (as well as in the absolute number) of students using these modes. In common with other sections of the population, students in the 13-18 age group walked and cycled in smaller proportions in 1996 than in 1986. The dominant modes for students are walking (40.9 per cent) and travelling by bus (26.1 per cent) although the largest increase occurred in the numbers travelling as a passenger in a car. Indeed, travelling as a passenger in a car replaced cycling as the third most popular mode of transport to secondary school over the period 1986-1996. In common with the experience in the UK, secondary schoolchildren use public transport in greater proportions than primary schoolchildren, reflecting the greater independence with age as well as the longer distances that older schoolchildren must travel [UK DETR (2001a)].

An examination of the trends across the four regions of Dublin in Tables 3.22 and 3.23 shows that while the number of students aged 13-18 years increased in Fingal and South Dublin, the numbers declined in Dublin County Borough and Dun Laoghaire-Rathdown. A common trend across all areas is an increase in the proportion of students travelling distances of two to four miles and ten or more miles with the largest increase again accruing to the longer distances. In South Dublin and Dublin County Borough, the majority of students live less than one mile from their school. In contrast, the majority of students in Dun Laoghaire-Rathdown and Fingal live distances of two miles and greater from school (60.9 per cent and 52.2 per cent in 1996 respectively).

The trends for modal share mirror those for the younger schoolchildren. Cycling decreased in proportion and absolute numbers in all areas whereas car passenger, train and bus increased their share. An interesting difference in trend over time applies to the proportion of students walking to school in Fingal, which increased in contrast to the experience in the other three areas. With the exception of Dun Laoghaire-Rathdown, walking to school remains the mode of transport used by the majority of the secondary school student population, followed by bus. In Dun Laoghaire-Rathdown, however, the majority of students are driven to school (as with the younger schoolchildren) and this mode has replaced cycling as the most popular mode of transport to school since 1986; the proportion of students who walk to school is consequently the lowest in the Dublin area at 22.5 per cent in 1996.

Travel to Third Level College

The trends in the travel patterns of the third level student population of the Dublin area are particularly interesting because of the large difference between these patterns and those of other categories (both workers and primary and secondary schoolchildren), but also because of the significant differences that exist between the four local authority regions. In addition, this category experienced spectacular rates of growth over the period 1986-1996, increasing by 85.1 per cent. Over the period 1986-1996, the proportions travelling the very shortest and the very longest distances increased. This is not surprising given the divergence in average distance travelled to college across the Dublin area, which will become clearer shortly with a discussion of the differences between regions in Dublin. The majority of students in Dublin in 1996 travelled distances of four miles or less to college (53.0 per cent) with a significant proportion travelling distances of five miles and greater (36.0 per cent). The most interesting aspect of the travel patterns of students aged 19+ years is the increasing dominance of the bus as the chosen mode of transport for the majority of students in the Dublin area. Walking and cycling also feature prominently although the proportion of students cycling declined sharply from 30.3 per cent in 1986 to 16.9 per cent in 1996.

An analysis of the trends in distance travelled and modal share across the four regions of Dublin highlights the problems in aggregating across a group of areas, for which the experience of one is very different to that of another. In all areas there has been an increase in the proportion of students living nearer to college. In Dublin County Borough the majority of students live within four miles of college (68.9 per cent) compared with 50.7 per cent in Dun Laoghaire-Rathdown, 33.1 per cent in South Dublin and only 8.6 per cent in Fingal. Fingal, however, also has a low proportion of the resident student population travelling distances of four miles and under with the result that the average distance travelled to college in Fingal is the longest in the Dublin area (82.7 per cent of Fingal students travelled more than five miles to college in 1996).[26] Given the increase in the proportion of students living nearer to their place of education, it is not surprising that the proportion walking to college has increased. However cycling, as in all other areas for all other categories, has declined in popularity and dramatically so in Dun Laoghaire-Rathdown. Bus use has increased, particularly in the areas with the longest average distances, namely, Fingal and South Dublin. With the exception of Dublin County

[26] The longer average distances to college experienced by students resident in Fingal is due in part to the location of third level institutions within the Dublin area. See Table 3.28 for a list of third level institutions in each of the local authority regions of Dublin.

Borough for which walking is the dominant mode, the majority of students in the other areas of Dublin use the bus to travel to college. Indeed in South Dublin in 1996, 56.1 per cent of the total number of students used the bus, the highest proportion of bus users in this study. The train is also a significant mode in Fingal, with 31.6 per cent travelling to college by train, reflecting the longer average distances to college for residents of Fingal. Together with the high levels of bus use in Fingal, nearly 76 per cent of students resident in Fingal in 1996 used public transport to travel to college. While the numbers travelling as a passenger in a car decreased, in all areas the numbers driving to college increased. However, the latter is still an insignificant mode of transport to college.

3.3.4 Summary of Patterns of Travel to Work, School and College

Examining the travel to work patterns, it is clear that distance is an important determinant of the choice of mode of transport. This is evident when we examine the contrasting data for Dublin County Borough and Fingal for example. Average distances to work are lower in Dublin County Borough and this results in a higher proportion of the population walking and cycling to work in this area than in Fingal. Secondly, it is evident that there are additional factors at play that influence the choice of mode of transport to work. While South Dublin and Dun Laoghaire-Rathdown have a similar distribution of proportions travelling each distance to work [see Table 3.12], the modal shares are quite different. Obviously factors such as income and car ownership, the type and quality of public transport services available (e.g. the availability of DART in Dun Laoghaire-Rathdown) and employment issues (such as the rate of female participation) also influence modal choice. In terms of gender differences, while males and females exhibit significantly different patterns with males driving and cycling to work in greater proportions than females, the differences in modal shares between males and females have been narrowing over time. Finally, the large decline in the proportions cycling (compared with the much smaller declines in walking) is a development not exclusive to the working population. This may suggest that factors such as comfort and safety are important factors which influence individuals in their choice of mode.

In terms of the travel patterns of Dublin students, distance once again is an important determinant of the demand for a particular mode. This is illustrated by the fact that the majority of primary schoolchildren travel one mile or less to school and consequently large proportions walk to school. Similarly students aged 19+ years resident in Fingal and South Dublin choose motorised forms of transport, most notably the bus, as the majority of students in these areas must travel more than five miles to college. As in the travel to work case, there is some evidence that there are additional forces at play. The car ownership of the family would seem to influence modal choice, as shown by the majority of schoolchildren travelling as a passenger in a car in Dun Laoghaire-Rathdown, an area with high rates of car ownership rates per household in 1991.[27] The increase in car use among the female working population may also explain the higher numbers of primary and secondary schoolchildren being driven to school in areas in which the female workforce can afford a car. This may also explain the decline in the proportions of

[27] The 1991 COP asked households about their car ownership status; the 1986 or 1996 COP did not. The 1991 results show that the proportion of households with at least one car ranged from 44.5 per cent in Dublin County Borough to 77.1 per cent in Fingal. However, Dun Laoghaire-Rathdown had the highest proportion of households with two or more cars (31.3 per cent), a finding that might explain the much higher proportion of schoolchildren that are driven to school in this area [CSO (1991)].

younger students walking and cycling or again it may be an indication of increasing parental concerns with safety.

3.4 Summary and Conclusions

The increase in the population and in particular the large increase in the numbers in employment, together with decreasing household size, increasing average incomes and car ownership, have all combined to increase substantially the demand for transport in the Dublin area since 1986. Data on the proportion of these increasing number of trips that are undertaken by the car as well as data for modal share for two significant journey types, the journey to work and the journey to school/college, confirm the trend found in urban areas elsewhere of a substantial shift towards the private car and away from more sustainable methods of transport such as walking, cycling and public transport. The data on travel patterns to work and school/college also indicate the extent to which behaviour is affected by socio-economic characteristics. While the data are limited and of an aggregated nature, they do indicate the possible influence that distance, area of residence and gender have on the demand for transport. Chapters 5, 6 and 7 extend this aggregated analysis by seeking to determine the extent to which these and additional factors such as income, household composition, age and level of education influence transport choices and also to examine the extent to which the influence of these factors has changed over the period 1987-2000. The next chapter, Chapter 4, introduces the micro-data sets that are used in these analyses, namely, the 1987/1988, 1994/1995 and 1999/2000 Irish Household Budget Surveys and the 1996 Irish Census of Population.

3A TABLES

Table 3.1 Population of the Greater Dublin Area: 1986-2002

	1986	1991	1996	2002	% change 1986-1991	% change 1991-1996	% change 1996-2002	% change 1986-2002
Dublin County Borough	502,749	478,389	481,854	495,101	-4.8	0.7	2.7	-1.5
County Dublin	518,700	546,915	576,410	627,499	5.4	5.4	8.9	21.0
of which:								
Dun Laoghaire-Rathdown	180,675	185,410	189,999	191,389	2.6	2.5	0.7	5.9
Fingal	138,479	152,766	167,683	196,223	10.3	9.8	17.0	41.7
South Dublin	199,546	208,739	218,728	239,887	4.6	4.8	9.7	20.2
Dublin City and County	**1,021,449**	**1,025,304**	**1,058,264**	**1,122,600**	**0.4**	**3.2**	**6.1**	**9.9**
Mid-East	314,670	325,291	347,407	412,650	3.4	6.8	18.8	31.1
of which:								
Kildare	116,247	122,656	134,992	163,995	5.5	10.1	21.5	41.1
Meath	103,881	105,370	109,732	133,936	1.4	4.1	22.1	28.9
Wicklow	94,542	97,265	102,683	114,719	2.9	5.6	11.7	21.3
Greater Dublin Area	**1,336,119**	**1,350,595**	**1,405,671**	**1,535,250**	**1.1**	**4.1**	**9.2**	**14.9**

Sources: CSO (1996d). Census of Population (Volume 1: Population Classified by Area).
CSO (2002b). Census of Population: Preliminary Results.

Notes: (i) Dublin County Borough roughly corresponds to the city centre [see Figure 3.1].
(ii) County Dublin refers to Dun Laoghaire-Rathdown, Fingal and South Dublin.
(ii) Mid-East refers to Kildare, Meath and Wicklow.
(iii) Greater Dublin Area refers to Dublin City and County and the Mid-East.

Table 3.2 Age Distribution of the Dublin Area Population: 1986-2001[28] (Percentage of Total)

	1986	1996	2001	% change 1986-1996	% change 1996-2001	% change 1986-2001
0-14	27.0	22.0	20.4	-15.7	-2.2	-17.5
15-24	19.9	18.6	17.5	-3.1	-4.7	-7.7
25-44	27.4	30.3	32.4	14.7	14.9	31.8
45-64	16.7	19.1	19.9	18.3	11.2	31.5
65+	8.9	9.9	9.8	15.3	7.9	24.4
25-64	**44.1**	**49.4**	**52.3**	**16.0**	**13.5**	**31.7**

Sources: CSO (1986a and 1996a). Census of Population (Volume 2: Ages and Marital Status).
CSO (2001b). Population and Migration Estimates.

Table 3.3 Numbers in Employment in the Dublin Area: 1986-2002[28]

	1986	1996	2002	% change 1986-1996	% change 1996-2002	% change 1986-2002
Males	209,307	229,648	298,900	9.7	30.2	42.8
Females	130,254	179,104	249,400	37.5	39.2	91.5
Total	339,561	408,752	548,300	20.4	34.1	61.5

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
CSO (2002c). Quarterly National Household Survey (Second Quarter) (Special Request).
Notes: 2002 figures refer to March-May 2002.

Table 3.4 Numbers in Education in the Dublin Area: 1986-1996[28]

	1986	1996	% change 1986-1996
Primary School Students (i.e., aged 5-12 years)	148,513	124,653	-16.1
Secondary School Students (i.e., aged 13-18 years)	94,973	96,152	1.2
Third Level Students (i.e., aged 19+ years)	22,021	40,764	85.1

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Table 3.5 Household Size in the Dublin Area: 1986-1998[28]

	1986	1996	1998	% change 1986-1998
Private Households	290,395	343,205	375,000	29.1
Persons per Household	3.41	2.99	2.92	-14.4

Sources: CSO (1986b and 1996b). Census of Population (Volume 3: Household Composition and Family Units).
CSO (2000a). Quarterly National Household Survey (Third Quarter 1998: Housing and Households Module).

[28] As the 2002 COP data are not fully released, the latest available data are presented.

Table 3.6 Disposable Income per Person in the Dublin Area: 1991-1999[28]

	1991	1996	1999	% change 1991-1996	% change 1996-1999	% change 1991-1999
Disposable Income (€)	9,063	11,166	14,469	23.2	29.6	59.6

Sources: CSO (1999 and 2002a). County Incomes and Regional GDP.

Notes: (i) Expressed in constant 1996 prices.

(ii) 1991 is the earliest date for which data on county incomes are available.

Table 3.7 Car Ownership in the Dublin Area: 1986-2000[28]

	1986	1996	2000	% change 1986-1996	% change 1996-2000	% change 1986-2000
Total Private Cars	194,693	300,941	376,547	54.6	25.1	93.4
Private Cars per Household	0.67	0.88	1.00[29]	31.3	13.6	49.3
Private Cars per 1,000 Inhabitants[30]	191 (201)	284 (292)	335[31] (337)	48.7 (45.3)	18.0 (15.4)	75.4 (67.7)

Sources: Department of the Environment and Local Government (1986, 1996 and 2000). Irish Bulletin of Vehicle and Driver Statistics.

Table 3.8 Car Ownership, Dublin Bus Passenger Journeys and DART Passenger Journeys: 1986-2000[28]

	TOTAL PRIVATE CARS[32]	BUS PASSENGER JOURNEYS (thousands)	DART PASSENGER JOURNEYS (thousands)
1986	194,693	165,200	14,600
1996	300,941	185,500	21,900
2000	376,547	185,700	22,995
% change 1986-2000	93.4	12.4	57.5

Sources: Department of Environment and Local Government (1986, 1996 and 2000). Irish Bulletin of Vehicle and Driver Statistics.

CIE (1986, 1996 and 2000). Annual Reports and Financial Statements.

Personal Communication from CIE Suburban Rail Division in September 2002.

[29] As the number of households is unavailable for 2000, the latest available figure, i.e., 1998, is used instead.

[30] Figures in parentheses refer to Ireland as a whole.

[31] As the population of Dublin is unavailable for 2000, the population for 2002 is used instead.

[32] Data on the number of car journeys over the period are unavailable so the number of private cars registered in the Dublin area is used as a proxy, while realising that this figure may under- or overestimate the actual number of car journeys over the period.

Table 3.9 Distance travelled to Work in the Dublin Area: 1986, 1996 and 2000

DISTANCE	1986	1996	2000	% change 1986-2000	1986 %	1996 %	2000 %
1 mile or less[33]	55,019	62,615	113,013	105.4	16.2	15.3	21.4
2-4 miles	115,273	127,853	199,094	72.7	33.9	31.3	37.7
5-9 miles	99,760	118,179	122,519	22.8	29.4	28.9	23.2
10 + miles	34,099	58,166	63,900	87.4	10.0	14.2	12.1
Not Stated	35,410	41,939	29,574	-16.5	2.6	10.3	5.6
Total	**339,561**	**408,752**	**528,100**	**55.5**	**100.0**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
CSO (2000b). Quarterly National Household Survey (First Quarter: Travel to Work Module).

Note: (i) Some figures may not add to 100 because of rounding.

Table 3.10 Mode of Transport to Work in the Dublin Area: 1986, 1996 and 2000

MODE	1986	1996	2000	% change 1986-2000	1986 %	1996 %	2000 %
On Foot	40,887	45,915	63,900	56.3	12.0	11.2	12.1
Bicycle	28,997	22,922	19,540	-32.6	8.5	5.6	3.7
Bus	69,618	69,669	85,024	22.1	20.5	17.0	16.1
Train	12,160	17,161	21,124	73.7	3.6	4.2	4.0
Car Driver	129,222	184,380	267,219	106.8	38.1	45.1	50.3
Car Passenger	19,994	24,875	26,933	34.7	5.9	6.1	5.1
Other	38,683	43,830	44,360	14.7	11.4	10.7	7.7
Total	**339,561**	**408,752**	**528,100**	**55.5**	**100.0**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
CSO (2000b). Quarterly National Household Survey (First Quarter: Travel to Work Module).

Notes: (i) "Other" includes motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.

[33] COP respondents are asked to state their distance travelled to work to the nearest mile with the published data then presented in nine categories: 0, 1, 2, 3, 4, 5-9, 10-14, 15 and over and not stated. The data in the tables in this Appendix further are further aggregated into five categories: one mile or less (0+1), two to four miles (2+3+4), five to nine miles (5-9), ten miles or greater (10-14 + 15 and over) and not stated.

Table 3.11 Mode of Transport to Work and Distance travelled to Work in the Dublin Area: 1986 and 1996

	1 MILE OR LESS	2 – 4 MILES	5 – 9 MILES	10 + MILES	NOT STATED
ON FOOT					
1986	48.7	9.1	0.3	0.0	9.4
1996	47.2	9.4	0.3	0.0	9.5
BICYCLE					
1986	8.4	14.0	6.6	1.4	3.4
1996	6.7	9.5	4.2	0.9	2.7
BUS					
1986	5.5	28.1	24.8	15.9	11.4
1996	5.8	22.7	21.0	12.8	11.1
TRAIN					
1986	0.1	1.4	6.2	11.3	1.3
1996	0.3	1.8	6.8	10.2	1.7
CAR DRIVER					
1986	14.3	36.6	48.9	57.4	30.7
1996	19.8	45.8	55.8	63.8	24.8
CAR PASSENGER					
1986	2.3	6.4	7.7	7.7	3.1
1996	3.1	7.1	7.3	6.6	3.4
OTHER					
1986	20.6	4.5	5.6	6.3	40.7
1996	17.2	3.8	4.4	5.7	46.9

Sources: CSO (1986 and 1996c). Census of Population (Special Request).

Notes: (i) OTHER includes motorcycle, lorry, van, other, none and not stated categories.

(ii) The figures in the table are interpreted as follows: of those travelling one mile or less to work in 1996, 47.2 per cent walked to work, 6.7 per cent cycled, 5.8 per cent travelled by bus, 0.3 per cent travelled by train, 19.8 per cent drove a car, 3.1 per cent travelled as a passenger in a car and 17.2 per cent used other means.

Table 3.12 Distance travelled to Work in the Dublin Area by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
1 mile or less	20.2	19.1	0.6	12.3	13.4	29.9	13.3	11.8	32.8	11.1	12.0	47.4
2-4 miles	43.0	39.6	-2.1	28.2	28.4	23.2	13.6	14.2	66.6	28.6	28.2	35.2
5-9 miles	21.7	21.7	6.4	37.6	36.6	19.5	33.8	31.2	38.5	39.8	36.1	23.9
10 + miles	4.2	7.1	79.2	11.8	14.3	48.3	29.5	33.5	69.9	10.8	14.8	87.2
Not Stated	11.0	12.6	22.6	10.1	7.7	-6.3	9.8	8.8	27.6	9.7	8.9	24.7
Total	**100.0**	**100.0**	**6.4**	**100.0**	**100.0**	**22.6**	**100.0**	**100.0**	**49.8**	**100.0**	**100.0**	**36.6**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) Some figures may not add to 100 because of rounding.

(ii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.13 Mode of Transport to Work in the Dublin Area by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
On Foot	17.1	17.1	6.5	7.3	6.4	7.8	6.1	5.6	37.5	6.8	7.1	42.1
Bicycle	11.0	7.8	-24.9	6.2	4.0	-20.4	4.1	2.6	-5.2	7.0	4.5	-11.9
Bus	25.9	20.9	-14.0	13.9	10.2	-9.9	11.2	11.8	57.4	18.6	18.9	38.8
Train	2.9	3.5	30.1	6.3	7.4	43.4	7.5	7.6	51.9	0.1	0.2	255.3
Car Driver	27.5	34.6	34.1	49.5	56.6	40.1	49.6	53.9	62.6	48.2	51.0	44.6
Car - Passenger	4.3	5.0	23.2	6.4	5.5	6.1	8.7	7.7	33.0	7.8	7.7	34.5
Other	20.9	11.0	3.7	10.4	9.9	16.8	12.7	10.8	27.1	11.5	10.7	26.0
Total	**100.0**	**100.0**	**6.4**	**100.0**	**100.0**	**22.6**	**100.0**	**100.0**	**49.8**	**100.0**	**100.0**	**36.6**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) "Other" includes motorcycle, lorry, van, other, none and not stated categories.

(ii) Some figures may not add to 100 because of rounding.

(iii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.14 Distance travelled to Work in the Dublin Area for Males and Females: 1986 and 1996 (Percentage of the Total)

	MALES			FEMALES		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**
1 mile or less	13.3	13.9	14.6	20.9	17.2	13.0
2-4 miles	31.6	28.8	0.0	37.7	34.4	25.6
5-9 miles	31.7	29.9	3.6	25.7	27.6	47.9
10 + miles	11.9	16.4	16.7	7.1	11.5	121.8
Not Stated	11.5	11.0	4.6	8.7	9.3	48.1
Total	**100.0**	**100.0**	**9.7**	**100.0**	**100.0**	**37.5**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) Some figures may not add to 100 because of rounding.
(ii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.15 Mode of Transport to Work in the Dublin Area for Males and Females: 1986 and 1996 (Percentage of the Total)

	MALES			FEMALES		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**
On Foot	8.7	8.1	1.7	17.4	15.3	20.9
Bicycle	9.0	7.4	-10.8	7.7	3.4	-40.1
Bus	15.5	12.8	-9.8	28.5	22.5	8.7
Train	3.4	3.7	19.5	3.8	4.8	72.1
Car Driver	47.1	50.1	16.7	23.5	38.7	126.4
Car - Passenger	3.6	4.0	21.1	9.6	8.8	26.4
Other	12.6	14.0	22.1	9.5	6.5	-5.3
Total	**100.0**	**100.0**	**9.7**	**100.0**	**100.0**	**37.5**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) "Other" includes motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.
(iii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.16 Distance travelled to School for Schoolchildren aged 5-12 years in the Dublin Area: 1986 and 1996

DISTANCE	1986	1996	% change 1986-1996	1986 %	1996 %
1 mile or less	99,160	73,344	-26.0	66.8	58.8
2-4 miles	23,321	23,132	-0.8	15.7	18.6
5-9 miles	3,829	3,868	1.0	2.6	3.1
10 + miles	524	776	48.1	0.4	0.6
Not Stated	21,679	23,533	8.6	14.6	18.9
Total	**148,513**	**124,653**	**-16.1**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Note: (i) Some figures may not add to 100 because of rounding.

Table 3.17 Mode of Transport to School for Schoolchildren aged 5-12 years in the Dublin Area: 1986 and 1996

MODE	1986	1996	% change 1986-2000	1986 %	1996 %
On Foot	92,999	62,043	-33.3	62.6	49.8
Bicycle	3,355	1,653	-50.7	2.3	1.3
Bus	14,669	15,203	3.6	9.9	12.2
Train	518	403	-22.2	0.3	0.3
Car Passenger	25,480	34,442	35.2	17.2	27.6
Other	11,492	10,909	-5.1	7.7	8.8
Total	**148,513**	**124,653**	**-16.1**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Notes: (i) "Other" includes car driver, motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.

Table 3.18 Distance travelled to School for Schoolchildren aged 5-12 years by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
1 mile or less	69.1	57.5	-33.9	58.4	53.9	-22.1	64.1	61.0	-9.3	70.4	62.1	-26.9
2-4 miles	13.4	16.1	-4.4	26.7	29.8	-5.9	15.1	16.8	5.8	12.6	14.2	6.4
5-9 miles	1.1	1.4	-4.4	4.2	4.8	-3.5	4.1	4.5	4.8	2.7	3.4	5.1
10 + miles	0.1	0.2	104.7	0.2	0.7	150.0	1.1	1.5	26.7	0.3	0.5	28.3
Not Stated	16.3	24.8	20.6	10.4	10.8	-12.7	15.6	16.2	-0.8	14.0	17.8	4.7
Total	**100.0**	**100.0**	**-20.6**	**100.0**	**100.0**	**-15.6**	**100.0**	**100.0**	**-4.7**	**100.0**	**100.0**	**-17.3**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Notes: (i) Some figures may not add to 100 because of rounding.
(ii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.19 Mode of Transport to School for Schoolchildren aged 5-12 years by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
On Foot	68.0	51.9	-39.4	43.6	31.8	-38.4	58.7	50.2	-18.4	69.4	58.1	-30.8
Bicycle	1.9	1.4	-41.6	3.8	1.8	-60.6	2.9	1.4	-54.9	1.4	0.9	-46.3
Bus	10.0	14.4	14.8	9.6	7.7	-32.8	11.1	11.9	2.4	9.1	12.2	11.1
Train	0.3	0.2	-42.9	1.0	1.1	-12.5	0.4	0.4	-22.8	0.0	0.0	0.0
Car - Passenger	10.5	19.7	48.2	36.7	52.6	20.9	19.8	29.1	39.7	12.8	21.7	40.5
Other	9.3	12.4	5.8	5.3	5.1	-18.2	7.1	7.1	-4.5	7.3	7.1	-20.1
Total	**100.0**	**100.0**	**-20.6**	**100.0**	**100.0**	**-15.6**	**100.0**	**100.0**	**-4.7**	**100.0**	**100.0**	**-17.3**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Notes: (i) "Other" includes car driver, motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.
(iii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.20 Distance travelled to School for Schoolchildren aged 13-18 years in the Dublin Area: 1986 and 1996

	1986	1996	% change 1986-200	1986 %	1996 %
1 mile or less	46,274	41,330	-10.7	48.7	43.0
2-4 miles	28,595	29,192	2.1	30.1	30.4
5-9 miles	9,002	10,454	16.1	9.5	10.9
10 + miles	2,086	3,221	54.4	2.2	3.3
Not Stated	9,016	11,955	32.6	9.5	12.4
Total	**94,973**	**96,152**	**1.2**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Note: (i) Some figures may not add to 100 because of rounding.

Table 3.21 Mode of Transport to School for Schoolchildren aged 13-18 years in the Dublin Area: 1986 and 1996

	1986	1996	% change 1986-2000	1986 %	1996 %
On Foot	41,686	39,322	-5.7	43.9	40.9
Bicycle	16,662	9,224	-44.6	17.5	9.6
Bus	20,046	25,126	25.3	21.1	26.1
Train	2,444	3,135	28.3	2.6	3.3
Car Passenger	8,278	13,490	63.0	8.7	14.0
Other	5,857	5,855	0.0	6.2	6.1
Total	**94,973**	**96,152**	**1.2**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Notes: (i) "Other" includes car driver, motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.

Table 3.22 Distance travelled to School by Schoolchildren aged 13-18 years by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
1 mile or less	57.6	49.4	-31.0	34.9	31.6	-21.0	38.0	37.8	39.7	51.1	46.1	22.6
2-4 miles	26.5	28.0	-14.8	42.5	42.9	-11.9	24.8	23.8	35.6	28.7	29.5	39.6
5-9 miles	4.1	4.3	-15.4	14.3	15.5	-5.7	19.0	18.3	35.5	9.7	11.0	54.4
10 + miles	0.5	0.9	69.6	1.4	2.4	45.9	9.4	10.1	51.0	1.9	2.3	65.5
Not Stated	11.3	17.2	22.7	6.9	7.5	-4.8	8.9	10.0	57.1	8.7	11.2	76.4
Total	**100.0**	**100.0**	**-19.5**	**100.0**	**100.0**	**-12.8**	**100.0**	**100.0**	**40.5**	**100.0**	**100.0**	**36.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) Some figures may not add to 100 because of rounding.
(ii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.23 Mode of Transport to School for Schoolchildren aged 13-18 years by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
On Foot	54.5	48.3	-28.7	25.1	22.5	-22.0	32.8	36.6	56.6	48.0	46.9	33.1
Bicycle	15.8	11.1	-43.7	25.8	13.3	-55.0	11.5	5.1	-37.6	16.8	8.3	-32.8
Bus	17.0	22.0	4.4	22.3	23.7	-7.2	30.6	31.9	46.5	22.5	29.1	76.0
Train	1.5	1.8	-1.9	4.8	7.3	31.1	6.1	6.4	47.0	0.0	0.1	162.5
Car Passenger	4.0	8.6	73.9	16.8	27.2	41.6	12.8	15.7	71.4	7.8	10.9	90.0
Other	7.2	8.1	-8.9	5.2	6.0	0.7	6.2	4.4	-0.1	4.9	4.6	29.2
Total	**100.0**	**100.0**	**-19.5**	**100.0**	**100.0**	**-12.8**	**100.0**	**100.0**	**40.5**	**100.0**	**100.0**	**36.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) "Other" includes car driver, motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.
(iii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.24 Distance travelled to College for Students aged 19+ years in the Dublin Area: 1986 and 1996

	1986	1996	% change 1986-200	1986 %	1996 %
1 mile or less	4,035	8,272	105.0	18.3	20.3
2-4 miles	8,731	13,328	52.7	39.6	32.7
5-9 miles	5,962	9,405	57.7	27.1	23.1
10 + miles	1,852	5,264	184.2	8.4	12.9
Not Stated	1,441	4,495	211.9	6.5	11.0
Total	**22,021**	**40,764**	**85.1**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Note: (i) Some figures may not add to 100 because of rounding.

Table 3.25 Mode of Transport to College for Students aged 19+ years in the Dublin Area: 1986 and 1996

	1986	1996	% change 1986-2000	1986 %	1996 %
On Foot	3,684	8,792	138.7	16.7	21.6
Bicycle	6,668	6,870	3.0	30.3	16.9
Bus	6,251	13,728	119.6	28.4	33.7
Train	1,728	3,911	126.3	7.8	9.6
Car Driver	1,026	2,277	121.9	4.7	5.6
Car Passenger	1,119	1,866	66.8	5.1	4.6
Other	1,545	3,320	114.9	7.0	8.1
Total	**22,021**	**40,764**	**85.1**	**100.0**	**100.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).
Notes: (i) "Other" includes motorcycle, lorry, van, other, none and not stated categories.
(ii) Some figures may not add to 100 because of rounding.

Table 3.26 Distance travelled to College for Students aged 19+ years by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
1 mile or less	25.3	28.1	97.9	14.5	18.9	98.3	2.1	2.9	325.0	3.6	7.2	350.6
2-4 miles	50.1	40.8	45.7	32.9	31.8	47.9	4.2	5.7	312.3	28.1	25.9	105.3
5-9 miles	14.6	12.9	57.8	39.2	31.8	23.8	37.4	32.3	164.4	51.2	40.2	75.6
10 + miles	2.7	5.2	241.6	7.6	9.3	86.9	51.3	50.4	200.6	11.4	17.3	239.5
Not Stated	7.3	13.1	221.7	5.8	8.2	115.7	5.0	8.8	434.6	5.7	9.6	279.5
Total	**100.0**	**100.0**	**78.8**	**100.0**	**100.0**	**52.7**	**100.0**	**100.0**	**206.1**	**100.0**	**100.0**	**124.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) Some figures may not add to 100 because of rounding.

(ii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.27 Mode of Transport to College for Students aged 19+ years by Area of Residence: 1986 and 1996 (Percentage of the Total)

	DUBLIN COUNTY BOROUGH			DUN LAOGHAIRE-RATHDOWN			FINGAL			SOUTH DUBLIN		
	1986	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**	**1986**	**1996**	**% change**
On Foot	24.3	31.6	32.6	11.4	16.2	118.4	2.1	3.0	350.0	2.3	7.3	605.6
Bicycle	33.5	19.8	5.5	29.0	18.2	-4.1	5.2	2.6	51.3	33.6	15.3	1.8
Bus	24.2	27.7	104.6	27.9	29.5	61.4	40.6	44.1	232.6	42.8	56.1	193.2
Train	4.0	5.0	125.7	12.2	13.7	71.7	31.8	31.6	204.5	0.2	0.9	1025.0
Car Driver	4.0	4.0	79.3	5.6	8.3	126.1	4.5	6.1	312.9	5.7	6.7	161.9
Car - Passenger	2.3	2.2	65.2	7.7	7.3	45.9	10.6	7.2	107.3	8.5	7.1	85.4
Other	7.7	7.9	127.1	6.3	6.7	62.9	5.2	5.4	214.8	6.8	6.7	121.5
Total	**100.0**	**100.0**	**78.8**	**100.0**	**100.0**	**52.7**	**100.0**	**100.0**	**206.1**	**100.0**	**100.0**	**124.0**

Sources: CSO (1986 and 1996c). Census of Population (Special Request for 1986 and Volume 6: Travel to Work, School and College for 1996).

Notes: (i) "Other" includes motorcycle, lorry, van, other, none and not stated categories.

(ii) Some figures may not add to 100 because of rounding.

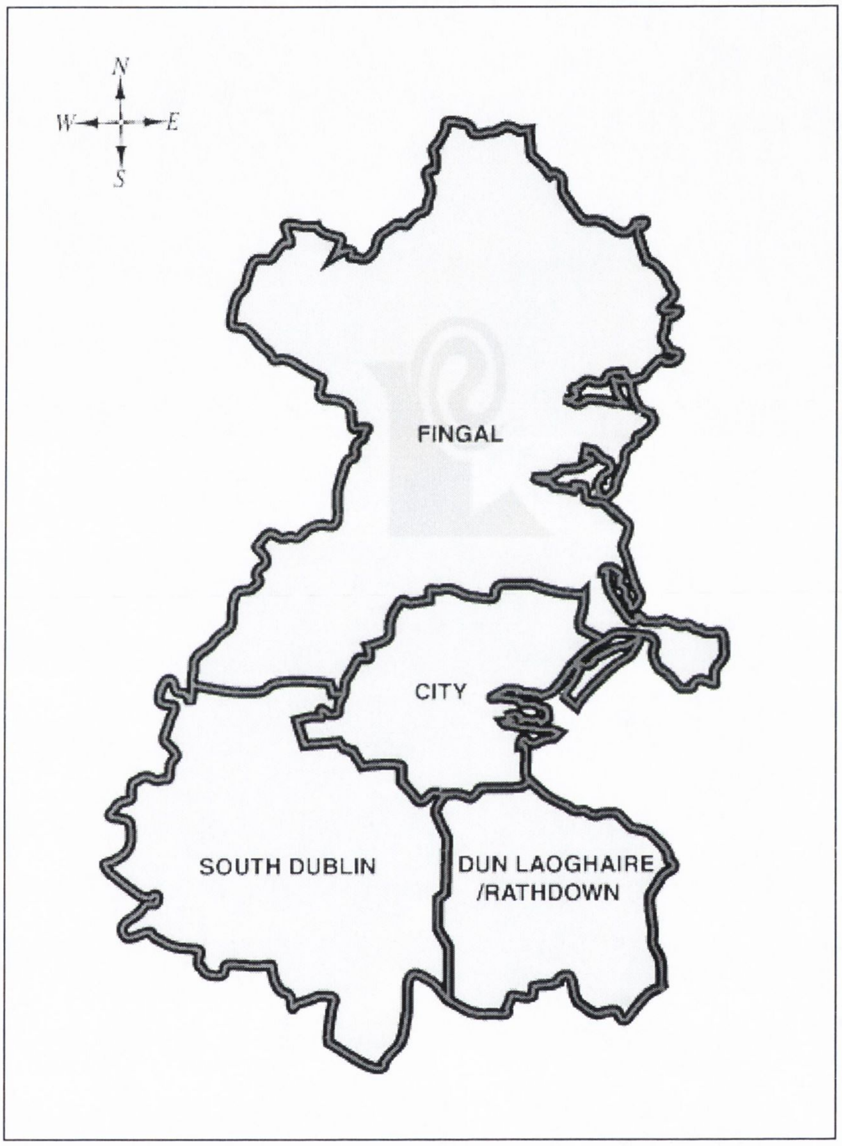
(iii) The percentage change figures refer to the percentage change in the absolute numbers.

Table 3.28 Location of Third Level Institutions in the Dublin Area

AREA	INSTITUTION
Dublin County Borough	American College
	Colaiste Mhuire, Marino
	Dublin Business School
	Dublin City University
	Griffith College
	Mater Dei Institute of Education
	Milltown Institute of Theology and Philosophy
	National College of Art and Design
	National College of Ireland
	Portobello College
	Royal College of Surgeons
	St. Patrick's College of Education
	Trinity College Dublin
	All Hallows College
Dun Laoghaire-Rathdown	Church of Ireland College of Education
	Dun Laoghaire Institute of Art, Design and Technology
	Froebel College of Education
	St. Catherine's College
	University College Dublin
Fingal	Blanchardstown Institute of Technology
South Dublin	Tallaght Institute of Technology

Source: Central Applications Office (2002).
Note: (i) University College Dublin, Trinity College Dublin and Dublin City University are the three largest institutions in the Dublin area with approximately 18,000, 15,000 and 7,000 students respectively.

Figure 3.1 Map of the Dublin Area showing the four local authority regions of Dublin County Borough, Dun Laoghaire-Rathdown, Fingal and South Dublin



Source: http://www.local.ie/general/map/dublin.shtml

Note: (i) "City" refers to Dublin County Borough.

CHAPTER 4

DATA SOURCES:

THE IRISH HOUSEHOLD BUDGET SURVEY AND CENSUS OF POPULATION DATASETS

4.1 Introduction

In this chapter, the data employed in the analyses of household transport decisions in Chapters 5 and 6 and in the analysis of individual modal choice decisions in Chapter 7 are described. Section 4.2 describes the Irish Household Budget Survey datasets that are used in the analysis of households' car ownership, car use and public transport use decisions in Chapters 5 and 6 and discusses such issues as sample sizes and the choice of dependent and independent variables. Section 4.3 introduces the Irish Census of Population dataset that is employed in the analysis of individuals' modal choice decisions for the journeys to work and school/college in Chapter 7. The sample sizes and the dependent and independent variables that are used in this analysis are described in this section. As the Census of Population data do not record individual incomes, this section also discusses the procedure whereby information from the Household Budget Survey is used to construct an income variable for use in the analysis in Chapter 7. Section 4.4 discusses data limitations while Section 4.5 summarises and concludes.

4.2 Household Budget Survey Data 1987-1999

The data employed in Chapters 5 and 6 are micro-data from the 1987/1988, 1994/1995 and 1999/2000 Irish Household Budget Survey (HBS). The surveys were carried out by the Irish Central Statistics Office (CSO) between February 1987 and April 1988, between May 1994 and July 1995 and between June 1999 and August 2000. The surveys are hereafter referred to as the 1987 HBS, 1994 HBS and 1999 HBS. The primary purpose of the HBS is to determine the current spending patterns of Irish households in order to update the weights in the Consumer Price Index (CPI). The HBS has been conducted approximately every seven years since 1951 and recently changed to a five-year cycle.

The HBS is a random survey of a representative sample of all private households in the state and different households are included in each survey. The 1987, 1994 and 1999 HBS consist of 7,705, 7,877 and 7,644 urban and rural households respectively. A household is defined by the CSO as *"a single person or group of people who regularly reside together in the same accommodation ... the household members are not necessarily related by blood or marriage"* [Central Statistics Office (2001a), pp.62]. Each household is asked to complete a questionnaire containing information on socio-economic characteristics and ownership of durable goods as well as an expenditure diary recording every item of expenditure by each adult member of the household over a two-week survey period.[34] Due to the absence of quantity data in the HBS, price information is not available.

[34] All household members aged 15 years and older are required to provide details of their personal expenditure over the 14 consecutive days of the survey. Data on each item of expenditure are then aggregated across household members and averaged across the two survey weeks to give household weekly expenditures on each item.

4.2.1 Sample Sizes

As this thesis concentrates on the income and socio-economic determinants of the demand for transport in the Dublin area[35], all households outside the Dublin area are eliminated resulting in sample sizes of 2,096, 2,148 and 1,789[36] households in 1987, 1994 and 1999 respectively. For the pooled cross-sectional analysis in Chapters 5 and 6, the sample of Dublin households amounts to 6,033 households. Four household-level transport decisions are examined, namely car ownership, car use, bus use and taxi use.[37] Table 4.1 illustrates the various sample sizes corresponding to each of these four transport decisions. While the car ownership decision is examined using the full sample, the car use decision is analysed for households owning one car and for households owning one or more cars.

For the public transport use decisions, the sample is divided on the basis of household car ownership. The sample was divided in order to identify differences in transport behaviour between households without access to a car, so-called captive public transport users, and those with access to one or more cars. It also had the effect of avoiding multicollinearity problems between income and car ownership levels [see Webster and Bly (1980)]. An examination of the summary statistics in Tables 4.3, 4.5 and 4.6 reveals large differences

[35] It is not possible to identify residents of Kildare, Meath and Wicklow from the micro-data; therefore, this thesis concentrates on the travel patterns of residents of Dublin city and county [see also Section 3.1].

[36] A reduction in the response rate of urban households in the 1999 HBS resulted in a smaller sample of Dublin households in that survey. In 1987, 61 per cent of surveyed rural households responded to the survey compared with 56 per cent of urban households. In 1994 and 1999 the corresponding figures were 61 per cent and 55 per cent and 59 per cent and 49 per cent respectively [Personal communication from the CSO in August 2002].

[37] Train use is not analysed due to the nature of the data; it is impossible to ascertain whether expenditure refers to trips on DART/Dublin suburban services or inter-city services. It may be argued that bus expenditure is subject to the same problem. However, the fact that the variance of bus expenditures is much smaller than for train expenditures as well as the fact that the bus service covers all areas of the city whereas certain parts of the Dublin area (e.g. South Dublin) have no train service means that it is more accurate to assume that the majority of bus expenditure recorded refers to trips on Dublin Bus services.

between non car- and car-owning households, in terms of their transport expenditures as well as their socio-economic characteristics. For those households which do not own a car, expenditures per capita on bus and taxi fares are higher than in car-owning households[38], while the proportions recording these expenditures are also higher in non car-owning households in 1987 and 1994. In terms of household socio-economic characteristics, significant differences between non car- and car-owning households are evident for many of the variables, especially household income, accommodation type and working status and the gender and education level of the head of household (HOH). As a result of the rejection of tests for coefficient stability across the two sub-samples of non car-owning and car-owning households[39], the regressions for bus and taxi fare expenditures are estimated separately for these two sub-samples (see also Section 6.5.1).

4.2.2 Dependent Variables

Table 4.2 presents variable definitions for the dependent variables that are used in the analyses in Chapters 5 and 6 while Table 4.3 presents the summary statistics for these variables. In examining car ownership, the dependent variable is a binary variable indicating whether or not the household owns one or more cars. For the car use decision, the dependent variable is petrol expenditure per car (which includes diesel expenditure). Public transport use is proxied by bus and taxi fare expenditures separately. As previously noted, expenditure on train fares is not analysed.

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[38] With the exception of average per capita taxi fare expenditures in 1999, which were higher in car-owning households than in non car-owning households.

[39] While the proportion of households owning two or more cars has been increasing over the period 1987-1999 (from 10.8 per cent in 1987 to 23.5 per cent in 1999), very few independent variables are significant with the result that bus and taxi use are not analysed separately for households owning two or more cars. However, to some extent, the inclusion of a variable indicating the number of household cars in the sample of households owning one or more cars will capture the behaviour of multi-car households.

Bus and taxi expenditures are adjusted for household size using EU adult equivalence scales as reported in the HBS.[40] As each household has a different interview date[41], for the analyses using independent data from each HBS, all expenditure variables are also adjusted for seasonality by regressing expenditure on monthly dummies and constructing an index based on the relationship between the constant and the estimated coefficients. This index is then used to seasonally adjust the expenditure variables [see Section 4A in the Appendix for further details]. Expenditures are seasonally adjusted before estimation rather than including eleven monthly dummies in an attempt to reduce the number of independent variables, especially in light of the complicated computations involved in the estimation of econometric models (see Chapters 5 and 6). For the analysis of the pooled data in Chapters 5 and 6, all expenditure variables are first adjusted for household size using the same EU adult equivalence scales and then adjusted for inflation by expressing all expenditure values in constant November 1994 prices [using the CPI figures published by the CSO (see statistics for "all prices" in Tables 4.7, 4.8 and 4.9)][42], an approach similar to that outlined in Atkinson *et al.* (1990).

[40] The head of household (HOH) is given a weight of one, any other adults over the age of 14 are given a weight of 0.7 and children up to the age of 14 are given a weight of 0.5. Petrol expenditures are not adjusted for household size as it is felt that car use decisions are more appropriately analysed as a household, rather than an individual, decision [see Kayser (2000) and Berkowitz *et al.* (1990)]. While it may be argued that for bus fare expenditures, which are not subject to economies of scale like taxi or total expenditures, all adults over the age of 14 should be given a weight of one while children under 14 should be given a weight of 0.5, we apply the conventional formula to total, bus and taxi expenditure.

[41] Each HBS is conducted over an approximate fifteen-month period (see Section 4.2).

[42] Tables 4.7 to 4.9 illustrate changes in the levels of overall prices, petrol prices, bus fares and taxi fares over the duration of each of the surveys. While cross-sectional studies of household expenditure using household budget data assume that prices are fixed over the duration of the survey, the data indicate that while price changes were slight over the course of the 1987 and 1994 surveys, more significant changes in prices occurred over the duration of the 1999 survey, in particular for petrol prices and bus fares. However, the changes in prices between each survey are in all cases larger than price changes within each survey period, thus justifying adjusting individual expenditures for seasonality only and pooled expenditures for CPI changes only. In addition, the seasonal adjustment to individual expenditures should eliminate some of the price differentials between different months.

The proportion of households owning one or more cars increased from 53.3 per cent in 1987 to 67.7 per cent in 1999, an increase wholly driven by the sharp increase in the proportion of households owning two or more cars from 1994 to 1999.[43] For households owning one car, average petrol expenditures changed slightly over the period 1987 to 1999[44] but the proportion of households recording petrol expenditures fell by nearly ten per cent.[45] Average per capita bus fare expenditures increased from £1.04 to £1.88[46] in nominal terms from 1987 to 1999. However, when expressed in constant November 1994 prices, average per capita bus fare expenditures actually decreased from £1.55 to £1.46 over the period 1987-1999. This probably reflects the significant decrease in the proportion of households recording positive bus fare expenditures, which fell from 58.4 per cent in 1987 to 47.1 per cent in 1999. An examination of the summary statistics for non car-owning and car-owning households reveals that average per capita bus fare expenditures are higher in non car-owning households and the proportions doing so are also higher in 1987 and 1994. Average per capita taxi fare expenditures increased in nominal (and constant) terms from £0.26 (£0.28) in 1987 to £1.77 (£1.34) in 1999, as did the proportion of households recording positive taxi fare expenditures. An examination of the summary statistics reveals that there are less distinct differences between non car-

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[43] While the proportion of households owning one car increased slightly from 42.5 per cent to 44.3 per cent from 1987 to 1999, the proportions recording ownership of two or more cars were 10.8 per cent in 1987, 12.3 per cent in 1994 and 23.5 per cent in 1999. In addition, the proportions recording ownership of three or more cars increased from 1.0 per cent in 1987 to 1.1 per cent in 1994 to 1.8 per cent in 1999.

[44] While the characteristics of the "average car" will have changed over the period 1987-1999 and therefore may impact on the accuracy of petrol expenditures in proxying car use (e.g. increased fuel efficiency over time does not mean that cars are being used less over time), there are no variables relating to household car characteristics available in the HBS.

[45] There are three explanations for zero observations on household expenditure data, namely, a standard corner solution (which leads to the Tobit model), non-participation and infrequency of purchase. Labeaga and Lopez (1997) rule out the possibility of infrequency of purchase for petrol expenditures when the survey period is a week (two weeks in our case). Non-participation is obviously not an option so an increase in the proportion of households not spending on petrol due to economic reasons is the most plausible reason (and validates the use of the Tobit methodology).

[46] All expenditure values in the micro-data files are expressed in Irish pounds; IR£1 = €1.27.

owning and car-owning households in terms of their taxi fare expenditures with average levels of expenditure slightly higher in non car-owning households in 1987 and 1994. Oscar Faber (1998) explain the significant increase in the demand for taxis in the Dublin area in the 1990s as a result of economic growth, increased car parking restrictions in the city centre and stricter drink driving legislation and enforcement.[47]

4.2.3 Independent Variables

Table 4.4 defines the various independent variables that are used in the analyses in Chapters 5 and 6 while Tables 4.5 and 4.6 present the summary statistics for the continuous and discrete independent variables respectively.

Income

Household income is found to be consistently significant in explaining households' transport decisions and has been used in nearly all previous studies in the area [see discussion in Chapter 2]. As it is widely acknowledged that there is considerable under-reporting of household income in surveys of this kind [see Asensio *et al.* (2001), Central Statistics Office (2001a) and Hagemann (1981)] and due to the desire to represent lifetime rather than current income[48], household income is proxied by total weekly

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[47] An additional factor may have been the subsequent deregulation of the market in November 2000, which substantially increased the supply of taxis in the Dublin area.

[48] Using expenditure to proxy income is a common approach in studies of household behaviour with Asensio *et al.* (2001), Alperovich *et al.* (1999), Hagemann (1981) and Archibald and Gillingham (1980) all discussing the rationale for using expenditure to proxy lifetime income which is regarded as more stable over time than current income.

household expenditure.[49] In common with the dependent expenditure variables, household expenditure is also adjusted for household size using EU adult equivalence scales as reported in the HBS and for seasonality using the procedure described in Section 4A in the Appendix. Finally, household expenditure is divided by one hundred for ease of interpretation. Squared and cubed terms are also included to capture non-linear relationships between the dependent variables and household expenditure [see Kayser (2000), Melenberg and Van Soest (1996), Blundell *et al.* (1993), McCracken and Brandt (1987), Archibald and Gillingham (1980), Cragg and Uhler (1970) and Bennett (1967)]. The summary statistics presented in Table 4.5 indicate that average per capita weekly household expenditures increased from £193 in 1987 to £273 in 1999. Expressed in constant November 1994 prices, average per capita weekly household expenditure increased from £204 in 1987 to £207 in 1999, an increase of 1.2 per cent.[50] Tables 4.10 to 4.12 illustrate differences in average car ownership levels, petrol, bus and taxi fare expenditures for the top, middle and bottom third of the expenditure distribution for the 1987, 1994 and 1999 HBS. An examination of this aggregated data indicates that while average levels of car ownership, petrol expenditure and taxi fare expenditure are positively correlated with household expenditure, average levels of bus fare expenditure first increase and then decline with increasing household expenditure in 1994 and 1999.

[49] A number of studies discuss the problem of endogeneity that may arise when expenditure is used as both a dependent and independent variable [Blundell *et al.* (1993), Reynolds and Shonkwiler (1991) and Hagemann (1981)]. However, where the dependent variables consist of disaggregated categories of expenditure, endogeneity is not considered a significant problem [Hagemann (1981)]. In the analyses of transport expenditures in Chapters 5 and 6, for those households reporting positive expenditures for each of these categories, the average budget shares for petrol, bus fare and taxi fare expenditures are only 7.6 per cent, 1.9 per cent and 1.6 per cent respectively (statistics derived from the pooled sample).

[50] While this figure seems very low in comparison with the large increase in per capita disposable incomes in the Dublin area from 1991-1999 presented in Table 3.6, the fact that the characteristics of the HBS samples changed somewhat over the period 1987-1999 may account for the more modest increase in average per capita weekly household expenditures, e.g., the larger proportion of elderly households surveyed in 1999 compared with 1994 and 1987 (see also Tables 4.5 and 4.6).

Adults

The number of adults in the household is the second continuous independent variable and has been previously employed in a number of other studies of households' transport decisions [see Asensio *et al.* (2001), Alperovich *et al.* (1999), Bjorner (1999), Dargay and Vythoulkas (1999), Hensher (1985), Lave and Train (1979), Cragg and Uhler (1970) and Bennett (1967)]. Schmalensee and Stoker (1999), Train (1980) and Ben-Akiva and Lerman (1975) include the number of adults in the household as a proxy for the number of licensed drivers in the household. For the purposes of this study, adults are defined as being aged 18 years and over. Squared and cubed terms are again included to capture non-linear effects [see Alperovich *et al.* (1999), Reynolds and Shonkwiler (1991) and Atkinson *et al.* (1990)]. The summary statistics, presented in Table 4.5, show that the average number of adults in the household decreased from 2.12 in 1987 to 2.05 in 1999. An examination of average car ownership levels, petrol, bus and taxi fare expenditures for each household type in Tables 4.10 to 4.12 indicates that there is a positive relationship between car ownership levels and household size. There is also some evidence for a possible non-linear effect with a large change in the proportion of households owning a car as the number of adults in the household increases above one and a stabilisation in car ownership levels once the number of adults passes three. For petrol, bus and taxi expenditure, the effect of increasing adult numbers is generally positive with occasional non-linear effects (e.g. taxi expenditure) but in all cases households with four or more adults spend more per capita than households with two adults or less.

Children

The final continuous variable represents the number of children in the household, i.e., the number of household members aged 17 years or younger. Previous applications, which have included the number of children in the household as a dependent variable, include those by Asensio *et al.* (2001), Bjorner (1999), Dargay and Vythoulkas (1999), Lave and Train (1979), Cragg and Uhler (1970) and Bennett (1967).[51] As with household expenditure and the number of adults in the household, non-linear terms are considered. The summary statistics in Table 4.5 show a decline in the average number of children per household from 1.26 in 1987 to 0.77 in 1999. Tables 4.10 to 4.12 indicate that as the number of children in the household increases, average levels of car ownership first increase and then decline. The relationships with average bus and taxi fare expenditure are in general negative, with some evidence to show that average per capita bus fare expenditures first increase and then decline as the number of children in the household increases. The relationship between the number of children in the household and petrol expenditure is less clear although in all years, households without children spend less than households with one or more children.

Accommodation Type

Accommodation type is a discrete variable with three categories: detached (base category), semi-detached[52] and apartment. This variable is included to proxy the quality and quantity of public transport links as well as distance from the city centre as the HBS

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[51] Kayser (2000) includes dummy variables for no children, one child and several children in the household while Bergantino (1997) includes a dummy variable for the presence of children in the household.
[52] Semi-detached includes terraced houses.

does not record information on any of these variables.[53] This assumes that those living in detached houses are more likely to live in outlying areas of Dublin and thus have longer distances to travel to the city centre and/or poorer public transport links than those living in semi-detached/terraced houses or apartments. Bhat and Pulugurtha (1998) and Ben-Akiva and Lerman (1975) similarly include dummy variables for single-family versus multi-family dwellings in their multinomial logit model of household car ownership and nested multinomial logit model of household car ownership and mode of transport to work respectively.[54] Numerous studies emphasise the importance of distance/public transport availability in determining household and individual transport choices [see Asensio *et al.* (2001), De Palma and Rochat (2000)), Kayser (2000), Alperovich *et al.* (1999), Bjorner (1999), Dargay and Vythoulkas (1999), Schmalensee and Stoker (1999), Berkowitz *et al.* (1990), Hensher (1985), Mannering and Winston (1985), Mannering (1983), Archibald and Gillingham (1980), Lave and Train (1979), De Donnea (1971) and Cragg and Uhler (1970)]. Table 4.6 illustrates that over 70 per cent of surveyed households live in semi-detached or terraced houses. Tables 4.10 to 4.12 show that while there are much higher rates of car ownership and use among those living in detached houses, their average per capita bus and taxi fare expenditures are lower than the averages for the other categories (with the exception of 1999 where those living in semi-detached/terraced homes spend the most on petrol and the least on taxi fares).

[53] Information on the location of the household within the four local authority regions of Dublin (Dublin County Borough, Dun Laoghaire-Rathdown, Fingal and South Dublin) is not revealed in the HBS micro-data.

[54] Bhat and Pulugurtha (1998) include this variable in the expectation that higher density development and a public transport friendly environment would be associated with multi-family dwelling units relative to single-family homes. Ben-Akiva and Lerman (1975) include this variable to account for the fact that individuals living in single-family dwellings have better access to parking facilities and are therefore more likely to own cars than those residing in multi-family dwellings.

Working Status

The working status of the household is represented by a binary variable in an attempt to differentiate between households that have at least one working member and households where no member works. This type of variable is common in analyses of this kind and is expected to highlight differences in travel behaviour between households where regular commuting needs are a feature [see Kayser (2000), Berkowitz *et al.* (1990), Archibald and Gillingham (1980) and Cragg and Uhler (1970)].[55] The summary statistics in Table 4.6 indicate that while the proportion of households with at least one working member declined from 1987 to 1994, it increased again to 71 per cent of all households surveyed in 1999. Tables 4.10 to 4.12 illustrate the clear positive correlation between household working status and average car ownership, petrol, bus and taxi expenditures. However, the statistics for average car ownership levels reveal that the proportion of non-working households with ownership of one or more cars increased more rapidly from 1987 to 1999 (from 21 to 37 per cent) than the proportion of working households who own car(s) (which increased from 70 to 80 per cent over the period 1987-1999).

Gender

The remainder of the independent socio-economic variables relate to head of household (HOH) characteristics.[56] No explicit instructions are given to survey respondents as to who should be regarded as the HOH but it is usually regarded as the person in whose

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[55] A number of studies include the number of workers in the household as a continuous independent variable [see Asensio *et al.* (2001), De Palma and Rochat (2000), Alperovich *et al.* (1999), Mannering and Winston (1985) and Lave and Train (1979)]. In an attempt to reduce collinearity with the number of adults in the household, we express this variable in binary, rather than, continuous form. Indeed, Cragg and Uhler (1970) and Bennett (1967) also include the number of adults in the household and consequently the number of income earners in the household is never significant.

[56] See also Section 2.3.

name the accommodation is owned or rented and who is mainly responsible for meeting household expenses. The choice of HOH is, however, left with the household. Due to this ambiguity and in an attempt to capture a pure gender effect, the gender of the HOH is expressed as a binary variable with the value one indicating households that have a female HOH who is the only adult in the household.[57] Much evidence exists for a gender difference in transport decisions with women generally found to be less likely to own and use cars and more willing to use public transport than men [see Kayser (2000), De Palma and Rochat (2000), Bjorner (1999), De Jong (1999), Mannering (1983), Archibald and Gillingham (1980) and De Donnea (1971)]. The summary statistics in Table 4.6 reveal a slight increase in the proportion of households headed by a single female between 1987 and 1994 and little change at approximately 20 per cent between 1994 and 1999. Tables 4.10 to 4.12 indicate that while single female-headed households have lower car ownership rates and average petrol and bus expenditures, they have similar per capita taxi fare expenditures in 1987, higher in 1994 and lower in 1999.

Age

The age of the HOH is intended to capture generational effects in household transport decisions and has been widely employed in previous work in the area [see Asensio *et al.* (2001), De Palma and Rochat (2000), Kayser (2000), Alperovich *et al.* (1999), Schmalensee and Stoker (1999), Bergantino (1997), Hensher (1985), Mannering and Winston (1985), Mannering (1983), Archibald and Gillingham (1980), Lave and Train (1980), De Donnea (1971), Cragg and Uhler (1970) and Bennett (1967)]. There are five categories for this variable with households with a HOH aged 29 years and younger taken

[57] This variable may also capture the effect of having a single adult in the household.

as the base category. The summary statistics in Table 4.6 indicate that the proportion of households with a HOH aged 60 years and older has increased since 1987 while the proportions with young HOHs has declined. Tables 4.10 to 4.12 reveal that while younger households have the highest average expenditures on bus and taxi fares, they also have the lowest average car ownership levels. In terms of petrol expenditure, households with young and old HOHs spend less than households with HOHs aged 30-59 years.

Education Level

The education level of the HOH enters as a categorical variable with three categories: primary level education, secondary level education and third level education (the latter is also the base category).[58] While it is difficult to say why the education level of the HOH should influence household transport decisions, it is included as an additional factor describing the tastes and preferences of the household. Asensio *et al.* (2001), Kayser (2000), Alperovich *et al.* (1999), Archibald and Gillingham (1980) and Lave and Train (1979) all find the education level of the HOH significant in explaining household transport decisions. The summary statistics in Table 4.6 indicate that the average education levels of households have been rising since 1987, and in particular between 1994 and 1999 when the proportion of households with a HOH having a third level qualification increased from 22.5 per cent in 1994 to 32.7 per cent in 1999. Tables 4.10 to

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[58] The original question used to construct this variable in 1994 and 1999 was different to that used in 1987. In 1994 and 1999 the household was asked for the highest level of education completed by the HOH while in 1987 the household was asked for the age at which the HOH finished his/her education. For the construction of this variable using the 1987 data, we assume that those finishing school up to and including the age of 13 years have a primary level education, between 14 and 18 years have a secondary level education and anything over 19 years is taken to mean a third level qualification.

4.12 indicate that increasing levels of education are clearly associated with increasing average car ownership rates and average petrol and taxi expenditures. While increasing levels of education are also associated with increasing expenditure on bus fares in 1994 and 1999, the opposite is true for 1987 where expenditure on bus fares falls as the education level of the HOH increases.

Transport Control Variables

Finally, there are a number of transport control variables included in all models, which are both continuous and binary in nature. A complicating issue for the bus fare expenditure models is the fact that certain categories of individual are entitled to free bus transport in Ireland.[59] This means that in these cases, one of the most important assumptions of the analysis is violated, i.e., that bus fare expenditure is an accurate reflection of bus use. To overcome this problem, a continuous independent variable representing the number of people in the household entitled to free public transport is included. Table 4.5 indicates that the proportion of households with at least one member entitled to free public transport has increased from 22 per cent in 1987 to 26 per cent of the total in 1999, which may reflect the increased proportion of elderly households surveyed in 1999. Similarly, a binary variable indicating whether at least one person in the household receives remuneration for motor expenses such as petrol is included.[60] Again, the proportion of households with at least one member entitled to travel expenses increased from 13.5 per cent in 1987 to nearly 18 per cent of all households in 1999. The

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[59] Pensioners and disabled persons are entitled to free bus travel at off-peak times while certain schoolchildren receive free bus transport to and from school.

[60] This variable enters in binary, rather than continuous, form as it is expected that there is considerable under-reporting of this item.

number of motorcycles owned by the household is included as expenditure on petrol could be significantly higher for households that own a motorcycle as well as a car and expenditure on bus and taxi fares could be significantly lower if the motorcycle is regarded as a competing mode.[61] Finally, in the car use models for households owning one or more cars, dummy variables indicating ownership of two cars and three or more cars are included. Table 4.6 indicates that the proportion of households owning two or more cars increased substantially over the period 1987-1999, in particular over the period 1994-1999. For the bus and taxi use regressions in households owning one or more cars, the number of household cars is included as a continuous variable. Once again, the summary statistics in Table 4.5 confirm the increase in multi-car households, particularly since 1994.

4.3 Census of Population Data 1996

The data employed in Chapter 7 are micro-data from the 1996 Irish Census of Population (COP). The COP is carried out every five years by the CSO and includes all individuals present in the country at a specified point in time, namely, the last Sunday in April.[62] The micro-data constitute a five per cent random sample. In total 181,321 individuals are included in the micro-data file, of which 52,915 individuals were surveyed in the Dublin area. Each individual observation contains information on socio-economic characteristics such as socio-economic group, gender, age, level of education and area of residence as well as mode of transport and distance travelled to work and school/college. As with the

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[61] Asensio *et al.* (2001) and Bergantino (1997) also include an independent variable indicating the number of motorcycles in the household.

[62] The 1996 COP is the latest Census for which data are available; the 2001 COP was postponed until 2002 and the results will not begin to become available until early 2003.

HBS, price information is not available. As there is no information relating to income in the COP, a proxy income variable is constructed using information from the 1994 HBS [see Section 4.3.3 and Section 4C of the Appendix].

4.3.1 Sample Sizes

The analysis in Chapter 7 focuses firstly on working individuals aged 15 years and over who are usually resident in the Dublin area, amounting to 20,009 individuals. Secondly, we examine the travel patterns of all students in full-time education usually resident in the Dublin area, which amounts to 12,730 individuals.[63] Individuals that work at home or that are resident at school/college are excluded from the samples[64] as are observations for which data on certain questions are missing[65] resulting in final sample sizes of 16,912 individuals and 10,610 individuals for the work and school samples respectively.

4.3.2 Dependent Variables

The dependent variables in Chapter 7 are mode of transport to work and mode of transport to school/college. Variable definitions and summary statistics for the dependent

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[63] Individuals usually resident outside the Dublin area are excluded from both the working and school samples as their travel patterns to work and school/college do not reflect choices made in the context of the Dublin transport system.

[64] These observations are excluded as there is no variation in mode of transport or distance travelled. In total, 765 such observations are deleted from the work sample and 141 observations are deleted from the school sample.

[65] The missing observations occur for four variables for the work sample (mode of transport and distance travelled to work, and level of education and type of work) and for two variables for the school sample (mode of transport and distance travelled to school/college). Due to the tiny number of observations with missing observations on the dependent variable of mode of transport to work/school/college - 49 for the work sample and 96 for the school sample - and the consequent insignificance of the Mill's ratio, a Heckman sample selection model is not employed. In order to test for the randomness of the excluded observations, a t-test as outlined in Puller and Greening (1999) and Johansson-Stenman (2002) is undertaken to test the null hypothesis of equal means for the two samples: a) the sample containing missing observations and b) the sample containing only complete observations for all variables of interest. While we reject the hypotheses of equal means in most cases [see Section 4B of the Appendix], we exclude observations with missing data while remembering that policy conclusions must bear this fact in mind.

variables are presented in Tables 4.13 and 4.14. For the analysis of mode of transport to work, the dependent variable is coded from 0 to 3 representing car driver, on foot/bicycle, bus/train and car passenger categories respectively. The dependent variable for the analysis of mode of transport to school/college is coded 0 to 3 representing on foot/bicycle, bus/train, car passenger and other (car driver, motorcycle, lorry or van) categories respectively. Mode of transport refers to the outward journey to work, school or college. Where more than one mode of transport is used, the mode of transport used for the greater part of the journey is recorded. The dependent variables are therefore discrete categorical variables with mutually exclusive unordered alternatives. The choice of dependent variable categories was motivated by the results of the Independence from Irrelevant Alternatives (IIA) specification tests outlined in Section 7.5.2. The choice sets comprise the sets of alternatives for which the IIA axiom cannot be rejected. As discussed in Section 7.5.2, the initial dependent variable categories[66] do not satisfy the IIA property with the result that some alternatives have to be merged. However, for comparison, the variable definitions and summary statistics in Tables 4.13 and 4.14 present both specifications of the dependent variables.

An examination of the summary statistics for the dependent variables in Table 4.14 reveals that nearly 53 per cent of the sample of employed persons drove to work with travelling by bus the next popular mode (18 per cent). For those in full-time education, the most popular mode was walking with travelling by bus and as a passenger in a car being next with approximately 22 per cent of the total each. These aggregated results

[66] For the work sample, the initial dependent variable has six categories (car driver, on foot, bicycle, bus, train and car passenger) while for the school sample the initial dependent variable also has six categories, namely, on foot, bicycle, bus, train, car passenger and other (car driver, lorry, van or motorcycle).

from the micro-data are in broad agreement with those obtained from the published data from the 1996 COP, which are presented in Tables 3.10, 3.17, 3.21 and 3.25.

4.3.3 Independent Variables

Variable definitions and summary statistics for the independent variables are detailed in Tables 4.15, 4.16 and 4.17. All independent variables are individual-specific rather than alternative-specific [see Sections 2.5 and 7.2 for a review of previous literature in this area].

Income

The COP does not record any information on the income of the individual in question and since the effect of income on the demand for transport is of particular interest, a value for income is computed based on the observed characteristics of individuals in the work sample. The procedure involves identifying variables that are common to both the 1994 HBS and 1996 COP datasets and using the estimated relationship between income and these variables in the 1994 HBS to predict income values for each observation in the COP based on their observed values of the same variables. The procedure is outlined in detail in Section 4C of the Appendix. Due to the difficulty in ascertaining the appropriate sample to use in the 1994 HBS, an income variable is not constructed for inclusion as an independent variable in the analysis of modal choice decisions for the journey to school/college in Chapter 7 (see also Section 4C of the Appendix).

The summary statistics in Table 4.16 indicate that average weekly household expenditure for the sample of working individuals is £255. The mean level of expenditure and the standard deviation of £58 are much higher and lower respectively than those of household expenditure in the 1994 HBS. This is due to the characteristics of the COP sample, i.e., it is only concerned with working individuals who, by definition, will be expected to have higher than average household expenditure than a sample of working and non-working households. Table 4.18 indicates that the proportions travelling on foot, by bicycle and by bus decline as income increases while the proportions travelling by train and driving a car to work increase; the latter effect is not surprising given the strong relationship found between household expenditure and average car ownership levels for the 1994 HBS in Table 4.11.

Socio-Economic Group

For the school sample, a household income variable cannot be constructed and therefore the socio-economic group of the student is used instead. In addition, the model for choice of mode of transport to work is also estimated with socio-economic group replacing household income. This variable is constructed as a binary variable with the value one indicating an individual in the top three socio-economic groups A, B or C (namely, employers and managers, higher professional and lower professional workers). It is expected that this variable will illustrate the same effect as household expenditure on choice of mode of transport to work and school/college with car driving and car passenger probability also significantly affected by the assumed positive correlation between socio-economic group and car ownership. An examination of the summary statistics in Table 4.17 indicates that just over 60 per cent of the working sample are in the ABC socio-economic group while just over 33 per cent of the school sample are in the ABC socio-economic group. One reason for this disparity may be the tendency for third level students to be categorised as "otherwise gainfully occupied and unknown" as they are not living at home.[67] A comparison of modal shares for the work sample indicates a clear distinction between those in the lower socio-economic groups who have higher modal shares for the on foot, bicycle, bus and car passenger categories in comparison with those in the higher socio-economic groups who have higher modal shares for the train and car driver categories. For the school sample, Table 4.19 illustrates that the most popular mode of transport to school/college for those in the ABC category is travelling as a passenger in a car while for those that are not in the ABC socio-economic grouping, walking is the most popular mode of transport to school/college.

Distance

One of the major advantages of the COP micro-data over the HBS is the ability to explicitly include distance travelled to work and school/college as an independent variable. Distance travelled to work is a common independent variable in studies of modal choice and enters as an independent variable in a number of different forms [see Bjorner (1999) and De Donnea (1971) for applications with distance to work as an independent variable and applications by De Palma and Rochat (2000) and Train (1980) which use travel time as an independent variable]. As the variable is entered in discrete,

[67] Students in full-time education are classified according to the socio-economic group of the person upon whom they are dependent, i.e., in the majority of cases this is the HOH. However, for third level students living away from home, they are classified as category Z, i.e., "otherwise gainfully occupied and unknown".

rather than continuous form on the data file, the distance variable consists of six categories with distances of ten miles or more regarded as the base category.[68] Table 4.17 indicates that the majority of commuters travel distances of four miles or less to work (50.3 per cent) with the majority of those in full-time education travelling distances one mile or less to school/college (55.7 per cent). In line with expectations and with the aggregated results presented in Section 3.3.2, walking is the most popular means of transport to work for those travelling distances of two miles or less to work while the majority of those travelling longer distances travel to work by car with the proportion doing so increasing as distance increases. While the proportions travelling by bus are highest for those travelling four to five miles to work, the proportions using the train increase as distance increases, especially at the longer distances. For the school sample, Table 4.19 shows that walking is the most popular mode for short distances although it is noteworthy that 17.3 per cent of students travelling one mile or less to school/college travel as a passenger in a car.

Area of Residence

In addition to distance, the area of residence is included to examine whether there is any systematic difference in travel patterns on a regional level after controlling for distance. A strong conclusion from Chapter 3 was that there were quite striking differences between different areas of Dublin in terms of travel behaviour [see Sections 3.3.2 and 3.3.3]. Location within the Dublin area is also included to proxy the availability of public transport facilities with Dun Laoghaire-Rathdown and Fingal being well-served with the

[68] As the COP asks respondents to state their distance travelled to work to the nearest mile, the distance variable contains six categories: one mile or less (0+1), two (2), three (3), four (4), five (5-9) and ten (10+), with the latter regarded as the base category. See also Section 3.3.2.

DART service in comparison with South Dublin for example. A number of other studies of modal choice include location as an independent variable [see Train (1980) and De Donnea (1971)]. While in all cases, most travel by car to work, the proportions differ across the four areas, ranging from 66 per cent in Dun Laoghaire-Rathdown to 41 per cent in Dublin County Borough. Not surprisingly, the residents of Dublin County Borough have the highest proportions walking, cycling and travelling by bus to work. The availability of public transport services is reflected in the higher proportions using the train to travel to work in Fingal and Dun Laoghaire-Rathdown. For the school sample, Table 4.19 indicates that the majority of students resident in Dublin County Borough, Fingal and South Dublin walk while the majority of students in Dun Laoghaire-Rathdown travel as a passenger in a car to school/college.

Gender

The gender of the individual is included as there is much evidence to show that males and females exhibit significant differences in their transport behaviour [see Chapter 2 and Section 3.3.2], with males more likely to drive and less likely to travel by public transport than females [see De Palma and Rochat (2000), Mannering (1983), Domencich and McFadden (1975) and De Donnea (1971)]. The variable is binary in nature with the value one indicating a female. The summary statistics in Table 4.18 indicate that women walk, travel by bus and train and as a passenger in a car in greater proportions than males. For the school sample, Table 4.19 shows that female students travel as passengers in a car and by bus in greater proportions than their male counterparts.

Age

The age of the individual enters as a categorical variable in an attempt to explain generational differences in travel behaviour. It has been found to be significant in a number of different studies of modal choice behaviour [see De Palma and Rochat (2000), Domencich and McFadden (1975) and De Donnea (1971). For the work sample, the variable has five categories with those aged 29 years and younger taken as the base category. In the school sample, the variable has four categories in an attempt to identify differences in the travel patterns of different types of students, namely, aged 5-10 years (primary school), aged 11-14 years (primary and secondary school), aged 15-19 years (secondary school and third level) and aged 20+ years (third level students), with the latter also being the base category.[69] The statistics in Table 4.18 illustrate that among workers aged 29 years or younger, the proportions travelling by bus and driving a car to work are very similar, while the car is the most popular method for those older than 30. Table 4.19 indicates that for primary schoolchildren, walking and travelling as a passenger in a car are most popular while for older secondary school students, walking and travelling by bus are most popular. The majority of third level students walk, cycle or travel by bus.

Level of Education

The level of education of the individual is only included in the analysis of mode of transport to work and enters as a categorical variable with three categories relating to the highest level of education completed by the individual, namely, primary level, secondary

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[69] The age variable is included in five-yearly intervals in the micro-data file; this accounts for the overlap between students in different levels of education.

level and third level education (the latter is taken as the base category). De Palma and Rochat (2000) also include the education level of the HOH in their analysis of choice between car and public transport for the journey to work in Geneva. The data in Table 4.18 show that more educated individuals drive to work or take the train in greater proportions than less educated individuals who walk, cycle or travel by bus to work in greater proportions. The latter result is in contrast to the data presented in Table 4.11 for the 1994 HBS, where well-educated households spend the most per capita on bus fares.

Marital Status

The marital status of the individual is included in the analysis of mode of transport to work in an attempt to proxy household type. It is expected that those that are married are more likely to have children[70] and other responsibilities and may be more likely to drive to work as a result. De Palma and Rochat (1999) similarly include a variable indicating whether or not there are children to drop to school in the household. There are three categories for this variable relating to married, separated or divorced and single (base category) individuals. The data in Table 4.18 indicate that married and separated and divorced individuals drive a car to work in greater proportions than those that are single who walk, cycle or travel by bus in greater proportions.

Type of Work

The type of work (whether part-time or full-time) is included to account for the fact that part-time workers may have more flexibility in their departure times and may be more

[70] The COP data are individual-level data and do not include any household characteristics such as the number of children in the household of which the individual is a member.

likely to travel during off-peak times. De Palma and Rochat (2000) include a dummy variable identifying individuals that have flexible work hours in their study of choice of mode of transport to work. It is unclear how this variable might affect modal choice. If part-time workers have access to a car, they may be more likely to travel by car, as levels of congestion may be less for travel off-peak. On the other hand, this may also make public transport a more attractive option. Table 4.18 indicates that part-time workers walk and take the bus to work in greater proportions than full-time workers. This may also be capturing the effect of gender, as females are more likely to work part-time than males.[71]

4.4 Data Deficiencies

A limitation of both the HBS and COP data is that they are not specifically designed for the purposes of transport demand estimation. This obviously limits the number and type of variables that can be considered. However, the inclusion of proxies for distance and public transport availability in the form of accommodation type in Chapters 5 and 6 attempts to overcome these shortcomings. While the COP data include information on distance and area of residence, which means that the impact of these factors can be quantified more accurately than in the HBS analysis, the omission of information on car ownership status implies that income elasticities are likely to include the effect of income on car ownership. This means that in the interpretation of empirical results in Chapter 7, it must be remembered that the effect of income is likely to be overstated.

The unit of analysis in each data set also causes problems. The fact that the data used in Chapters 5 and 6 are household-level disguises the fact that there may be significant

[71] In 2001, 3.9 per cent of males and 26.9 per cent of females were employed part-time [CSO (2002c)].

variations in behaviour at the individual level. For example, two households with the same characteristics may have the same level of average per capita bus fare expenditure even though in one household one person travels all the time using the bus whereas in another all household members use the bus, but less frequently.[72] The unit of analysis in Chapter 6 may also cause problems in that household characteristics are also important in determining mode of transport to work and school/college, most notably the availability of a household car but also issues such as whether there are children to drop to school *etc*. An attempt is made to capture these effects by including income and marital status variables. There is also the added complication that those individuals who say that they travel to work or school/college by car obviously own a car. It would be interesting for policy purposes to study the characteristics of individuals that live in a household with access to a car but who use other methods of transport to travel to work. Unfortunately this is impossible in this analysis. The 2002 COP asks about household car ownership and that is an important development, as it will facilitate the application of more sophisticated econometric methodologies to the related questions of car ownership status and choice of mode of transport to work and school/college [see Sections 2.5 and 7.2].

4.5 Summary

This chapter has described in detail the two principal datasets that are used in the subsequent econometric analyses of household and individual travel behaviour in Chapters 5, 6 and 7. Section 4.2 introduced the 1987, 1994 and 1999 Household Budget

[72] A possible solution to this is to analyse single-adult households [see Burton *et al.* (1996, 1995)]. However, the number of adults in the household is highly significant in most models in Chapters 5 and 6, which means that accurate inferences about the population cannot be made on the basis of the single-adult results.

Surveys, which form the basis for the analyses in Chapters 5 and 6. Broad relationships between the dependent and independent variables were identified and the change in these relationships over time was discussed. While car ownership rates and taxi fare expenditures have increased dramatically since 1994, petrol and bus fare expenditures have remained relatively stable. The summary statistics indicated the extent to which average levels of car ownership, petrol, bus and taxi expenditures differ markedly on the basis of household income and composition and on the basis of HOH characteristics, most notably gender and age.

Section 4.3 described the 1996 Census of Population data set, which is employed in the analysis of individual modal choice decisions for the journeys to work and school/college in Chapter 7. The brief overview of the summary statistics confirmed the patterns from the published COP data presented in Section 3.3 and offered an insight into travel patterns to work and school/college on the basis of other characteristics of the population not identified in the published data such as age, level of education and socio-economic group. As an examination of the effect of income on household and individual travel decisions is a primary objective of this thesis, this section also discussed the procedure whereby an income variable was constructed for inclusion as an independent variable using information from the 1994 HBS. Using the data presented in this chapter, Chapters 5 and 6 analyse the car ownership, car use and public transport use decisions of Dublin households over the period 1987-1999. Chapter 7 examines the determinants of choice of mode of transport for two specific journey purposes, namely, the journeys to work and school/college for a sample of Dublin individuals in 1996.

4A TABLES[73]

Table 4.1 Sample Sizes

DECISION	1987	1994	1999	POOL
CAR OWNERSHIP				
All	2,096	2,148	1,789	6,033
CAR USE				
One Car	890	935	792	2,617
Car(s)	1,117	1,198	1,212	3,527
BUS USE				
No Car	979	950	577	2,506
Car(s)	1,117	1,198	1,212	3,527
All	2,096	2,148	1,789	6,033
TAXI USE				
No Car	979	950	577	2,506
Car(s)	1,117	1,198	1,212	3,527
All	2,096	2,148	1,789	6,033

Table 4.2 Definitions of Dependent Variables

VARIABLE NAME	DEFINITION
CAR	=1 if the household owns one or more cars =0 otherwise
PETROLEXP	Petrol and Diesel Expenditure in IR£ (adjusted for seasonality)
BUSEXP	Bus Fare Expenditure in IR£ (adjusted for household size and seasonality)
TAXIEXP	Taxi Fare Expenditure in IR£ (adjusted for household size and seasonality)

[73] Tables 4.1 to 4.12 inclusive refer to the Household Budget Survey datasets that are used in Chapters 5 and 6 while Tables 4.13 to 4.19 inclusive refer to the Census of Population dataset that is used in Chapter 7.

Table 4.3 Summary Statistics of Dependent Variables

VARIABLE	NO CAR				ONE CAR				CAR(S)				ALL HOUSEHOLDS			
	Mean	Std.D.	Max.	% pos	Mean	Std.D.	Max.	% pos	Mean	Std.D.	Max.	% pos	Mean	Std.D.	Max.	% pos
CAR													0.53	0.50	1.00	53.3
													0.56	0.50	1.00	55.8
													0.68	0.47	1.00	67.7
													0.58	0.49	1.00	58.5
PETROLEXP					11.45	7.95	55.70	89.8	10.73	7.60	55.70	91.1				
					14.41	11.10	88.76	89.1	13.67	10.43	88.76	89.7				
					12.35	10.61	65.93	80.2	12.18	9.98	67.19	84.2				
					13.24	10.20	78.00	86.6	12.55	9.58	78.00	88.3				
BUSEXP	1.42	2.07	12.87	60.1					0.71	1.23	9.39	56.8	1.04	1.72	12.87	58.4
	2.21	3.45	24.32	56.3					1.22	2.04	14.17	51.7	1.66	2.79	24.32	53.7
	2.54	4.49	26.00	45.1					1.57	2.91	27.01	48.0	1.88	3.53	27.01	47.1
	2.09	3.31	21.56	55.2					1.18	2.04	21.56	52.1	1.56	2.68	21.56	53.4
TAXIEXP	0.37	1.62	26.34	14.1					0.17	0.59	5.34	13.5	0.26	1.19	26.34	13.8
	1.36	4.32	63.14	25.1					0.88	2.44	34.98	24.0	1.09	3.41	63.14	24.4
	1.70	4.12	50.76	30.0					1.80	4.16	45.17	37.2	1.77	4.15	50.76	34.9
	0.77	2.53	40.10	21.9					0.73	2.15	32.68	25.2	0.74	2.31	40.10	23.8

Note: (i) The first line refers to 1987, the second to 1994, the third to 1999 and the fourth to the pooled sample.

Table 4.4 Definitions of Independent Variables

VARIABLE	DEFINITION
CONTINUOUS VARIABLES	
HHEXP	Total Weekly Household Expenditure in IR£ (adjusted for household size and seasonality and divided by 100)
ADULTS	Number of Adults 18+ years
CHILDREN	Number of Children aged 17 years and younger
FREETRAV	Number of Persons entitled to Free Travel
MOTOR	Number of Motorcycles
CARS	Number of Cars
DISCRETE VARIABLES	
Accommodation Type	
APART, SEMI	APART=1 if apartment or bedsit, =0 otherwise SEMI=1 if semi-detached or terraced house, =0 otherwise (Base Category = detached house)
Household Working Status	
WORKING	=1 if at least one household member 15+ years at work =0 otherwise
Gender of HOH	
SINGLE FEMALE	=1 if household is headed by a female who is the only adult in the household =0 otherwise
Age of HOH	
THIRTY, FORTY, FIFTY, SIXTY	THIRTY=1 if the HOH is 30-39 years, =0 otherwise FORTY=1 if the HOH is 40-49 years, =0 otherwise FIFTY =1 if the HOH is 50-59 years, =0 otherwise SIXTY =1 if the HOH is 60+ years, =0 otherwise (Base Category = HOH is aged 29 years or younger)
Highest Education Level of HOH	
PRIMARY, SECOND	PRIMARY=1 if the HOH has a primary school education only, =0 otherwise SECOND=1 if the HOH has a secondary school education only, =0 otherwise (Base Category = HOH has a third level education)
Availability of Motor Expenses	
EXPENSES	=1 if the household receives motor expenses =0 otherwise
Car Ownership Status	
CAR2, CAR3	CAR2=1 if the household owns two cars, =0 otherwise CAR3=1 if the household owns three or more cars, =0 otherwise (Base Category = household owns one car)

Table 4.5 Summary Statistics of Continuous Independent Variables

VARIABLE	NO CAR				CAR(S)				ALL HOUSEHOLDS			
	Mean	Std.Dev.	Max.	% pos	Mean	Std.Dev.	Max.	% pos	Mean	Std.Dev.	Max.	% pos
HHEXP	1.43	0.85	8.57	100.0	2.37	1.24	8.60	100.0	1.93	1.17	8.60	100.0
	1.32	0.82	7.46	100.0	2.51	1.34	11.87	100.0	1.98	1.29	11.87	100.0
	1.67	1.22	10.06	100.0	3.24	1.73	16.96	100.0	2.73	1.75	16.96	100.0
	1.26	0.85	9.42	100.0	2.31	1.25	12.62	100.0	1.87	1.22	12.62	100.0
ADULTS	1.86	0.96	8.00	100.0	2.36	0.97	8.00	100.0	2.12	1.00	8.00	100.0
	1.72	0.92	7.00	100.0	2.19	0.93	7.00	100.0	1.98	0.96	7.00	100.0
	1.62	0.90	6.00	100.0	2.25	0.96	8.00	100.0	2.05	0.99	8.00	100.0
	1.75	0.94	8.00	100.0	2.26	0.96	8.00	100.0	2.05	0.98	8.00	100.0
CHILDREN	1.04	1.56	10.0	41.7	1.45	1.47	7.00	62.0	1.26	1.53	10.0	52.5
	0.82	1.34	7.00	36.3	1.07	1.30	7.00	50.3	0.96	1.32	7.00	44.1
	0.48	1.00	8.00	23.7	0.91	1.20	6.00	44.2	0.77	1.15	8.00	37.6
	0.83	1.38	10.00	35.5	1.13	1.34	7.00	51.9	1.01	1.37	10.00	45.1
FREETRAV	0.38	0.62	3.00	31.7	0.18	0.48	2.00	14.1	0.28	0.56	3.00	22.3
	0.39	0.61	3.00	32.5	0.23	0.55	3.00	16.9	0.30	0.58	3.00	23.8
	0.51	0.69	6.00	41.9	0.26	0.60	4.00	18.4	0.34	0.64	6.00	26.0
	0.42	0.63	6.00	34.4	0.23	0.55	4.00	16.5	0.30	0.59	6.00	23.9
MOTOR	0.02	0.12	2.00	1.5	0.03	0.19	3.00	2.9	0.02	0.16	3.00	2.2
	0.02	0.13	2.00	1.4	0.02	0.15	2.00	2.0	0.02	0.14	2.00	1.7
	0.01	0.19	3.00	1.2	0.03	0.26	3.00	1.9	0.03	0.24	3.00	1.7
	0.02	0.14	3.00	1.4	0.03	0.21	3.00	2.2	0.02	0.18	3.00	1.9
CARS					1.22	0.48	3.00	100.0	0.65	0.70	3.00	53.3
					1.24	0.47	3.00	100.0	0.69	0.71	3.00	55.8
					1.37	0.54	3.00	100.0	0.93	0.78	3.00	67.7
					1.28	0.49	3.00	100.0	0.75	0.74	3.00	58.5

Note: (i) The first line refers to 1987, the second to 1994, the third to 1999 and the fourth to the pooled sample.

Table 4.6 **Summary Statistics of Discrete Independent Variables (Percentage of Sample in Each Category)**

VARIABLE	NO CAR				CAR(S)				ALL HOUSEHOLDS			
	1987	**1994**	**1999**	**POOL**	**1987**	**1994**	**1999**	**POOL**	**1987**	**1994**	**1999**	**POOL**
APART	30.8	35.4	24.8	31.1	4.4	6.6	5.2	5.4	16.7	19.3	11.5	16.1
SEMI	67.1	61.4	71.4	65.9	82.5	78.0	80.0	80.1	75.3	70.7	77.2	74.2
Base=Detached	2.1	3.3	3.8	3.0	13.1	15.4	14.8	14.5	8.0	10.0	11.3	9.7
WORKING	41.9	35.9	42.8	39.8	86.4	80.3	83.8	83.4	65.6	60.7	70.6	65.3
Base= No household member working	58.1	64.1	57.2	60.2	13.6	19.7	16.2	16.6	34.4	39.3	29.4	34.7
SINGLE FEMALE	29.0	33.2	38.3	32.7	5.6	10.9	11.6	9.4	16.5	20.7	20.2	19.1
Base=All other households	71.0	66.8	61.7	67.3	94.4	89.1	88.4	90.6	83.5	79.3	79.8	80.9
THIRTY	22.7	19.2	15.3	19.6	26.6	18.9	14.4	19.8	24.8	19.0	14.6	19.7
FORTY	15.5	15.9	12.5	15.0	28.6	29.9	28.1	28.8	22.5	23.7	23.0	23.1
FIFTY	13.0	11.3	13.0	12.3	19.1	19.5	21.6	20.1	16.2	15.9	18.8	16.9
SIXTY	41.0	39.5	51.5	42.8	24.2	30.4	34.0	29.7	32.0	34.4	39.6	35.1
Base =29 years or younger	7.9	14.2	7.8	10.3	1.6	1.3	2.0	1.6	4.5	7.0	3.7	5.2
PRIMARY	51.2	55.3	49.9	52.4	21.7	18.6	17.9	19.4	35.5	34.8	28.2	33.1
SECONDARY	42.5	32.1	32.4	36.2	54.8	51.1	42.2	49.2	49.0	42.7	39.1	43.8
Base=Third Level Education	6.3	12.6	17.7	11.4	23.5	30.3	39.9	31.4	15.5	22.5	32.7	23.1
EXPENSES					25.2	24.3	26.1	25.2	13.5	14.0	17.7	14.9
Base = No motor expenses					74.8	75.7	73.9	74.8	86.5	86.0	82.3	85.1
CAR2					18.4	20.0	32.0	23.6				
CAR3					1.9	1.9	2.6	2.2				
Base = One Car					79.7	78.1	65.4	74.4				

Note: (i) Figures may not add up due to rounding.

Table 4.7 Price Changes over the Duration of the 1987 HBS (November 1994=100)

	ALL PRICES	PETROL/DIESEL	BUS FARES	TAXI FARES
1987				
January	81.3	99.0	83.3	88.1
February	**81.3**	**99.0**	**83.3**	**88.1**
March	**81.3**	**99.0**	**83.3**	**88.1**
April	**81.8**	**100.0**	**83.3**	**88.1**
May	**81.8**	**100.0**	**83.3**	**88.1**
June	**81.8**	**100.0**	**83.3**	**88.1**
July	**82.2**	**96.9**	**83.3**	**88.1**
August	**82.2**	**96.9**	**83.3**	**88.1**
September	**82.2**	**96.9**	**83.3**	**88.1**
October	**82.3**	**95.7**	**83.4**	**88.1**
November	**82.3**	**95.7**	**83.4**	**88.1**
December	**82.3**	**95.7**	**83.4**	**88.1**
1988				
January	**82.8**	**95.1**	**85.4**	**88.1**
February	**82.8**	**95.1**	**85.4**	**88.1**
March	**82.8**	**95.1**	**85.4**	**88.1**
April	**83.3**	**96.1**	**85.4**	**88.1**
May	83.3	96.1	85.4	88.1
June	83.3	96.1	85.4	88.1
July	84.0	98.1	85.4	88.1
August	84.0	98.1	85.4	88.1
September	84.0	98.1	85.4	88.1
October	84.5	97.4	85.4	88.1
November	84.5	97.4	85.4	88.1
December	84.5	97.4	85.4	88.1
Average 87	**82.0**	**97.8**	**83.3**	**88.1**
Average 88	**82.9**	**95.4**	**85.4**	**88.1**

Source: Own calculations based on data supplied by CPI division of CSO.

Notes: (i) Months in bold represent the months in which the survey was conducted.
(ii) Averages refer to the average over the HBS survey months in that year.
(iii) After January 1997, CPI figures were made available on a monthly basis; previously CPI figures were released once every three months.

Table 4.8 Price Changes over the Duration of the 1994 HBS (November 1994 = 100)

	ALL PRICES	PETROL/DIESEL	BUS FARES	TAXI FARES
1994				
January	98.3	97.5	99.2	100.0
February	98.3	97.5	99.2	100.0
March	98.3	97.5	99.2	100.0
April	99.1	99.2	99.2	100.0
May	**99.1**	**99.2**	**99.2**	**100.0**
June	**99.1**	**99.2**	**99.2**	**100.0**
July	**99.9**	**100.3**	**99.2**	**100.0**
August	**99.9**	**100.3**	**99.2**	**100.0**
September	**99.9**	**100.3**	**99.2**	**100.0**
October	**100.0**	**100.0**	**100.0**	**100.0**
November	**100.0**	**100.0**	**100.0**	**100.0**
December	**100.0**	**100.0**	**100.0**	**100.0**
1995				
January	**100.8**	**99.2**	**100.1**	**100.0**
February	**100.8**	**99.2**	**100.1**	**100.0**
March	**100.8**	**99.2**	**100.1**	**100.0**
April	**101.8**	**100.9**	**100.1**	**100.0**
May	**101.8**	**100.9**	**100.1**	**100.0**
June	**101.8**	**100.9**	**100.1**	**100.0**
July	**102.3**	**101.0**	**100.5**	**100.0**
August	102.3	101.0	100.5	100.0
September	102.3	101.0	100.5	100.0
October	102.4	101.3	100.8	100.0
November	102.4	101.3	100.8	100.0
December	102.4	101.3	100.8	100.0
Average 94	**99.7**	**99.9**	**99.5**	**100.0**
Average 95	**101.4**	**100.2**	**100.2**	**100.0**

Source: Own calculations based on data supplied by CPI division of CSO.

Notes: (i) Months in bold represent the months in which the survey was conducted.
(ii) Averages refer to the average over the HBS survey months in that year.
(iii) After January 1997, CPI figures were made available on a monthly basis; previously CPI figures were released once every three months.

Table 4.9 Price Changes over the Duration of the 1999 HBS (November 1994 =100)

	ALL PRICES	PETROL/DIESEL	BUS FARES	TAXI FARES
1999				
January	107.3	108.4	103.5	135.2
February	107.9	108.2	103.5	135.2
March	108.2	108.0	103.5	135.2
April	108.7	111.2	103.5	135.2
May	109.2	113.8	103.5	135.2
June	**109.5**	**114.4**	**103.5**	**135.2**
July	**109.1**	**115.8**	**103.5**	**135.2**
August	**109.8**	**118.6**	**103.5**	**135.2**
September	**110.2**	**121.8**	**103.5**	**135.2**
October	**110.3**	**122.1**	**103.5**	**135.2**
November	**110.5**	**122.3**	**103.5**	**135.2**
December	**111.7**	**124.0**	**103.5**	**135.2**
2000				
January	**111.5**	**126.4**	**110.2**	**135.2**
February	**112.5**	**126.7**	**110.2**	**135.2**
March	**113.2**	**131.7**	**110.2**	**135.2**
April	**114.0**	**137.8**	**110.2**	**135.2**
May	**114.8**	**135.3**	**110.2**	**135.2**
June	**115.6**	**140.1**	**110.2**	**135.2**
July	**115.9**	**143.8**	**110.2**	**135.2**
August	**116.5**	**141.9**	**110.2**	**135.2**
September	116.9	141.6	110.2	135.2
October	117.8	146.0	110.2	135.2
November	118.2	145.8	110.2	135.2
December	118.3	137.0	110.2	135.2
Average 99	**110.2**	**119.9**	**103.5**	**135.2**
Average 00	**114.3**	**135.5**	**110.2**	**135.2**

Source: Own calculations based on data supplied by CPI division of CSO.

Notes: (i) Months in bold represent the months in which the survey was conducted.
(ii) Averages refer to the average over the HBS survey months in that year.
(iii) After January 1997, CPI figures were made available on a monthly basis; previously CPI figures were released once every three months.

Table 4.10 Transport Behaviour in the 1987 HBS (Means)

	CAR	PETROLEXP[74]	BUSEXP	TAXIEXP	N
CONTINUOUS VARIABLES					
HHEXP					
1	0.77	12.79	1.28	0.45	700
2	0.59	11.85	1.12	0.24	698
3	0.24	9.71	0.73	0.10	698
ADULTS					
1	0.21	8.54	0.85	0.30	497
2	0.63	11.63	0.84	0.16	1,144
3	0.64	11.42	1.51	0.36	254
4+	0.67	13.76	2.05	0.65	201
CHILDREN					
0	0.43	11.01	1.17	0.35	995
1	0.62	11.53	1.23	0.33	322
2	0.65	11.86	0.95	0.15	329
3+	0.62	11.78	0.68	0.10	450
DISCRETE VARIABLES					
Accommodation Type					
APART	0.14	9.25	1.37	0.36	350
SEMI	0.58	11.42	1.01	0.25	1,579
Base	0.87	13.02	0.62	0.16	167
Working Status					
WORKING	0.70	12.00	1.26	0.33	1,375
Base	0.21	8.56	0.61	0.14	721
Gender					
SINGLE FEMALE	0.18	7.82	0.85	0.25	346
Base	0.60	11.72	1.08	0.26	1,750
Age					
THIRTY	0.57	12.89	1.09	0.26	519
FORTY	0.68	11.23	0.69	0.17	471
FIFTY	0.63	12.23	1.60	0.44	340
SIXTY	0.49	9.65	1.32	0.22	671
Base	0.19	7.99	2.25	0.81	95
Education					
PRIMARY	0.33	10.71	1.11	0.23	744
SECOND	0.60	11.50	1.06	0.27	1,028
Base	0.81	12.14	0.81	0.32	324

Note: (i) 1 refers to the top third of the income distribution, 2 to the middle third and 3 to the bottom third.

[74] The statistics for PETROLEXP refer to households with one car only.

Table 4.11 Transport Behaviour in the 1994 HBS (Means)

	CAR	PETROLEXP[75]	BUSEXP	TAXIEXP	N
CONTINUOUS VARIABLES					
HHEXP					
1	0.85	16.53	1.72	1.90	311
2	0.60	14.31	2.14	1.14	312
3	0.22	12.41	1.12	0.27	312
ADULTS					
1	0.32	11.02	1.24	1.12	702
2	0.67	15.03	1.26	0.82	1,009
3	0.68	15.31	2.91	1.33	264
4+	0.67	18.92	3.80	2.23	173
CHILDREN					
0	0.50	12.70	1.66	1.27	1,201
1	0.61	16.19	2.09	1.26	306
2	0.70	15.16	1.48	0.78	341
3+	0.58	17.91	1.42	0.57	187
DISCRETE VARIABLES					
Accommodation Type					
APART	0.19	11.57	2.22	1.75	415
SEMI	0.62	14.25	1.57	0.98	1,518
Base	0.86	17.17	1.22	0.62	215
Working Status					
WORKING	0.74	15.71	2.08	1.45	1,303
Base	0.28	10.10	1.01	0.55	845
Gender					
SINGLE FEMALE	0.29	10.47	1.45	1.34	445
Base	0.63	15.04	1.72	1.03	1,703
Age					
THIRTY	0.55	15.25	1.64	1.65	408
FORTY	0.70	15.28	1.43	0.72	509
FIFTY	0.69	16.55	2.36	1.16	341
SIXTY	0.49	11.99	1.02	0.55	739
Base	0.11	14.07	4.05	3.33	151
Education					
PRIMARY	0.30	13.88	1.35	0.78	748
SECOND	0.67	14.20	1.78	1.10	917
Base	0.75	15.27	1.92	1.57	483

Note: (i) 1 refers to the top third of the income distribution, 2 to the middle third and 3 to the bottom third.

[75] The statistics for PETROLEXP refer to households with one car only.

Table 4.12 Transport Behaviour in the 1999 HBS (Means)

	CAR	PETROLEXP[76]	BUSEXP	TAXIEXP	N
CONTINUOUS VARIABLES					
HHEXP					
1	0.89	14.05	2.16	2.97	597
2	0.78	13.20	2.39	1.80	596
3	0.36	9.79	1.09	0.54	596
ADULTS					
1	0.39	9.32	1.23	1.32	546
2	0.80	13.20	1.50	1.20	824
3	0.82	14.31	3.11	3.05	255
4+	0.82	13.59	4.05	4.15	164
CHILDREN					
0	0.61	11.59	1.97	2.02	1,116
1	0.77	13.10	2.41	2.16	221
2	0.82	12.52	1.47	1.07	264
3+	0.80	15.31	1.36	0.83	188
DISCRETE VARIABLES					
Accommodation Type					
APART	0.31	8.90	2.36	2.15	206
SEMI	0.70	12.64	1.87	1.71	1,381
Base	0.89	12.38	1.52	1.75	202
Working Status					
WORKING	0.80	13.42	2.33	2.25	1,263
Base	0.37	8.67	0.80	0.61	526
Gender					
SINGLE FEMALE	0.39	8.87	1.34	1.24	362
Base	0.75	13.09	2.02	1.90	1,427
Age					
THIRTY	0.66	13.86	2.24	2.39	262
FORTY	0.83	12.80	1.43	1.35	412
FIFTY	0.78	13.46	2.89	2.06	337
SIXTY	0.58	10.93	1.18	1.43	709
Base	0.35	10.66	5.55	3.93	69
Education					
PRIMARY	0.43	12.04	1.51	1.45	505
SECOND	0.73	12.33	1.86	1.66	699
Base	0.83	12.56	2.24	2.18	585

Note: (i) 1 refers to the top third of the income distribution, 2 to the middle third and 3 to the bottom third.

[76] The statistics for PETROLEXP refer to households with one car only.

Table 4.13[77] Definitions of Dependent Variables

VARIABLE	DEFINITION
Mode of Transport to Work (1)	
ON FOOT	= 1 if walks to work
BICYCLE	= 2 if cycles to work
BUS	= 3 if travels by bus to work
TRAIN	= 4 if travels by train to work
CAR PASSENGER	= 5 if travels as a passenger in a car to work
	(Base Category = drives a car, motorcycle, van or lorry to work)
Mode of Transport to Work (2)	
ON FOOT/BICYCLE	= 1 if walks or cycles to work
BUS/TRAIN	= 2 if travels by bus or train to work
CAR PASSENGER	= 3 if travels as a passenger in a car to work
	(Base Category = drives a car, motorcycle, van or lorry to work)
Mode of Transport to School/College (1)	
BICYCLE	= 1 if cycles to school/college
BUS	= 2 if travels by bus to school/college
TRAIN	= 3 if travels by train to school/college
CAR PASSENGER	= 4 if travels as a passenger in a car to school/college
OTHER	= 5 if drives a car, motorcycle, lorry or van to school/college
	(Base Category = walks to school/college)
Mode of Transport to School/College (2)	
BUS/TRAIN	= 1 if travels by bus or train to school/college
CAR PASSENGER	= 2 if travels as a passenger in a car to school/college
OTHER	= 3 if drives a car, motorcycle, lorry or van to school/college
	(Base Category = walks or cycles to school/college)

Note: (i) See Section 7.5.2 for specification test for Independence from Irrelevant Alternatives. Due to the fact that the IIA assumption is satisfied, specification (2) above is the final specification which forms the basis of the discussion of empirical results in Section 7.6.

[77] Tables 4.13 to 4.19 inclusive refer to the Census of Population dataset that is used in Chapter 7.

Table 4.14 Summary Statistics of Dependent Variables

VARIABLE	PERCENTAGE OF SAMPLE
Mode of Transport to Work (1)	
ON FOOT	11.3
BICYCLE	6.1
BUS	18.1
TRAIN	4.6
CAR PASSENGER	7.0
Base Category	52.9
Mode of Transport to Work (2)	
ON FOOT/BICYCLE	17.4
BUS/TRAIN	22.7
CAR PASSENGER	7.0
Base Category	52.9
Mode of Transport to School/ College (1)	
BICYCLE	7.2
BUS	22.4
TRAIN	3.1
CAR PASSENGER	22.3
OTHER	1.3
Base Category	43.6
Mode of Transport to School/ College (2)	
BUS/TRAIN	25.5
CAR PASSENGER	22.3
OTHER	1.3
Base Category	50.8

Note: (i) Figures may not add up due to rounding.

Table 4.15 Definitions of Independent Variables

VARIABLE	DEFINITION
Income	
HHEXP	Total weekly per capita household expenditure in IR£ (divided by 100); constructed using information from the 1994 HBS
Socio-Economic Group	
SEGABC	=1 if employer or manager, higher professional or lower professional =0 otherwise (i.e., non-manual, manual skilled, semi-skilled, unskilled, own account worker, farmer, agricultural worker or otherwise gainfully occupied and unknown categories)
Distance[78]	
ONELESS	=1 if one mile or less to work/school/college, =0 otherwise
TWO	=1 if two miles to work/school/college, =0 otherwise
THREE	=1 if three miles to work/school/college, =0 otherwise
FOUR	=1 if four miles to work/school/college, =0 otherwise
FIVE	=1 if five to nine miles to work/school/college, =0 otherwise (Base Category = ten miles or more to work/school/college)
Area of Residence[79]	
DLR	=1 if living in Dun Laoghaire-Rathdown, =0 otherwise
FINGAL	=1 if living in Fingal, =0 otherwise
SCD	=1 if living in South Dublin, =0 otherwise (Base Category = living in Dublin County Borough)
Gender	
FEMALE	=1 if the individual is female =0 otherwise
Age	
THIRTY	=1 if aged 30-39 years, =0 otherwise
FORTY	=1 if aged 40-49 years, =0 otherwise
FIFTY	=1 if aged 50-59 years, =0 otherwise
SIXTY	=1 if aged 60 years or over, =0 otherwise (Base Category = aged 29 years or younger)
Marital Status	
MARRIED	=1 if married, =0 otherwise
OTHERMAR	=1 if separated, divorced or widowed, =0 otherwise (Base Category = never married)
Highest Level of Education	
PRIMARY	=1 if have a primary school education only, =0 otherwise
SECONDARY	=1 if have a secondary school education only, =0 otherwise (Base Category = third level education)
Type of Work	
PART	=1 if engaged in part-time work =0 otherwise

[78] As the Census of Population asks respondents to state their distance travelled to work to the nearest mile, the distance variable contains six categories: one mile or less (0+1), two (2), three (3), four (4), five (5-9) and ten (10+), with the latter regarded as the base category. See also Sections 3.3.2 and 4.4.3.
[79] See Figure 3.1 for map of location of regional authorities within the Dublin area.

Table 4.15 continued

VARIABLE	DEFINITION
Age of Student	
PRIME	=1 if aged 5-10 years, i.e. primary school student, =0 otherwise
SEC1	=1 if aged 11-14 years, i.e. primary/secondary school student, =0 otherwise
SEC2	=1 if aged 15-19 years, i.e., secondary school/third level student, =0 otherwise
	(Base Category = aged 20+ years, i.e., third level student)

Table 4.16 Summary Statistics of Continuous Independent Variables

VARIABLE	MEAN	STD. DEV.	MIN.	MAX.
HHEXP	2.55	0.58	1.16	3.90

Note: (i) This variable is only relevant to the work sample (see Sections 4.3.1 and 4.3.3 for further details).

Table 4.17 Summary Statistics of Discrete Independent Variables (Percentage of the Sample in Each Category)

VARIABLE NAME	WORK SAMPLE	SCHOOL SAMPLE
Socio-Economic Group		
SEGABC	60.7	33.3
Base Category = All other socio-economic groups	39.3	66.7
Distance		
ONELESS	14.8	55.7
TWO	11.8	15.2
THREE	13.1	9.4
FOUR	10.6	5.2
FIVE	33.3	10.3
Base Category = Ten miles or greater	16.4	4.2
Area of Residence		
DLR	19.4	19.7
FINGAL	16.3	19.2
SCD	20.7	24.6
Base Category = Dublin County Borough	43.6	36.5
Gender		
FEMALE	44.2	49.9
Base Category = Male	55.8	50.1
Age		
THIRTY	27.9	
FORTY	20.4	
FIFTY	12.9	
SIXTY	3.7	
Base Category = 29 years or younger	35.1	
Highest Level of Education		
PRIMARY	11.2	
SECONDARY	51.9	
Base Category = Third Level	36.9	
Marital Status		
MARRIED	50.9	
OTHERMAR	5.4	
Base Category = Never Married	43.6	
Type of Work		
PART	86.0	
Base Category = Full-Time	14.0	
Age of Student		
PRIME		28.6
SEC1		32.0
SEC2		28.2
Base Category = College Student		11.2

Note: (i) Figures may not add up due to rounding.

Table 4.18 Transport Behaviour in the Work Sample

VARIABLE	ON FOOT	BI-CYCLE	BUS	TRAIN	CAR PASS	CAR DRIVER	N
HHEXP							
1	10.3	4.6	12.4	5.6	5.1	60.6	5,638
2	10.8	4.9	20.5	4.9	7.9	47.9	5,637
3	12.8	8.7	21.2	3.5	7.3	39.2	5,637
Socio-Economic Group							
SEGABC	8.6	4.4	10.3	4.9	5.2	66.5	6,650
Base	13.0	7.1	23.1	4.5	8.2	44.1	10,262
Distance							
ONELESS	54.1	7.5	6.6	0.2	4.8	26.8	2,500
TWO	19.3	11.5	18.4	0.8	6.4	43.6	1,992
THREE	5.4	10.1	23.5	1.8	7.9	51.3	2,216
FOUR	1.6	7.8	26.2	2.5	8.4	53.5	1,796
FIVE	0.4	4.0	20.8	7.1	7.3	60.4	5,628
Base	0.0	0.9	12.8	10.2	7.2	68.9	2,780
Area of Residence							
DLR	5.3	4.2	10.2	7.7	6.8	65.8	3,276
FINGAL	5.6	2.7	12.7	8.8	8.1	62.1	2,762
SCD	7.8	4.7	20.3	0.3	8.5	58.4	3,506
Base	17.7	8.8	22.5	3.8	6.0	41.2	7,368
Gender							
FEMALE	15.1	3.8	23.9	5.0	10.2	42.0	7,480
Base	8.2	7.9	13.4	4.3	4.5	61.6	9,432
Age							
THIRTY	8.9	5.2	12.4	3.9	7.0	62.6	4,726
FORTY	8.6	4.8	11.2	3.9	5.1	66.4	3,445
FIFTY	8.6	5.2	10.5	3.5	5.0	67.2	2,181
SIXTY	11.8	4.3	13.6	3.5	4.5	62.3	626
Base	15.7	8.0	29.8	6.2	9.2	31.2	5,934
Highest Level of Education							
PRIMARY	16.5	8.0	22.2	2.1	6.0	45.2	1,895
SECONDARY	11.3	6.3	21.1	4.4	8.2	48.6	8,769
Base	9.7	5.2	12.5	5.7	5.6	61.3	6,248
Marital Status							
MARRIED	6.9	5.1	9.8	3.8	7.2	67.3	8,613
OTHERMAR	12.7	4.2	17.4	4.5	4.4	56.8	919
Base	16.2	7.5	27.8	5.7	7.1	35.7	7,380
Type of Work							
PART	19.7	5.7	24.3	4.0	8.0	38.2	2,367
Base	9.9	6.1	17.0	4.8	6.9	55.3	14,545

Notes: (i) Figures may not add up due to rounding.
(ii) The figures are interpreted as follows: 8.6 per of those in the ABC socio-economic group walk to work, 4.4 per cent cycle *etc*.
(iii) 1 refers to the top third of the income distribution, 2 to the middle third and 3 to the bottom third.

Table 4.19 Transport Behaviour in the School Sample

VARIABLE	ON FOOT	BI-CYCLE	BUS	TRAIN	CAR PASS	OTHER	N
Socio-Economic Group							
SEGABC	29.7	7.8	19.0	4.8	36.9	1.8	3,536
Base	50.6	6.8	24.1	2.3	15.1	1.1	7,074
Distance							
ONELESS	71.8	4.9	5.8	0.0	17.3	0.2	5,906
TWO	19.2	14.7	31.1	0.7	33.2	1.1	1,616
THREE	6.2	12.9	39.7	2.3	36.6	2.2	999
FOUR	1.8	7.3	55.8	5.3	25.9	3.8	548
FIVE	0.6	5.7	56.4	11.1	22.8	3.5	1,092
Base	0.0	0.5	48.1	31.9	12.9	6.5	449
Area of Residence							
DLR	23.9	10.1	20.0	6.1	37.7	2.2	2,088
FINGAL	41.1	2.6	25.1	6.1	24.0	1.1	2,034
SCD	51.7	5.0	22.9	0.2	19.1	1.0	2,611
Base	50.1	9.4	21.9	1.9	15.4	1.2	3,877
Gender							
FEMALE	44.1	3.5	24.7	2.9	23.7	1.3	5,293
Base	43.2	10.9	20.1	3.4	21.0	1.4	5,317
Age of Student							
PRIME	48.4	0.6	13.2	0.0	37.7	0.0	3,034
SEC1	51.3	5.7	19.2	1.1	22.5	0.3	3,399
SEC2	38.5	10.9	30.5	5.7	13.5	1.0	2,992
Base	22.4	19.0	34.8	10.3	8.7	4.8	1,185

Notes: (i) Figures may not add up due to rounding.
(ii) The figures are interpreted as follows: 29.7 per of those in the ABC socio-economic group walk to school/college, 7.8 per cent cycle *etc*.
(iii) OTHER includes car driver, motorcycle, lorry or van.

4B APPENDICES

4A Adjustments to Expenditure Variables to account for Seasonality in the 1987, 1994 and 1999 HBS

Each item of expenditure is first regressed on monthly dummies using the sample of all households surveyed in the state (using OLS). Based on the results from these regressions, an index is constructed [see Tables 4A.1 to 4A.3]. The expenditure variables are then adjusted for seasonality by dividing expenditures by the value of the index for the month in which the observation was recorded, i.e., total weekly household expenditure for the months January-November inclusive is always adjusted upwards.

Table 4A.1 1987 Expenditure Adjustments

	HHEXP	INDEX	PETEXP	INDEX	BUSEXP	INDEX	TAXIEXP	INDEX
December (Constant)	170.843 (3.795)***	100.000	8.569 (0.471)***	100.000	0.478 (0.058)***	100.000	0.177 (0.035)***	100.000
January	-17.687 (6.037)***	89.647	0.820 (0.749)	109.564	0.330 (0.093)***	169.095	0.029 (0.056)	116.541
February	-15.264 (5.331)***	91.066	0.738 (0.662)	108.610	0.335 (0.082)***	170.113	0.001 (0.049)	100.793
March	-16.495 (4.724)***	90.345	1.123 (0.586)*	113.109	0.161 (0.073)**	133.707	-0.044 (0.044)	75.343
April	-23.362 (5.155)***	86.325	0.523 (0.640)	106.108	0.089 (0.079)	118.579	-0.050 (0.048)	71.689
May	-27.669 (5.278)***	83.804	0.937 (0.655)	110.934	0.037 (0.081)	107.692	-0.053 (0.049)	70.004
June	-32.684 (5.131)***	80.869	0.632 (0.637)	107.373	0.133 (0.079)*	127.855	-0.036 (0.048)	79.795
July	-27.053 (5.342)***	84.165	1.187 (0.663)*	113.849	-0.007 (0.082)	98.493	-0.076 (0.050)	57.148
August	-23.261 (5.665)***	86.384	0.983 (0.703)	111.471	0.051 (0.087)	110.722	0.090 (0.053)*	150.915
September	-31.073 (5.246)***	81.812	0.827 (0.651)	109.653	-0.019 (0.081)	96.091	-0.004 (0.049)	97.575
October	-32.074 (5.193)***	81.226	0.069 (0.645)	100.801	-0.135 (0.080)*	71.764	-0.033 (0.048)	81.547
November	-19.018 (5.203)***	88.868	1.184 (0.646)*	113.814	0.156 (0.080)*	132.604	-0.053 (0.048)	69.988
N	7,705		7,705		7,705		7,705	
R-squared	0.009		0.001		0.008		0.002	

Notes: (i) Standard errors are reported in parentheses.
(ii) *significant at 10% level; ** significant at 5% level; *** significant at 1% level
(iii) HHEXP is not scaled by 100.

Table 4A.2 1994 Expenditure Adjustments

	HHEXP	INDEX	PETEXP	INDEX	BUSEXP	INDEX	TAXIEXP	INDEX
December	164.038	100.000	12.542	100.000	0.845	100.000	0.627	100.000
(Constant)	(3.596)***		(0.558)***		(0.085)***		(0.064)***	
January	-44.845	72.662	-2.748	78.087	0.085	110.008	-0.193	69.130
	(5.079)***		(0.788)***		(0.120)		(0.091)**	
February	-39.805	75.734	-2.180	82.616	-0.115	86.352	-0.155	75.307
	(5.035)***		(0.781)***		(0.119)		(0.090)*	
March	-26.688	83.731	-0.233	98.145	0.251	129.704	-0.176	71.869
	(4.873)***		(0.756)		(0.115)**		(0.087)**	
April	-29.742	81.869	-0.208	98.342	-0.012	98.599	-0.125	80.073
	(5.277)***		(0.819)		(0.125)		(0.094)	
May	-40.071	75.572	-1.667	86.710	-0.034	95.920	-0.254	59.499
	(4.922)***		(0.764)**		(0.116)		(0.088)***	
June	-42.113	74.327	-1.564	87.527	-0.064	92.446	-0.258	58.758
	(4.605)***		(0.715)**		(0.109)		(0.082)***	
July	-50.426	69.260	-0.606	95.167	-0.176	79.217	-0.333	46.917
	(4.976)***		(0.772)		(0.118)		(0.089)***	
August	-49.722	69.689	-2.207	82.402	-0.144	82.923	-0.348	44.460
	(4.872)***		(0.756)***		(0.115)		(0.087)***	
September	-32.029	80.475	-0.698	94.438	0.013	101.555	-0.220	64.843
	(4.828)***		(0.749)		(0.114)		(0.086)**	
October	-33.814	79.386	-1.520	87.880	0.163	119.299	-0.137	78.164
	(5.001)***		(0.776)*		(0.118)		(0.089)	
November	-31.084	81.050	-1.796	85.683	0.008	100.965	-0.266	57.552
	(4.865)***		(0.755)**		(0.115)		(0.087)***	
N	7,877		7,877		7,877		7,877	
R-squared	0.020		0.004		0.003		0.003	

Notes: (i) Standard errors are reported in parentheses.
(ii) *significant at 10% level; ** significant at 5% level; *** significant at 1% level
(iii) HHEXP is not scaled by 100.

Table 4A.3 1999 Expenditure Adjustments

	HHEXP	INDEX	PETEXP	INDEX	BUSEXP	INDEX	TAXIEXP	INDEX
December	221.229	100.000	15.714	100.000	0.943	100.000	1.003	100.000
(Constant)	(6.230)***		(0.906)***		(0.103)***		(0.124)***	
January	-31.614	85.710	0.878	105.585	-0.277	70.589	-0.391	60.991
	(8.947)***		(1.301)		(0.148)*		(0.179)**	
February	-42.843	80.634	2.168	113.797	0.069	107.348	-0.356	64.506
	(8.542)***		(1.242)*		(0.142)		(0.171)**	
March	-31.323	85.841	1.914	112.180	0.056	105.904	-0.106	89.439
	(8.194)***		(1.192)*		(0.136)		(0.164)	
April	-28.995	86.894	3.273	120.826	0.017	101.807	0.083	108.302
	(8.326)***		(1.211)***		(0.138)		(0.166)	
May	-16.939	92.343	3.028	119.272	-0.245	74.039	0.110	111.020
	(8.155)**		(1.186)**		(0.135)*		(0.163)	
June	-40.891	81.516	0.970	106.173	-0.298	68.414	-0.322	67.852
	(7.397)***		(1.076)		(0.123)**		(0.148)**	
July	-35.805	83.816	0.100	100.634	-0.122	87.110	-0.240	76.023
	(7.372)***		(1.072)		(0.122)		(0.147)*	
August	-32.341	85.381	0.655	104.168	-0.315	66.542	-0.288	71.277
	(8.169)***		(1.188)		(0.136)**		(0.163)*	
September	-39.958	81.938	0.694	104.413	-0.012	98.722	-0.204	79.695
	(8.186)***		(1.191)		(0.136)		(0.164)	
October	-40.520	81.684	-0.813	94.823	-0.090	90.453	0.047	104.648
	(8.362)***		(1.216)		(0.139)		(0.167)	
November	-39.337	82.219	-2.242	85.731	-0.107	88.619	-0.148	85.235
	(8.339)***		(1.213)*		(0.138)		(0.167)	
N	7,644		7,644		7,644		7,644	
R-squared	0.007		0.006		0.004		0.004	

Notes: (i) Standard errors are reported in parentheses.
(ii) *significant at 10% level; ** significant at 5% level; *** significant at 1% level
(iii) HHEXP is not scaled by 100.

4B Mean Equality Tests for COP Data

For the work sample, missing observations occur for four variables: mode of transport to work (the dependent variable), distance travelled to work, level of education and type of work. For the school sample, missing observations occur for two variables: mode of transport to work (the dependent variable) and distance travelled to work. We test for the equality of the means between the sample of complete observations and the sample of missing observations, i.e.,

H_0: $\mu = m$

H_1: $\mu = m$

where μ is the mean of the sample of missing observations and m is the mean of the sample of complete observations.

The test statistic is:

$$Z = \frac{\overline{X} - m}{\sigma / \sqrt{n}} \qquad (4B.1)$$

with n - 1 degrees of freedom.

where $\overline{X}$ is the mean of the sample of missing observations, σ is the specified standard deviation of the missing observations and n is the size of the sample of missing observations.

Table 4B.1 Mean Equality Tests for the Work Sample

VARIABLE	MEAN COMPLETE OBS	MEAN MISSING OBS	TEST STATISTIC
Income			
HHEXP	2.55	2.48	Z=-6.026
	(0.58)	(0.56)	Reject
Socio-Economic Group			
SEGABC	0.39	0.22	Z=-17.083
	(0.49)	(0.41)	Reject
Base = All other socio-	0.61	0.78	Z=17.083
economic groups	(0.49)	(0.41)	Reject
Area of Residence			
DLR	0.19	0.12	Z=-8.579
	(0.40)	(0.33)	Reject
FINGAL	0.16	0.14	Z=-3.297
	(0.37)	(0.35)	Reject
SCD	0.21	0.17	Z=-3.297
	(0.41)	(0.38)	Reject
Base = Dublin County Borough	0.44	0.57	Z=-4.313
	(0.50)	(0.50)	Reject
Gender			
FEMALE	0.44	0.40	Z=-3.937
	(0.50)	(0.49)	Reject
Base = Male	0.56	0.60	Z=3.937
	(0.50)	(0.49)	Reject
Age			
THIRTY	0.28	0.23	Z=-5.153
	(0.45)	(0.42)	Reject
FORTY	0.20	0.18	Z=-3.217
	(0.40)	(0.38)	Reject
FIFTY	0.13	0.14	Z=1.190
	(0.34)	(0.34)	Do not reject
SIXTY	0.04	0.07	Z=7.423
	(0.19)	(0.25)	Reject
Base = 29 years or younger	0.35	0.39	Z=3.851
	(0.48)	(0.49)	Reject
Marital Status			
MARRIED	0.51	0.39	Z=-11.459
	(0.50)	(0.49)	Reject
OTHERMAR	0.05	0.06	Z=0.757
	(0.23)	(0.23)	Do not reject
Base = Never Married	0.44	0.55	Z=11.206
	(0.50)	(0.50)	Reject
N	**16,912**	**2,332**	

Notes: (i) Figures may not add up due to rounding.
(ii) Standard deviations are reported in parentheses.
(iii) Z-statistic 1 per cent critical value with 2,331 degrees of freedom = approx. 2.576

Table 4.B2 Mean Equality Tests for the School Sample

VARIABLE	MEAN COMPLETE OBS	MEAN MISSING OBS	TEST STATISTIC
Socio-Economic Group			
SEGABC	0.33	0.17	Z=-15.476
	(0.47)	(0.38)	Reject
Base = All other socio-	0.67	0.83	Z=15.476
economic groups	(0.47)	(0.38)	Reject
Area of Residence			
DLR	0.20	0.10	Z=-10.485
	(0.40)	(0.30)	Reject
FINGAL	0.19	0.17	Z=-2.820
	(0.39)	(0.37)	Reject
SCD	0.25	0.23	Z=-1.514
	(0.43)	(0.42)	Do not reject
Base = Dublin County Borough	0.36	0.50	Z=12.317
	(0.48)	(0.50)	Reject
Gender			
FEMALE	0.50	0.48	Z=-1.271
	(0.50)	(0.50)	Do not reject
Base = Male	0.50	0.52	Z=1.271
	(0.50)	(0.50)	Do not reject
Type of Student			
PRIME	0.29	0.40	Z=10.998
	(0.45)	(0.49)	Reject
SEC1	0.32	0.34	Z=2.168
	(0.47)	(0.47)	Reject at 5%
SEC2	0.28	0.17	Z=-10.744
	(0.45)	(0.38)	Reject
Base = College Student	0.11	0.09	Z=-3.642
	(0.31)	(0.28)	Reject
N	**10,610**	**1,979**	

Notes: (i) Figures may not add up due to rounding.
(ii) Standard deviations are reported in parentheses.
(iii) Z-statistic 1 per cent critical value with 1,978 degrees of freedom = approx. 2.576

4C Construction of Income[80] Variable for 1996 COP using 1994 HBS

As the COP does not record the income of the individual, information available in the 1994 HBS is used to construct an income variable for inclusion as an independent variable in the analysis of individual modal choice decisions for the journey to work in Chapter 7.[81] The relationship between a set of characteristics x_i and income in the 1994 HBS is estimated and the resulting coefficients are used to predict incomes for the COP sample given their observed values of the same x_i variables. Previous applications of this procedure include Farrell and Walker (1999) and Arellano and Meghir (1992).[82]

The first step is the identification of variables that are common to both the 1994 HBS and the 1996 COP. Individual characteristics in the COP are matched to HOH characteristics in the HBS [see Table 4C.1]. The second step involves using the 1994 HBS sample of Dublin households with at least one person in employment to regress HHEXP94 on the set of common independent variables. Using the results of this estimated relationship [see Table 4C.2], an income value is predicted for each observation in the COP work sample based on the values of their observed characteristics. To avoid perfect multicollinearity between the newly constructed income variable and the independent variables used in the

[80] While information on car ownership is not included in the COP data but is collected in the HBS, a car ownership variable was not constructed in the same way as the income variable primarily because it could result in an individual who drives their car to work having a predicted value of zero for car ownership.

[81] For the work sample, a natural sample in the 1994 HBS is apparent: households where at least one person works. The socio-economic characteristics of the individual in the COP are taken to correspond with the characteristics of the HOH in the 1994 HBS. However, in the school sample, no natural counterpart exists in the HBS. A possibility is to use the sample of households with at least one student. However a problem then exists in determining the matching of characteristics. Should those of the educational level are only recorded for the HOH and spouse of HOH.

[82] Farrell and Walker (1999) use the 1995/1996 UK Family Resources Survey to construct an income variable for inclusion as an independent variable in their study of the demand for lottery tickets in the UK using survey data from the lottery industry regulator (OFLOT). Arellano and Meghir (1992) use data from the UK Family Expenditure Survey (FES) to construct an earnings variable for inclusion as an independent variable in their study of female labour supply using UK Labour Force Survey (LFS) data.

COP analysis, the variables indicating whether or not the individual is self-employed and social class are dropped from the COP analysis. While the unit of analysis is different in both samples (the unit of analysis in the HBS is the HOH while the individual in the COP is not necessarily the HOH) and while the goodness of fit of the equation below is poor, the effects of the constructed income variable on modal choice are as expected and all variables retain their signs and significance levels when the constructed income variable is replaced with a close proxy, namely, social group.

Table 4C.1 Common Variables in the 1994 HBS and 1996 COP[83]

1994 HBS VARIABLE	DEFINITION	1996 COP VARIABLE	DEFINITION
FEMALE94	Female HOH (Base Category = Male HOH)	FEMALE96	Female (Base Category = Male)
THIRTY94 FORTY94 FIFTY94 SIXTY94	HOH aged 30-39 years HOH aged 40-49 years HOH aged 50-59 years HOH aged 60 years and older (Base Category = HOH aged 29 years or younger)	THIRTY96 FORTY96 FIFTY96 SIXTY96	Aged 30–39 years Aged 40-49 years Aged 50-59 years Aged 60 years and older (Base Category = Aged 29 years or younger)
PRIMARY94 SECOND94	HOH has a primary level education HOH has a secondary level education (Base Category = HOH has a third level education)	PRIMARY96 SECOND96	Primary level education Secondary level education (Base Category = Third level education)
MARRIED94 OTHERMAR94	HOH is married HOH is separated or divorced (Base Category = Never married)	MARRIED96 OTHERMAR96	Married Separated or divorced (Base Category = Never married)
SOC94	HOH is in social class 1 or 2 (Base Category = HOH is in social classes 3-7)	SOC96	Social class 1 or 2 (Base Category = Social Classes 3-7)
SELF94	HOH is self-employed (Base Category = HOH is not self-employed)	SELF96	Self-employed (Base Category = not self-employed)

[83] Due to the difficulty in ascertaining the appropriate sample to use in the 1994 HBS, an income variable is not constructed for inclusion as an independent variable in the analysis of modal choice decisions for the journey to school/college in Chapter 7.

Table 4C.2 Results for Regression of Income Variable in 1994 HBS (HHEXP) on Socio-Economic Variables in 1994 HBS

VARIABLES	COEFFICIENTS
Constant	272.749
	(17.060)***
FEMALE94	8.629
	(12.000)
THIRTY94	47.933
	(16.656)***
FORTY94	23.545
	(16.875)
FIFTY94	54.220
	(18.230)***
SIXTY94	58.736
	(19.225)***
MARRIED94	-41.906
	(13.815)***
OTHERMAR94	-43.150
	(18.363)**
PRIMARY94	-109.620
	(12.106)***
SECOND94	-68.129
	(10.588)***
SOC94	47.775
	(8.852)***
SELF94	-9.036
	(12.033)***
Number of Observations	1,125
R-squared	0.213
Adjusted R-squared	0.205

Notes: (i) Standard errors are reported in parentheses
(ii) *significant at 10% level; ** significant at 5% level; *** significant at 1% level
(iii) HHEXP is not scaled by 100

CHAPTER 5

AN ECONOMETRIC ANALYSIS OF THE DEMAND FOR CAR OWNERSHIP AND USE IN THE DUBLIN AREA: 1987-1999

5.1 Introduction

The aggregated data presented in Chapter 3 illustrate the clear differences that exist between different sectors of the Dublin population in their rates of car ownership[84] and in their car use decisions, in particular for the journey to work. In addition, the data highlight the significant changes that have occurred in the structure of the Dublin population over the period 1986-2002 and the implications this has had for car ownership rates as well as choice of mode of transport to work, school and college. A thorough understanding of the income and socio-economic factors influencing household car ownership and use decisions is useful for a number of reasons including forecasting future levels of car ownership and use, identifying sectors of the population that need to be targeted if a decrease in car use and an increase in the numbers walking and cycling and using public transport use is to be achieved, and assessing the distributional impacts of increasingly popular measures such as parking restrictions and road pricing.

[84] However, the latest data available at the local authority region in Dublin refer to 1991, data that are now very much out of date.

The purpose of this chapter is to explain differences in car ownership and use behaviour at the household level in Dublin using a variety of socio-economic characteristics as independent variables. Using Household Budget Survey (HBS) data from 1987, 1994 and 1999, probit models of car ownership and Tobit models of car use, as proxied by petrol expenditures, are estimated. In an attempt to examine the extent to which the influence of these socio-economic factors changed over the period 1987-1999, the three datasets are pooled together and a probit model is estimated for the car ownership decision and Tobit models of petrol expenditure are estimated for the car use decisions.

Section 5.2 presents an overview of previous literature in the area of car ownership and use modelling while Section 5.3 briefly describes the data used in this analysis. Section 5.4 describes in detail the econometric methodologies that are employed in this chapter and Section 5.5 deals with issues associated with model specification. Section 5.6 presents empirical results for all models while Section 5.7 summarises the main findings and concludes the chapter.

5.2 Previous Literature

Section 2.3 presented a more general discussion of previous literature related to the demand for car ownership and use. Due to the nature of the dependent variable, discrete choice econometric methodologies are most commonly employed in examining car ownership decisions and it is this approach that is followed in this chapter [Section 5.4.1 describes in detail the binary probit econometric methodology used in this chapter to model car ownership]. In contrast, numerous methodologies have been employed to model the car use decision, in part due to the differing dependent variables used in the analyses. While Hensher (1985) and Mannering (1983) use mileage data and Johansson-Stenman (2002) uses petrol consumption in gallons to proxy car use, the approach in this chapter follows those of Asensio *et al.* (2001), Labeaga and Lopez (1997) and Archibald and Gillingham (1980) who use petrol expenditures to proxy car use. This is the first time that the Tobit econometric methodology has been applied to the estimation of car use[85] and therefore the approach is similar to that used by others to estimate the demand for various commodities using household micro-data [see Section 5.4.2]. As discussed in Section 2.3, a number of studies examine the joint demand for car ownership and use using a variety of econometric methodologies including the Heckman sample selection method. However, both Johansson-Stenman (2002) and Asensio *et al.* (2001) reject the Heckman sample selection methodology in favour of independent estimation of the car ownership and use decisions due to the insignificance of the Mill's ratio, which is used to detect selection. Asensio *et al.* (2001) also reject this methodology on the basis that it is difficult, if not impossible, to identify variables that affect the probability of owning a car but are insignificant in explaining petrol expenditures. While we find that the education level of the HOH is significant in explaining the probability of owning a car but insignificant in explaining petrol expenditures (see Sections 5.6.1 and 5.6.2), we do not employ the Heckman sample selection methodology as it is not logical to consider the concept of positive potential petrol expenditures in households that do not own a car.[86]

[85] See Section 5.4.2 for a discussion of the validity of modelling petrol expenditures using the Tobit methodology.

[86] See also Melenberg and Van Soest (1996, pp.67) who question the application of the Heckman sample selection methodology to the question of holiday expenditures: *"the problem is not modelling selectivity but zero expenditures. Whereas a continuous distribution of (positive) potential wage rates in the population of workers and non-workers makes sense, the concept of positive potential expenditures of people who do not spend anything does not seem very useful."*

Accordingly, the approach in this chapter is to estimate the demand for car ownership and use independently, i.e., to follow the approach of Johansson-Stenman (2002), Asensio *et al.* (2001), Labeaga and Lopez (1997), Hensher (1985), Mannering (1983) and Archibald and Gillingham (1980). In other words, the car use relationship is assumed to be a short-run, static relationship, i.e., assuming that the stock of cars is fixed.

The review of the literature in Section 2.3 confirms the importance of household/individual characteristics in determining variations in car ownership and use. In addition, many studies highlight the change in the nature of the relationship between these income and socio-economic determinants and car ownership and use over time. While income is found to have a consistently positive effect on car ownership demand, the magnitude of the relationship has changed over time. While many of the earlier studies based on aggregated data for industrialised countries classified the private car as a luxury [McCarthy (1977), Buxton and Rhys (1972), Bennett (1967) and Fairhurst (1965)], more recent studies have concluded that the private car is now regarded as a necessity with income elasticities that are less than unity [Johansson-Stenman (2002), Dargay (2001) and Dargay and Vythoulkas (1999)]. In other words, as car ownership becomes increasingly common, the effect of income in explaining variations in car ownership levels declines over time. The demand for car use, on the other hand, is consistently classified as a necessity [Johansson-Stenman (2002), Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Schmalensee and Stoker (1999), Labeaga and Lopez (1997), De Jong (1990) and Archibald and Gillingham (1980)]. Once a household owns a car, therefore, income has a positive but inelastic effect on the demand for car use.

Apart from household income, other household characteristics such as household size and composition and the characteristics of the head of household (HOH) or principal driver are also found to be significant determinants of variations in car ownership and use. While some variables have similar effects on car ownership and use, such as the number of adults and children in the household, household location and the gender of the HOH, other variables are found to have conflicting effects on car ownership and on car use. In contrast to the studies that find that the age of the HOH exerts a positive, albeit diminishing, effect on car ownership [Johansson-Stenman (2002), Asensio *et al.* (2001), Dargay (2001), Alperovich *et al.* (1999) and Bennett (1967)], Asensio *et al.* (2001), Bjorner (1999), De Jong (1990), Hensher (1985), Mannering (1983) and Archibald and Gillingham (1980) find that car use is negatively related to the age of the HOH.

This is the first time that the demand for car ownership and use have been estimated at the micro-level in Ireland. A study by McCarthy (1977) estimated the demand for car ownership at the county level in Ireland using data on average county incomes and population densities. While confirming that car ownership rates are positively affected by income and negatively affected by population density, the nature of the data limited the number and type of explanatory variables that could be considered. It is, therefore, important to determine if the relationships found between various household socio-economic characteristics and car ownership and use in other countries are applicable to Ireland, and in particular, to Dublin.

5.3 Data

The data employed in this chapter are micro-data from the 1987/1988, 1994/1995 and 1999/2000 Household Budget Surveys (1987 HBS, 1994 HBS and 1999 HBS respectively). Section 4.2 contains further information on the conduct of the HBS, the type of variables extracted from the survey and the preparation of the data for analysis. For the car ownership decision, the dependent variable is a binary variable indicating whether or not the household owns one or more cars. In modelling car use, petrol expenditure adjusted for the number of cars in the household and seasonality is the dependent variable. Following the approach of Archibald and Gillingham (1980), in order to ascertain if multi-vehicle households behave differently to those households owning only one car, the car use models are estimated for two samples of households: those owning one car and those owning one or more cars.[87] Table 4.1 presents the respective sample sizes for the 1987, 1994, 1999 and pooled samples, variable definitions are presented in Tables 4.2 and 4.4 and summary statistics for the various dependent and independent variables are detailed in Tables 4.3, 4.5 and 4.6.

5.4 Econometric Methodologies

5.4.1 Binary Probit

In modelling the demand for car ownership, a binary probit model as applied by Alperovich *et al.* (1999) and Stanovnik (1990) is employed. The binary probit model is used in situations where the dichotomous dependent variable indicates the choice between two discrete alternatives (e.g., to own a car or not). It is commonly characterised

[87] Due to the small sample sizes and consequent poor fit of the regressions, models of car use for households owning two or more cars are not presented [see also Section 4.2.1].

by an underlying unobserved continuous latent variable y_i^* that is taken to represent the utility difference between the two alternatives. This utility difference, y_i^*, is a linear function of a set of independent variables x_i and unobserved factors captured in the error term ε_i. Different values of the latent variable determine the actual value of the dependent variable y_i that is observed, i.e.,

$$\begin{aligned} & y_i^* = x_i'\beta + \varepsilon_i, \qquad \varepsilon_i \sim NID(0,1) \\ & and \\ & y_i = 0 \quad if \quad y_i^* \leq 0 \\ & y_i = 1 \quad if \quad y_i^* > 0 \end{aligned} \qquad (5.1)$$

It is assumed that the individual/household chooses to own a car when the utility difference exceeds a certain threshold, which in this case is set to zero.[88] Assuming a standard normal distribution for the error term, the probabilities of observing the two alternatives may be expressed as follows:

$$P(y_i = 0) = 1 - \Phi(x_i'\beta) \qquad (5.2)$$

$$P(y_i = 1) = \Phi(x_i'\beta) \qquad (5.3)$$

where Φ is the cumulative standard normal distribution function. The model is estimated by means of the maximum likelihood method of estimation where the following log-likelihood function is maximised with respect to each of the parameters:

$$log\ L = \sum_{y_i=0} log\ [1 - \Phi(x_i'\beta)] + \sum_{y_i=1} log\ \Phi(x_i'\beta) \qquad (5.4)$$

[88] The assumption of a zero value for the threshold level is standard in the econometrics literature [see Greene (2000), Verbeek (2000) and Amemiya (1981)] as well as in many econometrics packages [e.g. Eviews, Limdep]. The actual value of the threshold is irrelevant as long as a constant term is included in the set of independent variables.

Heteroscedasticity

A common feature of many binary choice models is that the error terms are heteroscedastic, in which case the estimated coefficients are inconsistent. By allowing the error terms to vary across observations, this problem can be overcome. Heteroscedasticity of the following form is assumed [Greene (2000) and Verbeek (2000)]:

$$\sigma_i = exp\left(z_i'h \right)^{89} \qquad (5.5)$$

where z_i is a vector of continuous[90] independent variables assumed to cause the heteroscedasticity. When $h=0$, the heteroscedastic probit model reduces to the original probit model with a homoscedastic error structure.[91]

5.4.2 Tobit

The econometric methodology employed in this chapter to examine household car use follows the approach initially outlined by Tobin (1958) and subsequently applied to various transport decisions by Melenberg and Van Soest (1996), Hagemann (1981) and Bennett (1967)[92] and to numerous other decisions.[93] The Tobit model is used in situations where the dependent variable is censored, i.e., values within a certain range are all reported as a single value, usually zero. It is widely employed in modelling cross-

[89] This specification is the most commonly employed in empirical work [see Greene (2000), Verbeek (2000), Melenberg and Van Soest (1996) and Yen *et al.* (1996)] as it ensures that the variance is strictly positive.

[90] See also Section 5.5.2.

[91] On the basis of a likelihood ratio test (see Section 5.5.2 on model specification and Table 5.1), the null hypothesis of a homoscedastic error structure is not rejected in any year and therefore the log-likelihood function adjusted for heteroscedastic errors is not presented.

[92] Melenberg and Van Soest (1996) and Hagemann (1981) estimate Tobit models of holiday expenditures while Bennett (1967) uses the Tobit methodology to examine expenditure on cars.

[93] Fleischer and Seiler (2002), Cai (1998), Yen *et al.* (1996), Kitchen and Powells (1991), Lankford and Wyckoff (1991), Reynolds and Shonkwiler (1991), Atkinson *et al.* (1990) and McCracken and Brandt (1987) all use the Tobit methodology to examine the number of days spent on holiday, food expenditures, the level of nitrate concentrations in groundwater, lottery expenditures, expenditure on charitable donations, vegetable expenditure, alcohol expenditure and expenditure on food away from home respectively.

sectional expenditure decisions in which a large proportion of respondents report zero expenditure. In such cases, OLS estimation will lead to biased estimates since the clustering of observations at zero violates the assumption of a continuous dependent variable. In common with the binary probit model, it also assumes the existence of an underlying continuous latent variable y_i*, the values of which determine the actual value of the observed limited dependent variable y_i, i.e.,

$$y_i^* = x_i'\beta + \varepsilon_i, \qquad \varepsilon_i \sim NID(0, \sigma^2)$$

and

$$y_i = 0 \quad if \quad y_i^* \leq 0, \qquad (5.6)$$

$$y_i > 0 \quad if \quad y_i^* > 0$$

The continuous latent variable, which is assumed to be a linear function of a set of independent variables x_i and unobserved heterogeneity described by the error term ε_i, is taken to represent desired expenditure, thus allowing for negative desired expenditure. All negative and zero values of desired expenditure are transformed to a single value of zero for observed expenditure. The Tobit model therefore assumes that zero observations are due to corner solutions, i.e., if relative prices or incomes change by a sufficient amount, expenditure occurs. All zero observations in the Tobit model are therefore due to economic reasons [Pudney (1989)]. Cragg (1971) was the first to suggest that there may be other explanations for zero observations such as infrequency of purchase and non-participation in the market, which are ignored in the Tobit model. The possibility of infrequency of purchase determining zero observations for petrol expenditure is dismissed by Labeaga and Lopez (1997) who argue that their week-long survey period is an adequate reference period for petrol. As the HBS is conducted over a two-week survey period, it is assumed that zero observations on petrol expenditure are not due to infrequency of purchase. The third source of zero observations, namely non-participation or abstention from the market, does not make sense for petrol expenditures because once a household owns one or more cars, it is implausible that the household would never use the car(s) just as it is plausible that some households may try to limit their petrol consumption for economic reasons and use cheaper forms of transport instead, such as walking or cycling.

As with the binary probit model, the Tobit model is estimated by maximum likelihood estimation whereby the following log-likelihood function is maximised with respect to each of the parameters:

$$log\ L = \sum_{y_i=0} log\left[1 - \Phi\left(\frac{x_i'\beta}{\sigma}\right)\right] + \sum_{y_i>0}\left[-log\ \sigma + log\ \phi\left(\frac{y_i - x_i'\beta}{\sigma}\right)\right] \qquad (5.7)$$

where ϕ is the standard normal density function.

Heteroscedasticity

The estimated Tobit coefficients are sensitive to the distributional assumptions that are made about the error term. If the error terms are heteroscedastic, the coefficient estimates are inconsistent [see Reynolds and Shonkwiler (1991), Pudney (1989), Arabmazar and Schmidt (1982), Maddala (1983), Amemiya (1984) and Nelson (1981)]. As in the binary probit model, the variance of the error terms is allowed to vary across observations as follows:

$$\sigma_i = exp\left(z_i'h\right) \qquad (5.8)$$

where z_i is a vector of continuous independent variables assumed to cause the heteroscedasticity.

Non-Normality

Non-normality in the Tobit model also leads to inconsistent coefficient estimates. To adjust for non-normality, recent applications involve transforming the dependent variable to account for the non-normal structure of the errors [see Yen *et al.* (1996), Melenberg and Van Soest (1996), Lankford and Wyckoff (1991), Reynolds and Shonkwiler (1991) and Burbidge *et al.* (1988)] although Atkinson *et al.* (1990) assume an alternative gamma distribution in their analysis of expenditure on alcohol. In this chapter, the approaches of Yen *et al.* (1996), Reynolds and Shonkwiler (1991) and Burbidge *et al.* (1988) are followed by applying an inverse hyperbolic sine (IHS) transformation to the dependent variable as follows:

$$\begin{aligned} y_i(\theta) &= log[\theta\, y_i + (\theta^2 y_i^2 + 1)^{1/2}]/\theta \\ &= sinh^{-1}(\theta\, y_i)/\theta \end{aligned} \tag{5.9}$$

where θ is a parameter estimated by the model. This transformation overcomes the problem of non-normality caused by the presence of outliers by behaving logarithmically for large values of the dependent variable. It also overcomes a major failing of the alternative Box-Cox transformation by being defined for zero values of the dependent variable [Reynolds and Shonkwiler (1991) and Burbidge *et al.* (1988)]. The log-likelihood function incorporating the adjustments for heteroscedastic and non-normal errors is:

$$log\ L = \sum_{y_i=0} log\left[1-\Phi\left(\frac{x_i'\beta}{\sigma_i}\right)\right] + \sum_{y_i>0}\left[log\left(1+\theta^2 y_i^2\right)^{-\frac{1}{2}} - log\ \sigma_i + log\ \phi\left(\frac{y_i(\theta)-x_i'\beta}{\sigma_i}\right)\right]$$

(5.10)

When $\theta = 0$ and $\sigma_i = \sigma$ the log-likelihood reduces to that presented in Equation (5.7), i.e., assuming homoscedasticity and normality of the errors.

5.4.3 Pooled Analyses

In order to identify changes in the relationship between the independent variables and the demand for car ownership and use over the period 1987-1999, the data from the three surveys are pooled and the expenditure data are expressed in constant November 1994 prices [see Section 4.2]. A binary probit model is then estimated for the car ownership decision and Tobit models of petrol expenditure are applied to the car use decision. 1994 is treated as the base year and dummy variables for observations recorded in 1987 and 1999 are included to capture changes in the intercepts of the relationships over the period. In addition, each independent variable is interacted with the 1987 and 1999 dummies in order to identify changes in the slope parameters or changes in the magnitude of the relationships between the dependent and independent variables over the period 1987-1999. This methodology follows the approach of Burton *et al.* (1996, 1995).[94] Section 5.5.2 contains further details on the choice of the most appropriate specification to capture these relationships.

[94] Burton *et al.* (1996, 1995) estimate double-hurdle models of the demand for meat using UK Family Expenditure Survey (FES) data for 1973, 1978, 1983, 1988 and 1993 with 1988 regarded as the base year. Atkinson *et al.* (1990) also pool UK FES data from 1970-1983 in their analysis of expenditure on alcohol but include a time trend only.

Heteroscedasticity

As discussed in Sections 5.4.1 and 5.4.2, heteroscedastic errors in the binary probit and Tobit models can render coefficient estimates inconsistent. In the pooled models, heteroscedasticity of the same form as expressed in Equations (5.5) and (5.8) is assumed, i.e., that the heteroscedasticity is caused by the some of the (continuous) independent variables in the model. Section 5.5.2 discusses the test procedures employed in detecting heteroscedasticity in the pooled probit and Tobit models.

Non-Normality

Similarly, non-normality in the pooled Tobit model may lead to inconsistent parameter estimates. In the pooled Tobit models, an IHS transformation is applied to the dependent variable to overcome the problem of non-normality caused by the presence of outliers in the data. Section 5.4.2 discusses the IHS transformation in more detail. Section 5.5.2 discusses further the likelihood ratio tests that are used to test for the presence of non-normal errors in the pooled Tobit models.

5.5 Model Specification

5.5.1 Choice of Independent Variables

For comparison purposes, the same set of independent variables relating to household characteristics is employed in all years. The probability of owning a car and expenditure on petrol are therefore expressed as a linear combination of various household characteristics and an error term. The three transport control variables relating to the number of motorcycles in the household, receipt of motor expenses and the number of household cars are included where appropriate.[95] For the household income variable and variables relating to the number of adults and children in the household, non-linear terms are included in the specification where they are significant to account for the fact that the effect of these independent variables may differ over the range of the variables [see Kayser (2000), Alperovich *et al.* (1999), Melenberg and Van Soest (1996), Reynolds and Shonkwiler (1991), Atkinson *et al.* (1990), McCracken and Brandt (1987), Cragg and Uhler (1970) and Bennett (1967)]. Section 4.2.3 contains further details on the choice of independent variables for analysis. All models are estimated using the LIMDEP econometrics package.

5.5.2 Specification Testing

As the heteroscedastic binary probit and heteroscedastic and non-normal Tobit models nest the more restrictive specifications, likelihood ratio tests were used to decide on the most appropriate model specification [see Yen *et al.* (1996), Melenberg and Van Soest (1996), Lankford and Wyckoff (1991) and Reynolds and Shonkwiler (1991)].

Independent Models for 1987, 1994 and 1999

In allowing for heteroscedasticity, only significant continuous independent variables were included in the heteroscedasticity function.[96] In the binary probit model, all of the continuous independent variables in the heteroscedasticity term were insignificant, i.e., the likelihood ratio test of a homoscedastic error structure was not rejected at the one per

[95] For example, the dummy variables indicating ownership of two cars or three or more cars are only included in the Tobit models of petrol expenditure in households that own one or more cars.
[96] As there are no guidelines as to the choice of variables to include in the heteroscedasticity function, we follow the approach of Yen *et al.* (1996) and assume that the heteroscedasticity in both the binary probit and Tobit models is caused by the continuous variables.

cent level [see Table 5.1]. However in all of the Tobit models, the significance of at least one continuous independent variable in the heteroscedasticity adjustment and of the IHS parameter resulted in the rejection of the null hypotheses of homoscedastic and normal error structures at the one per cent level of significance. See Table 5.2 for the results of the three likelihood ratio tests of homoscedastic errors (h=0), normal errors (θ=0) and heteroscedastic and non-normal errors (h=0 and θ=0).

Pooled Models

A number of steps were followed in order to decide on the most appropriate model specification for the pooled models of household car ownership and use. For the binary probit and Tobit models, likelihood ratio tests were used to successively test the following hypotheses:

- Common intercept and slope parameters in all three years, i.e.,

  $$y_{it} = \alpha + x_{it}'\beta \qquad (5.11)$$

  where α is the common intercept term and β is the vector of common slope parameters.

- Common slope parameters but differing intercept terms in the three years, i.e.,

  $$y_{it} = \alpha + D_{87}\alpha_{87} + D_{99}\alpha_{99} + x_{it}'\beta \qquad (5.12)$$

  where D_{87} and D_{99} are dummy variables taking the value one if an observation is recorded in 1987 and 1999 respectively, β is the vector of common slope parameters, α is the intercept term for observations recorded in 1994, $\alpha + \alpha_{87}$ is the intercept term for observations recorded in 1987 and $\alpha + \alpha_{99}$ is the intercept term for observations recorded in 1999.

- Differing slope parameters and differing intercept terms in the three years, i.e.,

$$y_{it} = \alpha + \alpha_{87} D_{87} + \alpha_{99} D_{99} + x_{it}'\beta + x_{it}'\beta_{87} D_{87} + x_{it}'\beta_{99} D_{99} \quad (5.13)$$

where D_{87} and D_{99} are dummy variables taking the value one if an observation is recorded in 1987 and 1999 respectively, α is the intercept term for observations recorded in 1994, $\alpha + \alpha_{87}$ is the intercept term for observations recorded in 1987, $\alpha + \alpha_{99}$ is the intercept term for observations recorded in 1999, β is the vector of parameter estimates for observations recorded in 1994, $\beta + \beta_{87}$ is the vector of parameter estimates for observations recorded in 1987 and $\beta + \beta_{99}$ is the vector of parameter estimates for observations recorded in 1999.

- Significant[97] differing slope parameters and differing intercept terms in the three years, i.e.,

$$y_{it} = \alpha + \alpha_{87} D_{87} + \alpha_{99} D_{99} + x_{it}'\beta + x_{it}'\beta_{87} D_{87} + x_{it}'\beta_{99} D_{99} \quad (5.14)$$

where D_{87} and D_{99} are dummy variables taking the value one if an observation is recorded in 1987 or 1999 respectively, α is the intercept term for observations recorded in 1994, $\alpha + \alpha_{87}$ is the intercept term for observations recorded in 1987, $\alpha + \alpha_{99}$ is the intercept term for observations recorded in 1999, β is the vector of parameter estimates for observations recorded in 1994, $\beta + \beta_{87}$ is the vector of

[97] Burton *et al.* (1996, 1995) also exclude insignificant slope coefficients from the final specification of their models.

significant parameter estimates for observations recorded in 1987 and $\beta + \beta_{99}$ is the vector of significant parameter estimates for observations recorded in 1999.

The results of these likelihood ratio tests for the binary probit model of household car ownership are presented in Table 5.3 and for the Tobit models of household car use are presented in Table 5.4.[98] In all cases, the null hypothesis of a common intercept term is rejected at the one per cent level of significance. For the car ownership model and the car use model for the sample of households owning one or more cars, the preferred model is (5.14) as the null hypothesis of differing intercepts and common slope parameters is rejected and the specification with insignificant slope parameters excluded results in the best fit. For the sample of households owning one car however, the null hypothesis of differing intercepts and common slope parameters is not rejected at the one per cent level of significance even when insignificant slope interactions are excluded from the model. The preferred specification for the car use model for household owning one car is therefore model (5.12).

These final specifications are further tested for the presence of heteroscedastic errors in the case of the pooled binary probit model of household car ownership and for the presence of heteroscedastic and non-normal errors in the case of the pooled Tobit models of household car use. The null hypothesis of homoscedastic errors in the pooled probit model is not rejected at the one per cent level of significance [see Table 5.5], while the

[98] Following Burton *et al.* (1996, 1995) we do not consider the possibility of a model characterised by common intercept terms and differing slope parameters. Due to the minimum of five years that elapsed between each survey, we consider it important to control for unobservable factors that may have changed over time, e.g., changes in the characteristics of the "typical car" such as fuel efficiency over the period or the introduction of Quality Bus Corridors on certain bus routes in the Dublin area over the 1990s.

null hypotheses of homoscedastic errors, normal errors and the joint null hypothesis of homoscedastic and normal errors are all rejected at the one per cent level of significance for both pooled Tobit models [see Table 5.6]. The results of these likelihood ratio tests as well as the significance of at least one of the heteroscedasticity parameters and the IHS parameter guided the final specification of the pooled Tobit models of household car use. The pooled Tobit results presented in Tables 5.14 and 5.15 are therefore adjusted for the presence of heteroscedastic and non-normal errors. The results of the pooled binary probit model of household car ownership presented in Table 5.13 assume homoscedasticity since this assumption was not rejected by the likelihood ratio test.[99]

5.5.3 Interpretation of Parameter Estimates

Independent Models for 1987, 1994 and 1999

In both the binary probit and Tobit models, the estimated β coefficients cannot be interpreted in the same way as in a linear regression model. Marginal effects for the continuous independent variables in the models are calculated by differentiating the expected value of the dependent variable with respect to the independent variable of interest, evaluated at the sample mean of this independent variable of interest.[100] Due to the discrete nature of many of the independent variables in the models, marginal effects for discrete independent variables must be calculated instead as the difference in the expected value of the dependent variable when the variable takes the value one and when

[99] We do not test for the possibility of autocorrelated errors as different households are surveyed in each year. In addition, the inclusion of yearly dummies should capture the influence of unobservable factors that may have changed over the period 1987-1999.

[100] McDonald and Moffitt (1980) describe a procedure whereby the Tobit marginal effects may be decomposed into two effects: the effect on the probability of participation and the effect on the conditional level of expenditure. However, due to the fact that it is assumed that all those who spend on petrol participate in the market, this decomposition is invalid in this instance.

it takes the value zero [see Yen *et al.* (1996)]. Elasticities of demand with respect to the continuous independent variables may then be calculated by multiplying the marginal effects by the ratio of the independent to the dependent variable sample means.[101] In order to make more accurate comparisons about the magnitude of the elasticities across the three survey years, elasticities of demand with respect to the continuous independent variables are also calculated at the 1994 sample mean values. Table 5.12 presents the elasticities evaluated at this common reference point. In order to ascertain the reliability of all marginal effects in the Tobit models, standard errors for the marginal effects must be calculated. These are approximated using the delta method as presented in Yen *et al.* (1996). The adjustments to the Tobit models to account for heteroscedastic and non-normal errors complicates the calculation of both the marginal effects and the standard errors and the formulae for these are presented in Sections 5A and 5B of the Appendix respectively.[102] Tables 5.9, 5.10 and 5.11 present the marginal effects for the correctly specified binary probit and Tobit models of household car ownership and use. For comparison purposes, Tables 5.7 and 5.8 present the estimated coefficients from the respective models, which are not adjusted for heteroscedastic and non-normal errors.

Pooled Models

As we are only interested in the changes over time that have occurred in the relationships between the independent variables and car ownership and use, we do not compute

[101] An elasticity measure with respect to the number of adults and children in the household is not strictly accurate as these variables are ordinal, rather than continuous, in nature. For example, in 1994, the maximum number of adults was eight, meaning that a 12.5 per cent increase in the number of adults in the household leads to a 2.5 per cent increase in the probability of car ownership in 1994. However, due to the fact that the maximum of each of these ordinal variables differs over each survey year, the continuous elasticities form the basis of discussions in this chapter and Chapter 6.

[102] The author is very grateful to Dr. Carol Newman, TCD, for assistance with the derivation of marginal effects and standard errors in the Tobit models.

marginal effects and elasticities based on the pooled sample. Tables 5.13, 5.14 and 5.15 present the estimated coefficients from the pooled probit model of car ownership and the pooled Tobit models of car use adjusted for heteroscedastic and non-normal errors.

5.6 Empirical Results

5.6.1 Car Ownership

Income

Table 5.9 shows that in each of the three survey years, income exerts a positive and significant effect on the probability of car ownership. In all three survey years, non-linear terms are also found to be significant. The significance of the squared term indicates that once income passes a certain threshold, car ownership probability continues to increase but at a decreasing rate, a result also found by Dargay and Vythoulkas (1999), Cragg and Uhler (1970) and Bennett (1967). The significance of the cubed term suggests that once income passes a second threshold, car ownership probability increases at an increasing rate once again. The income elasticities evaluated at the common reference point indicate that car ownership may be considered a luxury in 1987 and 1994 but a necessity in 1999. The decline in the income elasticity of car ownership supports recent research, which has reported income elasticities of car ownership that are less than unity [see Johansson-Stenman (2002), Dargay (2001), Dargay and Vythoulkas (1999) and Bergantino (1997)]. In other words, income has become less important in determining variations in car ownership rates in Dublin since 1987. The results of the pooled regression in Table 5.13 confirm that the effect of income was significantly smaller in 1999 than in 1994 although there was no significant difference between 1987 and 1994.

Adults

Table 5.9 indicates that car ownership probability is positively affected by increasing numbers of adults in the household, a result consistent with those of Dargay (2001), Dargay and Vythoulkas (1999), Train (1980), Cragg and Uhler (1970) and Fairhurst (1965). The significance of the squared and cubed terms indicates that the effect is non-linear with Alperovich *et al.* (1999) also finding a significant negative effect for the number of adults squared in the household. The significance of the squared term may indicate a scale economies effect while the significance of the cubed term may suggest initial increasing returns to scale in household car ownership that diminish as the size of the household becomes larger. The non-linear effects may be explained by the tendency for households with a large number of adults to comprise unrelated individuals who have fewer opportunities for shared activities unlike a household with a smaller number of adults such as a married couple with children. The income elasticities calculated at the common reference point, namely the 1994 sample means, indicate that the elasticity of car ownership with respect to the number of adults in the household declined from 0.45 to 0.20 from 1987 to 1994 and increased again to 0.57 in 1999. The results of the pooled regression in Table 5.13 confirm these trends with positive interaction terms for 1987 and 1999 with a larger interaction term for 1999 than for 1987. Nonetheless, the elasticities indicate that for a one per cent increase in the number of adults in the household, the probability of car ownership increases by a smaller percentage.

Children

The number of children aged 17 and under in the household exerts a positive and significant effect on car ownership probability in each survey year. This is in contrast to the results of Dargay (2001), Dargay and Vythoulkas (1999) and Cragg and Uhler (1970) who all find an insignificant effect of the number of children on household car ownership. The significance of the squared terms may suggest economies of scale in car ownership probability. The elasticities evaluated at 1994 sample means indicate that elasticities of demand with respect to the number of children in the household declined from 0.27 to 0.18 from 1987 to 1994 but increased again to 0.20 in 1999 [see Table 5.12]. Once again, the results of the pooled regression support this trend with positive interaction coefficients for 1987 and 1999, with the larger and more significant interaction coefficient for 1987 suggesting that the largest change in the effect of the number of children on car ownership probability occurred between 1987 and 1994.

Accommodation Type

The effect of accommodation type supports the inclusion of this variable as a proxy for distance from the city centre, population density and the quality and quantity of public transport services. The results suggest that those households living in apartments are least likely to own cars in comparison with the base category of those living in detached houses. Numerous studies also find that as distance from the city centre increases, population density declines and public transport provision deteriorates, the demand for car ownership increases [see Alperovich *et al.* (1999), Dargay and Vythoulkas (1999), Train (1980), McCarthy (1977), Buxton and Rhys (1972), Cragg and Uhler (1970), Bennett (1967) and Fairhurst (1965)]. The consistency of the marginal effects in sign and magnitude across 1987, 1994 and 1999 as well as the insignificance of the interaction terms in the pooled regression in Table 5.13 suggests that there was no significant change in the relationship between accommodation type and car ownership probability over the period 1987 to 1999.

Working Status

For 1987 and 1994, the positive and significant effect of having at least one person in employment in the household is in agreement with the results of De Palma and Rochat (2000), Alperovich *et al.* (1999) and Bennett (1967)[103] and indicates the effect that the presence of individuals in the household with regular mobility needs has on car ownership probability. The insignificance of having at least one person in employment in the household in 1999 may suggest that car ownership has become more widespread among the Dublin population over the period 1994-1999. In other words, as car ownership becomes a necessity, the socio-economic differences between non car-owning and car-owning households become less marked over time. The results from the pooled regression in Table 5.13 support this decline in significance for the working status variable in 1999 with a negative and significant coefficient on the interaction term.

Gender

Single female-headed households are significantly less likely to own cars than other household types in 1987 and 1994. One explanation for the lower probability of car

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[103] There are slight differences in the form of this variable [see also Section 4.2.3] with De Palma and Rochat (2000) and Bennett (1967) employing the number of earners in the household and Alperovich *et al.* (1999) using a dummy variable indicating whether two or more members of the household are working.

ownership among single female-headed households in 1987 and 1994 may be the lower percentage of females who hold driving licences, while the narrowing gap between the percentage of males and females holding driving licences may account for the insignificance of the single female-headed household variable in 1999.[104] The results from the pooled regression in Table 5.13 support the decline in significance for this variable in 1999 with a significant interaction term indicating that the effect of having a single female HOH is significantly less negative in 1999 in comparison with 1994. Again, this may indicate a diffusion of car ownership into categories of the population previously traditionally classified as non car-owners such as households headed by a single female.

Age

The results for age of HOH show that the probability of car ownership increases with the age of the HOH. The effect is slightly non-linear in 1987 and 1999 where the order of increasing car ownership relative to the base category of those aged 29 years or younger is 30-39 years, 50-59 years, 40-49 years and 60 years and over. This is in comparison to 1994 where the effect of increasing age of the HOH on car ownership probability is strictly linear. In all years however, households in which the HOH is aged 60 years and older display the highest probability of car ownership relative to the base category of those aged 29 years and younger. This result is in conflict with those of Alperovich *et al.* (1999), Dargay and Vythoulkas (1999) and Bennett (1967) where the effect of the age of

[104] While data on driving licences by gender are not available for Ireland, UK data indicates that the proportion of males over 17 years holding driving licences increased from 74 per cent in 1986 to 81 per cent in 1994 to 82 per cent in 2000 while the proportion of females over 17 years holding driving licences increased from 41 per cent in 1986 to 54 per cent in 1994 to 60 per cent in 2000 [UK DETR (2001d)].

HOH, while initially positive, decreases in magnitude as the age of the HOH increases and with the results of Buxton and Rhys (1972) and Cragg and Uhler (1970) where increasing age linearly reduces the probability of car ownership. In addition, Bennett (1967) only finds a significant age effect for those aged 65 and over who spend significantly less on cars relative to the base category of those aged 34-45 years. However, the results are in agreement with those of Dargay (2001) where the probability of car ownership increases as the household moves through the life cycle, as proxied by the age of the HOH. Explanations for this divergence in results may lie in different costs, with the costs of car insurance being particularly high for young people in Ireland. The pooled regression results in Table 5.13 indicate that there were significant differences in the effect of the age of the HOH between 1987 and 1994 with the signs of the coefficients indicating that the effects are smaller in magnitude in 1987 than in 1994. The insignificance of the 1999 interaction terms suggests that the effects of the age of the HOH were broadly similar in 1994 and 1999.

Education Level

The highest level of education variable suggests that those with a primary education are consistently least likely to own a car relative to the base category of those with a third level qualification. Alperovich *et al.* (1999) also find that those with the highest levels of education are most likely to own cars although they admit that there is no obvious reason why this should be the case, given that household income has been taken into account. However, in 1999, there is no significant difference between those with a secondary level education and those with a third level education in their car ownership probability, which again may reflect the diffusion of car ownership across the population over time. However, the insignificance of the interaction terms for the education categories in the pooled regression in Table 5.13 indicates that the effect of the variable is similar across the three survey years.

Changes over Time

The results from the pooled regression in Table 5.13 suggest that while income, working status and the gender of the HOH had significantly different relationships with car ownership probability in 1999 compared with 1994, for the number of children and the age variable, significant changes in the relationship occurred between 1987 and 1994. For the number of adults in the household, significant differences occurred between the three survey years. The insignificance of the year dummy for 1999 indicates that changes in the relationship between the independent variables and car ownership probability between 1994 and 1999 were accounted for by changes in the slope parameters of the relationship, rather than a change in the intercept values. In contrast, the changes that occurred in the relationship between the independent variables and car ownership probability between 1987 and 1994 were due to changes in both the intercept and slope parameters.

5.6.2 Car Use

Income

Tables 5.10 and 5.11 indicate that household income exerts a positive and significant effect on car use in households owning one car and in households owning one or more cars, in part reflecting the costs such as petrol, tax and insurance that are incurred in running a car. It may also indicate that households with higher incomes may place a greater value on time savings and comfort relative to poorer households, thus choosing the car over more time consuming and less comfortable methods of transport such as walking, cycling or using the bus. The low but positive income elasticities of 0.60, 0.51 and 0.34 for one-car households in 1987, 1994 and 1999 respectively and 0.57, 0.48 and 0.32 for households with one or more cars in 1987, 1994 and 1999 respectively suggests that car use demand may be classified as a necessity, a result consistent with those of Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Schmalensee and Stoker (1999), Labeaga and Lopez (1997), Blundell *et al.* (1993), Button *et al.* (1993), De Jong (1990), Mannering (1983) and Archibald and Gillingham (1980). The consistently larger elasticities in households owning one car only suggests that income is a more important factor in these households than in households owning one or more cars. This is consistent with expectations since households able to afford more than one car should be less concerned with economic factors in deciding on the level of car use. This result is in agreement with the findings of Asensio *et al.* (2001) and Hensher (1985) where income elasticities decline as the number of cars increases. The significance of the squared terms indicates that a non-linear relationship exists, a result also found by Kayser (2000) and Archibald and Gillingham (1980). In addition, the significance of the cubed term in 1987 suggests that once income passes a second threshold, the effect of income on car use increases at an increasing rate once more. While the income elasticities in Table 5.12 suggest that the value of the elasticity has been declining over time, the insignificance of the interaction terms in the results from the pooled regressions in Tables 5.14 and 5.15 show that the effect of income on car use was similar across the three survey years.

Adults

The effect of increasing number of adults in the household on car use is positive and significant in all cases with the exception of one-car households in 1999. The results for 1987 and 1994 are consistent with the results of Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Schmalensee and Stoker (1999) and Hensher (1985). The insignificance of any squared or cubed terms suggests that the effect is linear. A number of studies interpret the number of adults as a proxy for the number of eligible drivers in the household with Schmalensee and Stoker (1999) including the number of drivers in the household in addition to a household size variable. The fact that the elasticity with respect to the number of drivers (0.6) is larger than that for household size (0.1) in the Schmalensee and Stoker (1999) study may suggest that, for our study, the effect of the number of adults in the household is primarily reflecting the effect of the number of potential drivers in the household.[105] The elasticities evaluated at the 1994 sample means are similar for 1987 and 1994 and indicate that a one per cent increase in the number of adults in the household in 1987 leads to a 0.15 per cent and 0.23 per cent increase in car use in the two samples respectively. For 1994, a one per cent increase in the number of adults in the household leads to a 0.23 per cent increase in car use in each of the two samples. However, the results from the pooled regressions in Tables 5.14 and 5.15 suggest that there has been no significant change in the relationship between the number of adults and car use in either sample over the period 1987-1999.

[105] Irish HBS data do not provide data on the number of household members with a driving licence.

Children

The effect of the number of children in the household on car use is positive and linear in all cases, with the magnitudes of the elasticities being slightly higher in households with one car than in households with one or more cars. While the elasticities indicate that the effect of children was smaller in 1987 and 1999 than in 1994, the pooled regression interaction coefficients were insignificant indicating no significant difference in the effect of children on car use over the period 1987 to 1999. The positive effect of children on car use is consistent with the results of Johansson-Stenman (2002), Dargay and Vythoulkas (1999) and Bergantino (1997) and reflects the more diverse range of activities that households with children are engaged in, as well as the fact that young children need to be escorted to school and other activities.

Accommodation Type

The accommodation type variables are of the expected sign, showing how car use increases with distance and/or the non-availability of public transport. In 1987 and 1994 households living in semi-detached/terraced houses use their car(s) significantly less than households living in detached houses, while the effect of living in an apartment reduces car use in 1987 and 1994 in one car-owning households and in 1994 in households that own one or more cars. The results are very similar to those of Asensio *et al.* (2001), Kayser (2000), Bjorner (1999), Schmalensee and Stoker (1999), Mannering (1983), and Archibald and Gillingham (1980) who all find that urban residents use their cars less than rural residents. In addition, Bjorner (1999) finds a positive effect on car use of distance travelled to work while Kayser (2000) reports a significant negative effect of public transport availability on car use. The effect of accommodation type is insignificant in 1999 however, which may reflect the increasing tendency for apartment complexes to be built in suburban areas of Dublin in recent years in response to planning guidelines.

Working Status

In common with the results of Asensio *et al.* (2001), Kayser (2000), Mannering and Winston (1985) and Archibald and Gillingham (1980)[106], the presence of one or more persons in employment increases car use in 1994 and 1999, suggesting that the effect of regular commuting patterns on car use is positive. The insignificance of the working status variable for 1987 may indicate an increased use of the car for commuting purposes since 1987, a trend that is confirmed by the significant increase in the proportion of workers driving their cars to work over the period 1986-2000 [see Table 3.10].

Gender

The effect of a single female HOH is consistently negative and significant, in accordance with the results of Kayser (2000), Bjorner (1999), De Jong (1990), Mannering (1983) and Archibald and Gillingham (1980). The negative effect of a single female HOH may mean that such single women are engaged in activities that require less travelling such as part-time local work and/or are more willing to walk and use public transport than men. Even with access to a car, single female households use their cars less than all other household types, i.e., they select *"frequencies and types of activities that require less vehicular travel than do males"* [Mannering (1983, pp. 186)].

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[106] While Asensio *et al.* (2001), Kayser (2000) and Archibald and Gillingham (1980) include dummy variables for the number of workers in the household, Mannering and Winston (1985) include the number of workers as a continuous variable.

Age

The age of the HOH is only marginally significant in explaining variations in household car use in 1987 and insignificant in 1994 and 1999. The 1987 results suggest that car use is highest for households with a HOH aged 30-39 years and declines thereafter, results consistent with those of Asensio *et al.* (2001), Schmalensee and Stoker (1999), De Jong (1990), Mannering (1983) and Archibald and Gillingham (1980). These results are in direct contrast to the positive effect of the age of the HOH on household car ownership probability. However, the positive marginal effects for the age variables greater than the age of 30 suggest that households with a HOH aged 29 years and younger are least likely to own one or more cars and also use their car(s) the least.

Education Level

The education level of the HOH is not significant, a result consistent with those of Asensio *et al.* (2001) and Kayser (2000). While the education level of the HOH significantly affects the probability of household car ownership, once a car is owned, there is no variation in car use among households with HOHs that have differing levels of educational achievement.

Transport Control Variables

The number of motorcycles in the household, while expected to exert a significant positive effect, is insignificant in all cases. Asensio *et al.* (2001) and Bergantino (1997) also report an insignificant effect. This may be due to the small percentage of households that own motorcycles [see Table 4.5]. The variable indicating entitlement to expenses is consistently negative and significant across all survey years. While this result may seem contrary to expectations, the negative sign indicates that those households with at least one person entitled to remuneration for motor expenses, primarily petrol expenditure, do not report this as petrol expenditure. Unfortunately, it is impossible to ascertain from these results whether those entitled to motor expenses use their car(s) more, due to the lower costs of doing so.

The significance of the variables relating to whether the household owns two cars or three or more cars indicates that car use per car is lower when the household owns two or more cars. This result was also found by Archibald and Gillingham (1980) and suggests that there are economies of scale in car use with households owning one car only using the car more intensively than multi-car households. The significant effect for two-car households and insignificance of the three-car dummy in 1999 may be due to the nature of these households. Two-car households may be more likely to be families who would undertake some joint activities while households with three or more cars may be more likely to consist of unrelated individuals who do not car-share as much as families would. The significance of the 1999 interaction term in Table 5.15 illustrates the weaker negative effect in 1999, in part due to the substantial increase in the number of households owning two cars that occurred over the period 1994 to 1999 [see Table 4.6]. This may also indicate that the level of joint activities in multi-car households has declined, i.e., in 1987 the effect of having a second and third car was to spend £4.12 and £4.07 less on petrol respectively whereas in 1999 the effect of having a second car was to spend £1.95 less on petrol and there was no difference between households owning one car and households owning three cars in average levels of petrol expenditure per car.

Changes over Time

In Tables 5.14 and 5.15, the significance of the 1999 year dummies in both samples indicates that the major shift in the intercepts occurred between 1994 and 1999. The negative coefficient indicates that average petrol expenditures per car declined over the period, which may be due to the reduced proportion of households reporting petrol expenditures in 1999 compared with 1994 and 1987.[107] The insignificance of any interaction terms in the sample of one-car households suggests that there was no significant change in the relationship between the independent variables and car use over the period 1987-1999. The significance of the car ownership status interaction terms for 1999 indicates that the nature of the relationship between this variable and car use in the sample of households owning one or more cars changed over the period 1994-1999. Both sets of results indicate, however, that the change in the relationships between the independent variables and car use behaviour were very slight over the period 1987-1999.

5.7 Summary and Conclusions

In this chapter Household Budget Survey micro-data were used to estimate the income and socio-economic determinants of Dublin households' car ownership and use decisions. The most significant results relate to the effects of income (as proxied by per capita weekly household expenditure), the number of adults in the household and the

[107] The proportion of households recording positive petrol expenditures in one-car households in 1987, 1994 and 1999 were 89.8, 89.1 and 80.2 per cent respectively while in households owning one or more cars, the proportions were 91.1, 89.7 and 84.2 per cent in 1987, 1994 and 1999 respectively [see Table 4.3].

gender and age of the HOH. Household income is consistently positive and significant in explaining differences in households' car ownership and use decisions. An examination of income elasticities of demand reveals that while car ownership may be classified as a luxury good in 1987 and 1994 and a necessity in 1999, car use may be consistently characterised as a necessity. The gender of the HOH is generally significant in explaining variations in car ownership and car use. Households headed by a single female are less likely to own cars and also use their car(s) significantly less than other households types. The effects of the age of the HOH on car use are consistent with the expectation that younger households are more mobile and are engaged in more activities than older households. The positive effect of age of the HOH on car ownership is, however, in conflict with many other studies and may reflect different costs of car ownership in Ireland in comparison with other countries, with the costs of insurance being particularly high for young people. There is some evidence to show that the socio-economic differences between non car-owning and car-owning households have been lessening over time with the working status, gender and education level variables declining in significance from 1994 to 1999. The results of the pooled analyses suggest that there have been changes in the relationships over time, in particular for the relationship between car ownership and the socio-economic characteristics. For car use however, the changes over time are slight and indicate that the change occurred more in the intercepts of the relationships rather than in the slope coefficients. The following chapter, Chapter 6, extends the analysis in this chapter to consider the public transport use of Dublin households over the period 1987-1999.

5A TABLES

Table 5.1 Likelihood Ratio Tests of Homoscedastic Error Structure for Binary Probit Model of Car Ownership

	1987	1994	1999
Homoscedastic Errors*			
Test Statistic	4.093	9.625	1.508
Critical Value	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{3,0.01} = 11.345$
	Do not reject H_0	Do not reject H_0	Do not reject H_0

Note: * H_0 = Homoscedastic Error Structure (h = 0); H_1 = Heteroscedastic Error Structure ($h \neq 0$)

Table 5.2 Likelihood Ratio Tests of Homoscedastic Error Structure, Normal Error Structure and Homoscedastic and Normal Error Structure for Tobit Models of Car Use

	ONE CAR			CAR(S)		
	1987	**1994**	**1999**	**1987**	**1994**	**1999**
Homoscedastic Errors*						
Test Statistic	43.048	87.998	15.462	28.428	54.352	11.958
Critical Value	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{1,0.01} = 6.635$
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0
Normal Errors**						
Test Statistic	37.316	110.982	29.842	67.302	146.246	73.066
Critical Value	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0
Homoscedastic and Normal Errors***						
Test Statistic	60.126	140.174	40.662	81.896	163.906	83.900
Critical Value	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{4,0.01} = 13.277$	$\chi^2_{2,0.01} = 9.210$
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0

Notes:
* H_0 = Homoscedastic Error Structure ($h = 0$); H_1 = Heteroscedastic Error Structure ($h \neq 0$)
** H_0 = Normal Error Structure ($\theta = 0$); H_1 = Non-Normal Error Structure ($\theta \neq 0$)
*** H_0 = Homoscedastic and Normal Error Structure ($h = 0$ and $\theta = 0$); H_1 = Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)

Table 5.3 Likelihood Ratio Specification Tests for Pooled Binary Probit Model of Car Ownership

	CAR OWNERSHIP
Year Dummies*	
Test Statistic	173.966
Critical Value	$\chi^2_{2,0.01} = 9.210$
	Reject H_0
Year Dummies and Year Interactions **	
Test Statistic	94.378
Critical Value	$\chi^2_{36,0.01} = 58.619$
	Reject H_0
Year Dummies and Year Interactions (Best Fit) ***	
Test Statistic	86.418
Critical Value	$\chi^2_{34,0.01} = 56.061$
	Reject H_0

Notes:
* H_0 = Tobit (5.11); H_1 = Tobit + Year Dummies (5.12)
** H_0 = Tobit +Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (5.13)
*** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (Best Fit), i.e., with insignificant year interactions omitted (5.14)

Table 5.4 Likelihood Ratio Specification Tests for Pooled Tobit Models of Car Use

	ONE CAR	CAR(S)
Year Dummies*		
Test Statistic	26.840	17.480
Critical Value	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{2,0.01} = 9.210$
	Reject H_0	Reject H_0
Year Dummies and Year Interactions**		
Test Statistic	39.338	64.880
Critical Value	$\chi^2_{34,0.01} = 56.061$	$\chi^2_{38,0.01} = 61.162$
	Do not reject H_0	Reject H_0
Year Dummies and Year Interactions (Best Fit)***		
Test Statistic	3.962	20.360
Critical Value	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{4,0.01} = 13.277$
	Do not reject H_0	Reject H_0

Notes:
* H_0 = Tobit (5.11); H_1 = Tobit + Year Dummies (5.12)
** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (5.13)
*** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (Best Fit), i.e., with insignificant year interactions omitted (5.14)

Table 5.5 Likelihood Ratio Test of Homoscedastic Error Structure in Pooled Binary Probit Model of Car Ownership

	CAR OWNERSHIP
Homoscedastic Errors*	
Test Statistic	2.570
Critical Value	$\chi^2_{3,0.01}$ = 11.345
	Do not reject H_0

Note: * H_0 = Best Fit + Homoscedastic Error Structure (h = 0); H_1 = Best Fit + Heteroscedastic Error Structure ($h \neq 0$)

Table 5.6 Likelihood Ratio Tests of Homoscedastic Error Structure, Normal Error Structure and Homoscedastic and Normal Error Structure in Pooled Tobit Models of Car Use

	ONE CAR	CAR(S)
Homoscedastic Errors*		
Test Statistic	110.096	74.160
Critical Value	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{2,0.01}$ = 9.210
	Reject H_0	Reject H_0
Normal Errors**		
Test Statistic	154.152	257.960
Critical Value	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635
	Reject H_0	Reject H_0
Homoscedastic and Normal Errors***		
Test Statistic	209.448	296.740
Critical Value	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{4,0.01}$ = 13.277
	Reject H_0	Reject H_0

Notes: * ONE CAR SAMPLE: H_0 = Best Fit + Homoscedastic Error Structure (h = 0); H_1 = Best Fit + Heteroscedastic Error Structure ($h \neq 0$);
CAR(S) SAMPLE: H_0 = Best Fit + Homoscedastic Error Structure (h = 0); H_1 = Best Fit + Heteroscedastic Error Structure ($h \neq 0$)

** ONE CAR SAMPLE: H_0 = Best Fit + Normal Error Structure (θ = 0); H_1 = Best Fit + Non-Normal Error Structure ($\theta \neq 0$)
CAR(S) SAMPLE: H_0 = Best Fit + Normal Error Structure (θ = 0); H_1 = Best Fit + Non-Normal Error Structure ($\theta \neq 0$)

*** ONE CAR SAMPLE: H_0 = Best Fit + Homoscedastic and Normal Error Structure (h =0 and θ = 0); H_1 = Best Fit + Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)
CAR(S) SAMPLE: H_0 = Best Fit + Homoscedastic and Normal Error Structure (h =0 and θ = 0); H_1 = Best Fit + Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)

Table 5.7 Estimated Coefficients from Binary Probit Models of Car Ownership

VARIABLE	1987	1994	1999
Constant	-4.445	-3.607	-4.509
	(0.573)***	(0.495)***	(0.532)***
HHEXP	2.231	1.630	1.272
	(0.275)***	(0.226)***	(0.135)***
$HHEXP^2$	-0.399	-0.258	-0.151
	(0.083)***	(0.071)***	(0.028)***
$HHEXP^3$	0.022	0.013	0.005
	(0.007)***	(0.006)**	(0.002)***
ADULTS	1.478	0.935	2.207
	(0.402)***	(0.431)**	(0.507)***
$ADULTS^2$	-0.388	-0.305	-0.601
	(0.118)***	(0.147)**	(0.179)***
$ADULTS^3$	0.030	0.029	0.050
	(0.011)***	(0.015)*	(0.019)***
CHILDREN	0.568	0.343	0.444
	(0.075)***	(0.082)***	(0.098)***
$CHILD^2$	-0.067	-0.042	-0.052
	(0.013)***	(0.017)**	(0.023)**
APART	-0.477	-0.478	-1.008
	(0.167)***	(0.131)***	(0.196)***
SEMI	-1.201	-1.078	-0.392
	(0.197)***	(0.178)***	(0.159)**
WORKING	-0.445	-0.408	0.075
	(0.165)***	(0.151)***	(0.115)
SINGLE FEMALE	0.354	0.395	-0.014
	(0.095)***	(0.094)***	(0.140)
THIRTY	0.468	1.135	0.722
	(0.203)**	(0.196)***	(0.207)***
FORTY	0.991	1.517	1.209
	(0.213)***	(0.200)***	(0.215)***
FIFTY	0.801	1.727	1.203
	(0.214)***	(0.202)***	(0.210)***

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 5.7 continued

VARIABLE	1987	1994	1999
SIXTY	0.998	2.001	1.558
	(0.205)***	(0.195)***	(0.205)***
PRIMARY	-0.925	-0.986	-0.725
	(0.133)***	(0.127)***	(0.125)***
SECONDARY	-0.410	-0.269	-0.152
	(0.122)***	(0.113)**	(0.110)
Number of Observations	2,096	2,148	1,789
Log-Likelihood	-850.044	-823.844	-660.898
Heteroscedastic Log-Likelihood	-847.997	-819.031	-660.144
Elasticities:			
HHEXP	1.481***	1.145***	0.772***
ADULTS	0.509***	0.197***	0.487***
CHILDREN	0.375***	0.178***	0.129***

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 5.8 Estimated Coefficients from Tobit Models of Car Use

VARIABLE	ONE CAR 1987	ONE CAR 1994	ONE CAR 1999	CAR(S) 1987	CAR(S) 1994	CAR(S) 1999
Constant	-9.577	0.245	-3.004	-9.426	1.960	-1.466
	(3.524)***	(3.942)	(3.971)	(2.853)***	(3.370)	(3.078)
HHEXP	12.544	5.349	3.369	10.698	4.294	2.992
	(2.541)***	(1.038)***	(0.734)***	(1.808)***	(0.743)***	(0.587)***
$HHEXP^2$	-2.837	-0.395	-0.215	-2.324	-0.292	-0.188
	(0.810)***	(0.138)***	(0.065)***	(0.525)***	(0.088)***	(0.053)***
$HHEXP^3$	0.208			0.166		
	(0.078)***			(0.046)***		
ADULTS	1.045	1.551	0.669	1.478	1.520	1.122
	(0.388)***	(0.538)***	(0.648)	(0.274)***	(0.436)***	(0.447)**
CHILDREN	0.855	1.760	1.408	0.714	1.521	1.111
	(0.269)***	(0.386)***	(0.497)***	(0.244)***	(0.318)***	(0.353)***
APART	-2.241	-4.082	-2.884	-1.543	-3.224	-2.926
	(1.524)	(1.818)**	(2.293)	(1.446)	(1.510)**	(1.776)*
SEMI	-1.808	-2.617	0.938	-1.071	-1.368	0.059
	(0.951)*	(1.173)**	(1.497)	(0.723)	(0.887)	(0.948)
WORKING	0.531	2.807	2.890	0.723	2.598	3.315
	(0.900)	(1.186)**	(1.414)**	(0.749)	(1.014)**	(1.129)***
SINGLE FEMALE	-4.003	-2.923	-3.337	-3.453	-2.895	-2.722
	(1.234)***	(1.276)**	(1.419)**	(1.278)***	(1.151)**	(1.197)**
THIRTY	5.582	-0.240	1.995	5.193	0.372	0.526
	(2.217)**	(3.066)	(3.125)	(1.776)***	(2.748)	(2.462)
FORTY	4.581	-0.688	0.678	4.488	-0.871	-0.255
	(2.247)**	(3.061)	(3.092)	(1.791)**	(2.749)	(2.448)
FIFTY	3.902	0.751	1.354	3.374	0.991	1.015
	(2.287)*	(3.113)	(3.054)	(1.816)*	(2.780)	(2.415)

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 5.8 continued

VARIABLE	ONE CAR 1987	1994	1999	CAR(S) 1987	1994	1999
SIXTY	2.950	-0.878	1.817	3.310	-1.151	1.352
	(2.241)	(3.121)	(3.021)	(1.768)*	(2.787)	(2.388)
PRIMARY	0.250	2.180	1.550	0.487	1.281	1.288
	(0.921)	(1.273)*	(1.412)	(0.751)	(1.048)	(1.046)
SECONDARY	0.443	0.448	0.698	0.550	-0.484	0.453
	(0.732)	(0.972)	(1.060)	(0.583)	(0.759)	(0.748)
MOTOR	-0.163	3.586	1.890	-0.577	3.072	1.360
	(1.330)	(2.503)	(1.827)	(1.187)	(2.059)	(1.245)
EXPENSES	-3.771	-5.521	-2.055	-3.239	-4.484	-2.626
	(0.737)***	(1.068)***	(1.295)	(0.598)***	(0.803)***	(0.810)***
CAR2				-4.971	-5.834	-2.676
				(0.558)***	(0.855)***	(0.801)***
CAR3				-5.297	-7.316	0.940
				(1.127)***	(2.354)***	(2.162)
σ	7.995	11.158	12.072	7.451	10.441	*10.946*
	(0.205)***	(0.280)***	(0.355)***	(0.246)***	(0.231)***	*(0.251)****
Number of Observations	890	935	792	1,117	1,198	1,212
Log-Likelihood	-2898.910	-3301.768	-2638.360	-3604.694	-4182.870	-4089.239
Het Log-Likelihood	-2877.386	-3257.769	-2630.629	-3590.480	-4155.694	-4083.260
IHS Log-Likelihood	-2880.252	-3246.277	-2623.439	-3571.043	-4109.747	-4052.706
IHS Het Log-Likelihood	-2868.847	-3231.681	-2618.029	-3563.746	-4100.917	-4047.289
Elasticities:						
HHEXP	0.688***	0.506***	0.409***	0.657***	0.465***	0.400***
ADULTS	0.188***	0.198***	0.091	0.298***	0.219***	0.176**
CHILDREN	0.099***	0.112***	0.077***	0.089***	0.106***	0.070***

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 5.9 Marginal Effects for Binary Probit Model of Car Ownership

VARIABLE	1987	1994	1999
Constant	-1.769	-1.415	-1.408
	(0.229)***	(0.196)***	(0.170)***
HHEXP	0.888	0.640	0.397
	(0.110)***	(0.089)***	(0.043)***
$HHEXP^2$	-0.159	-0.101	0.047
	(0.033)****	(0.0280***	(0.009)***
$HHEXP^3$	0.009	0.005	0.002
	(0.003)***	(0.002)**	(0.001)***
ADULTS	0.588	0.367	0.689
	(0.160)***	(0.169)**	(0.158)***
$ADULTS^2$	-0.154	-0.120	-0.188
	(0.047)***	(0.058)**	(0.056)***
$ADULTS^3$	0.012	0.011	0.016
	(0.004)***	(0.006)*	(0.006)***
CHILDREN	0.226	0.135	0.139
	(0.030)***	(0.032)***	(0.030)***
$CHILD^2$	-0.027	-0.016	-0.016
	(0.005)***	(0.006)**	(0.007)**
APART	-0.430	-0.406	-0.315
	(0.078)***	(0.070)***	(0.061)***
SEMI	-0.173	-0.156	-0.122
	(0.065)***	(0.059)***	(0.049)**
WORKING	0.140	0.155	0.023
	(0.038)***	(0.037)***	(0.036)
SINGLE FEMALE	-0.189	-0.189	-0.004
	(0.066)***	(0.051)***	(0.044)
THIRTY	0.182	0.378	0.225
	(0.081)**	(0.077)***	(0.065)***
FORTY	0.360	0.480	0.377
	(0.085)***	(0.079)***	(0.067)***
FIFTY	0.295	0.486	0.376
	(0.085)***	(0.080)***	(0.065)***
SIXTY	0.372	0.626	0.487
	(0.082)***	(0.077)***	(0.064)***
PRIMARY	-0.356	-0.378	-0.226
	(0.053)***	(0.049)***	(0.039)***
SECOND	-0.162	-0.106	-0.048
	(0.048)***	(0.044)**	(0.034)
Number of Observations	2,096	2,148	1,789
Log-Likelihood	-850.044	-823.844	-660.898
Elasticities:			
HHEXP	1.482***	1.145***	0.772***
ADULTS	0.509***	0.197**	0.487***
CHILDREN	0.375***	0.178***	0.129***

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 5.10 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Car Use (One Car Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-8.120	1.554	2.430	1.741	-3.338	2.137
	(3.102)**	(0.081)***	(3.642)	(0.066)***	(3.492)	(0.076)***
HHEXP	3.723	0.128	3.183	0.124	2.122	0.060
	(1.786)**	(0.028)***	(0.920)***	(0.022)***	(0.837)**	(0.020)***
ADULTS	1.046		1.564		0.637	
	(0.226)***		(0.423)***		(0.522)	
CHILDREN	0.871	0.052	1.604	0.074	1.316	
	(0.348)***	(0.018)***	(0.336)***	(0.021)***	(0.390)***	
APART	-2.570		-3.333		-1.934	
	(1.325)*		(1.441)**		(1.836)	
SEMI	-1.847		-2.551		1.252	
	(0.812)**		(0.959)***		(1.100)	
WORKING	0.298		2.737		2.290	
	(0.775)		(0.910)***		(1.095)**	
SINGLE FEMALE	-3.623		-2.552		-2.518	
	(1.075)***		(1.143)**		(1.261)**	
THIRTY	4.890		0.057		1.994	
	(1.975)**		(2.902)		(2.654)	
FORTY	4.030		-0.190		0.604	
	(1.994)**		(2.904)		(2.631)	
FIFTY	3.074		0.648		1.317	
	(2.001)		(2.969)		(2.618)	
SIXTY	2.561		-0.419		1.986	
	(1.988)		(2.928)		(2.599)	
PRIMARY	0.341		1.633		1.262	
	(0.834)		(1.046)		(1.088)	
SECOND	0.487		0.388		0.700	
	(0.715)		(0.870)		(0.926)	
MOTOR	0.233		3.366		0.757	
	(1.242)		(2.079)		(1.828)	
EXPENSES	-3.633		-5.357		-2.298	
	(0.699)***		(0.893)***		(0.930)**	
θ	0.037		0.043		0.034	
	(0.006)***		(0.006)***		(0.006)***	
Observations	890		935		792	
Non-linear terms	$HHEXP^2$, $HHEXP^3$		$HHEXP^2$		$HHEXP^2$	
Log-Likelihood	-2868.847		-3231.681		-2618.029	
Elasticities:						
HHEXP	0.729**		0.514***		0.502**	
ADULTS	0.078***		0.225***		0.106	
CHILDREN	0.064***		0.115***		0.088***	

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 5.11 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Car Use (One or More Cars Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-7.894	1.541	3.608	1.898	-1.256	2.027
	(2.488)***	(0.070)***	(3.142)	(0.090)***	(2.661)	(0.059)***
HHEXP	3.134	0.082	2.613	0.060	1.741	0.044
	(1.357)**	(0.022)***	(0.696)***	(0.019)***	(0.503)***	(0.013)***
ADULTS	1.411		1.415	-0.041	0.970	
	(0.286)***		(0.361)***	(0.024)*	(0.384)**	
CHILDREN	0.729	0.038	1.369	0.055	1.053	
	(0.197)***	(0.016)**	(0.299)***	(0.018)***	(0.291)***	
APART	-1.690		-2.897		-2.177	
	(1.137)		(1.252)**		(1.436)	
SEMI	-1.093		-1.322		0.359	
	(0.657)*		(0.764)*		(0.775)	
WORKING	0.459		2.393		2.688	
	(0.696)		(0.834)***		(0.904)***	
SINGLE FEMALE	-2.984		-2.236		-2.196	
	(0.921)***		(1.071)**		(1.017)**	
THIRTY	4.745		0.410		0.760	
	(1.630)***		(2.526)		(2.017)	
FORTY	4.074		-0.600		0.042	
	(1.651)**		(2.536)		(2.012)	
FIFTY	2.789		0.908		1.225	
	(1.655)*		(2.575)		(1.996)	
SIXTY	2.871		-0.950		1.556	
	(1.643)*		(2.552)		(1.985)	
PRIMARY	0.493		0.932		1.021	
	(0.702)		(0.885)		(0.835)	
SECOND	0.533		-0.417		0.386	
	(0.579)		(0.686)		(0.659)	
MOTOR	-0.295		2.529		0.799	
	(1.099)		(1.712)		(1.082)	
EXPENSES	-3.083		-4.358		-2.691	
	(0.533)***		(0.710)***		(0.657)***	
CAR2	-4.122		-4.493		-1.954	
	(0.787)***		(0.874)***		(0.798)**	
CAR3	-4.066		-5.256		1.143	
	(2.376)*		(3.494)*		(2.447)	
θ	0.051		0.050		0.042	
	(0.006)***		(0.006)***		(0.005)***	
Observations	1,117		1,198		1,212	
Non-linear terms	$HHEXP^2$, $HHEXP^3$		$HHEXP^2$		$HHEXP^2$	
Log-Likelihood	-3563.746		-4100.917		-4047.289	
Elasticities:						
HHEXP	0.693**		0.479***		0.463***	
ADULTS	0.310***		0.227***		0.179**	
CHILDREN	0.099***		0.107***		0.078***	

Notes: (i) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(ii) The calculation of elasticities incorporates non-linear terms.
(ii) The significance levels of elasticities are those of the underlying marginal effects.

Table 5.12 Car Ownership and Use Elasticities at 1994 Sample Means[108]

	HHEXP	ADULTS	CHILDREN
CAR OWNERSHIP			
1987	1.449***	0.454***	0.272***
1994	1.145***	0.197**	0.178***
1999	0.678***	0.572***	0.195***
CAR USE - ONE CAR			
1987	0.602**	0.150***	0.063***
1994	0.514***	0.225***	0.115***
1999	0.343**	0.091	0.094***
CAR USE – CAR(S)			
1987	0.574**	0.226***	0.057***
1994	0.479***	0.227***	0.107***
1999	0.319***	0.155**	0.082***

Notes: (i) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(ii) The calculation of elasticities incorporates non-linear terms.
(iii) The significance levels of elasticities are those of the underlying marginal effects.

[108] In contrast to the elasticities reported in Tables 5.7 to 5.11 inclusive, which are calculated using the sample means of the year in question, the elasticties reported in Table 5.12 are calculated using the 1994 sample means to enable more accurate comparisons over the period 1987-1999.

Table 5.13 Coefficient Estimates for Pooled Binary Probit Model of Car Ownership

VARIABLE	1987	1994	1999
Constant	-0.944	-3.927	-0.205
	(0.531)*	(0.388)***	(0.489)
HHEXP	-0.260	2.434	-0.768
	(0.392)	(0.301)***	(0.352)**
$HHEXP^2$	0.187	-0.550	0.284
	(0.142)	(0.124)***	(0.134)**
$HHEXP^3$	-0.021	0.040	-0.027
	(0.015)	(0.014)***	(0.015)*
ADULTS	0.578	1.074	0.767
	(0.242)**	(0.255)***	(0.246)***
$ADULTS^2$	-0.080	-0.362	-0.102
	(0.038)**	(0.075)***	(0.041)**
$ADULTS^3$		0.035	
		(0.007)***	
CHILDREN	0.111	0.415	0.048
	(0.050)**	(0.055)***	(0.060)
$CHILD^2$		-0.056	
		(0.009)***	
APART		-1.080	
		(0.110)***	
SEMI		-0.407	
		(0.091)***	
WORKING	-0.040	0.372	-0.291
	(0.133)	(0.094)***	(0.148)**
SINGLE FEMALE	-0.009	-0.464	0.416
	(0.195)	(0.124)***	(0.178)**
THIRTY	-0.581	1.083	-0.334
	(0.277)**	(0.193)***	(0.282)
FORTY	-0.408	1.449	-0.208
	(0.286)	(0.196)***	(0.288)
FIFTY	-0.786	1.657	-0.408
	(0.285)***	(0.197)***	(0.282)
SIXTY	-0.879	1.919	-0.318
	(0.268)***	(0.187)***	(0.266)
PRIMARY		-0.845	
		(0.074)***	
SECOND		-0.261	
		(0.066)***	
Number of Observations		6,033	
Log-Likelihood		-2325.449	

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 5.14 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Car Use (One Car Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-0.404 (0.454)	-1.705 (1.917)	-2.078 (0.412)***	1.796 (0.057)***
HHEXP		6.549 (1.270)***		0.112 (0.014)***
$HHEXP^2$		-0.977 (0.421)**		
$HHEXP^3$		0.039 (0.041)		
ADULTS		1.065 (0.250)***		0.031 (0.017)*
CHILDREN		1.047 (0.176)***		0.046 (0.011)***
APART		-2.573 (0.837)***		
SEMI		-1.090 (0.542)**		
WORKING		1.602 (0.509)***		
SINGLE FEMALE		-2.691 (0.609)***		
THIRTY		2.741 (1.337)**		
FORTY		1.777 (1.338)		
FIFTY		2.043 (1.345)		
SIXTY		1.561 (1.326)		
PRIMARY		1.010 (0.549)*		
SECOND		0.508 (0.457)		
MOTOR		0.705 (0.947)		
EXPENSES		-3.772 (0.454)***		
θ		0.036 (0.003)***		
Number of Observations		2,617		
Log-Likelihood		-8929.093		
IHS Het Tobit Log-Likelihood		-8834.024		

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 5.15 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Car Use (One or More Cars Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-0.239	-1.738	-2.069	1.913
	(0.371)	(1.479)	(0.349)***	(0.049)***
HHEXP		6.149		0.063
		(0.932)***		(0.011)***
$HHEXP^2$		-1.026		
		(0.284)***		
$HHEXP^3$		0.054		
		(0.026)**		
ADULTS		1.154		-0.027
		(0.172)***		(0.013)**
CHILDREN		0.829		0.030
		(0.133)***		(0.009)***
APART		-1.947		
		(0.675)***		
SEMI		-0.492		
		(0.384)		
WORKING		1.697		
		(0.427)***		
SINGLE FEMALE		-2.373		
		(0.532)***		
THIRTY		2.410		
		(1.037)**		
FORTY		1.586		
		(1.040)		
FIFTY		2.004		
		(1.036)*		
SIXTY		1.619		
		(1.023)		
PRIMARY		0.812		
		(0.418)*		
SECOND		0.280		
		(0.331)		
MOTOR		0.464		
		(0.604)		
EXPENSES		-3.113		
		(0.325)***		
CAR2	-0.305	-4.039	2.170	
	(1.058)	(0.702)***	(0.855)**	
CAR3	0.367	-4.953	5.429	
	(4.098)	(3.267)	(3.664)	
θ		0.046		
		(0.003)***		
Number of Observations		3,527		
Log-Likelihood		-11973.480		
IHS Het Tobit Log-Likelihood		-11825.110 (4)		

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

5B APPENDICES

5A Formulae for the Calculation of Marginal Effects for Binary Probit and Tobit Models

Probit Marginal Effects

$$ME_j = \frac{\partial E(y_i)}{\partial x_{ij}} = \phi(x_i'\beta).\beta_j \tag{5A.1}$$

Tobit Marginal Effects

$$ME_j = \frac{\partial E(y_i)}{\partial x_{ij}} = \Phi\left(\frac{x_i'\beta}{\sigma}\right).\beta_j \tag{5A.2}$$

Heteroscedastic and Non-Normal Tobit Marginal Effects

$$ME_j = \frac{\partial E(y_i)}{\partial x_{ij}} = \int_0^\infty \left(\begin{array}{c} \dfrac{y_i}{\sigma_i\sqrt{1+\theta^2 y_i^2}}\phi\left(\dfrac{y(\theta)-x_i'\beta}{\sigma_i}\right)\times \\ \left(\left(\dfrac{y(\theta)-x_i'\beta}{\sigma_i}\right)\left(\dfrac{\beta_j}{\sigma_i}\right)+\left(\dfrac{y(\theta)-x_i'\beta}{\sigma_i}\right)^2 h_j - h_j\right) \end{array} \right) dy_i \tag{5A.3}$$

where $E(y_i)$ is the expected value of the dependent variable, ϕ is the standard normal density function, Φ is the cumulative standard normal distribution function, σ_i is the estimated standard error, θ is the estimated IHS parameter and β_j and h_j are the estimated coefficients on the independent variable x_j and the heteroscedasticity term z_j respectively. All marginal effects are calculated at the sample means of the independent variables.

5B Formulae for the Calculation of Standard Errors for Heteroscedastic and Non-Normal Tobit Models

Standard errors in the Tobit models adjusted for heteroscedastic and non-normal errors are approximated using the delta method. The delta method approximates the variance of the estimated marginal effect, ME_j, by pre- and post-multiplying the variance-covariance matrix of the parameter estimates by a vector of derivatives as follows:

$$\text{var}(ME_j) = \left[\frac{\partial\, ME_j}{\partial\, \psi}\right]' \Sigma \left[\frac{\partial\, ME_j}{\partial\, \psi}\right]$$

where ψ is a vector of parameter estimates and Σ is the estimated variance-covariance matrix of the parameters [Yen *et al.* (1996)]. The vector of derivatives is obtained by differentiating each marginal effect, ME_j, by each estimated parameter of the model (see 5B.1 to 5B. below).

$$\frac{\partial\, ME_j}{\partial\, \beta_q} = \int_0^\infty \left(\begin{array}{l} \dfrac{y_i}{\sigma_i \sqrt{1+\theta^2 y_i^2}} \phi\left(\dfrac{y(\theta) - x_i'\beta}{\sigma_i}\right) \times \\ \left(\left(\dfrac{y(\theta) - x_i'\beta}{\sigma_i}\right)\left(\dfrac{x_{iq}}{\sigma_i}\right) \times (.) \right. \\ \left. -\left(\dfrac{x_{iq}\beta_j}{\sigma_i^2}\right) - 2\left(\dfrac{y(\theta) - x_i'\beta}{\sigma_i}\right)\left(\dfrac{x_{iq} h_j}{\sigma_i}\right) \right) \end{array} \right) dy_i \qquad (5B.1)$$

$$\frac{\partial\, ME_j}{\partial\, \beta_j} = \int_0^\infty \left(\begin{array}{l} \dfrac{y_i}{\sigma_i \sqrt{1+\theta^2 {y_i}^2}} \phi\left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right) \times \\ \left(\begin{array}{l} \left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right) \left(\dfrac{x_{ij}}{\sigma_i} \right) \times (.) \\ - \left(\dfrac{x_{ij}\beta_j}{{\sigma_i}^2} \right) - 2\left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right) \left(\dfrac{x_{ij} h_j}{\sigma_i} \right) \\ + \left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right) \left(\dfrac{1}{\sigma_i} \right) \end{array} \right) \end{array} \right) dy_i \qquad \text{(5B.2)}$$

$$\frac{\partial\, ME_j}{\partial\, h_q} = \int_0^\infty \left(\begin{array}{l} \dfrac{y_i}{\sigma_i \sqrt{1+\theta^2 {y_i}^2}} \phi\left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right) \times \\ \left(\begin{array}{l} - z_{iq} \times (.) + \left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right)^2 z_{iq} \times (.) \\ - \left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right) \left(\dfrac{z_{iq}\beta_j}{\sigma_i} \right) \\ - 2\left(\dfrac{y(\theta) - x_i{'}\beta}{\sigma_i} \right)^2 \left(z_{iq} h_k \right) \end{array} \right) \end{array} \right) dy_i \qquad \text{(5B.3)}$$

$$\frac{\partial ME_j}{\partial h_j} = \int_0^\infty \left(\begin{array}{l} \frac{y_i}{\sigma_i \sqrt{1+\theta^2 y_i^{\ 2}}} \phi\left(\frac{y(\theta) - x_i{'}\beta}{\sigma_i}\right) \times \\ \left(\begin{array}{l} -z_{ij} \times (.) + \left(\frac{y(\theta) - x_i{'}\beta}{\sigma_i}\right)^2 z_{ij} \times (.) \\ -\left(\frac{y(\theta) - x_i{'}\beta}{\sigma_i}\right)\left(\frac{z_{ij}\beta_j}{\sigma_i}\right) \\ -2\left(\frac{y(\theta) - x_i{'}\beta}{\sigma_i}\right)^2 \left(z_{ij} h_j\right) \\ +\left(\frac{y(\theta) - x_i{'}\beta}{\sigma_i}\right)^2 - 1 \end{array} \right) \end{array} \right) dy_i \qquad (5B.4)$$

$$\frac{\partial ME_j}{\partial \theta} = \int_0^\infty \left(\begin{array}{l} \dfrac{y_i}{\sigma_i \sqrt{1+\theta^2 y_i^{\,2}}} \phi \left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right) \times \\ \left(\begin{array}{l} - \left(\dfrac{\theta y^2}{1+\theta^2 y^2} \right) \times (.) \\ - \left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right) \left(\dfrac{y}{\theta y \sqrt{1+\theta^2 y^2}} \right) \times (.) \\ + \left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right) \left(\dfrac{y(\theta)}{\theta \sigma_i} \right) \times (.) \\ + \left(\dfrac{y}{\theta y \sqrt{1+\theta^2 y^2}} \right) \left(\dfrac{\beta_j}{\sigma_i} \right) - \left(\dfrac{y(\theta)}{\theta \sigma_i} \right) \left(\dfrac{\beta_j}{\sigma_i} \right) \\ + 2 \left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right) \left(\dfrac{y}{\theta y \sqrt{1+\theta^2 y^2}} \right) \left(h_j \right) \\ - 2 \left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right) \left(\dfrac{y(\theta)}{\theta \sigma_i} \right) \left(h_j \right) \end{array} \right) \end{array} \right) dy_i \qquad (5B.5)$$

where $(.) = \left(\left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right) \left(\dfrac{\beta_j}{\sigma_i} \right) + \left(\dfrac{y(\theta) - x_i' \beta}{\sigma_i} \right)^2 h_j - h_j \right)$

CHAPTER 6

AN ECONOMETRIC ANALYSIS OF THE DEMAND FOR BUS AND TAXI USE IN THE DUBLIN AREA: 1987-1999

6.1 Introduction

The analysis in Chapter 5 illustrated the extent to which income and socio-economic characteristics are important in determining variations in household car ownership and use. In this chapter, the analysis is extended to consider the determinants of Dublin households' bus and taxi use using micro-data from the 1987, 1994 and 1999 Household Budget Surveys. Tobit models of bus and taxi use, as proxied by bus and taxi fare expenditures, are estimated for each individual year and for the pooled sample. The aim of this chapter is to quantify the impact of income and socio-economic factors on households' bus and taxi use and to subsequently examine the extent to which the influence of these factors changed over the period 1987 to 1999.

The aggregated COP data presented in Chapter 3 illustrate the extent to which factors such as distance, area of residence and gender impact on the travel patterns of Dublin workers and students. In addition, the data clearly indicate a shift over time away from public transport for the journeys to work, school and college. It is important to quantify the influence of these and additional factors, such as household size and composition, age, education level and most importantly, income and car ownership, on public transport use. A detailed knowledge of these influences, and of the nature of their change over time, can aid in forecasting future levels of public transport patronage as well as highlighting areas to target if a decrease in car use and a corresponding increase in the numbers walking, cycling and using public transport is to be achieved.

In addition to examining the socio-economic influences on public transport use in Ireland for the first time, this chapter adds to the literature by analysing public transport use for separate samples of households, namely, those not owning cars and those owning cars. This is also the first time that the demand for public transport has been divided into its different components. While Bergantino (1997) stresses the importance of dividing total transport expenditures into public and private expenditures, she does not consider further disaggregation of the public transport expenditure component. To our knowledge, this is the first time that bus and taxi use have been estimated separately using cross sectional expenditure micro-data.

Section 6.2 briefly reviews previous literature which focuses on the demand for public transport and Section 6.3 briefly describes the data used in the analysis in this chapter. Section 6.4 describes the econometric methodology employed, much of which has been discussed in Section 5.4. Section 6.5 deals with model specification issues while Section 6.6 presents empirical results for all models and Section 6.7 summarises and concludes.

6.2 Previous Literature

As discussed in Section 2.4, there is much evidence to show that income and socio-economic factors are important in determining differences in public transport use. Section 2.4 highlighted the differences in data sources and econometric methodologies that are used to examine public transport use and this may account for the disparity in results between studies. The effect of income is particularly ambiguous with a number of studies classifying public transport as a necessity [Fitzroy and Smith (1998, 1994) and Bergantino (1997)] while Johansson-Stenman (2002) finds that income exerts a negative effect on the probability and conditional levels of public transport use respectively, although the latter effect is insignificant. To our knowledge, no study examines public transport use at more disaggregated levels and this may explain the wide disparity in income elasticity measures. It is expected that the income elasticity of taxi use will be higher than that for bus use and consequently separate models of bus and taxi use are estimated in an attempt to decipher if income elasticities differ for these two different components of public transport. Using household surveys to examine transport demand means that factors such as public transport availability are often not available. However, a number of studies use household location/residence as a proxy for factors such as distance from the city centre and the quality and quantity of public transport links and find it significant [Johansson-Stenman (2002), Bergantino (1997) and Berkowitz *et al.* (1990)].

The approach in this chapter follows on from previous research using micro-data to examine the income and socio-economic influences on public transport use [see

Johansson-Stenman (2002) and Bergantino (1997)] but the econometric methodology follows research using Tobit models to examine expenditure on various commodities [see Fleischer and Seiler (2002), Cai (1998), Melenberg and Van Soest (1996), Yen *et al.* (1996), Hagemann (1981), Kitchen and Powells (1991), Lankford and Wyckoff (1991), Reynolds and Shonkwiler (1991), Atkinson *et al.* (1990), McCracken and Brandt (1987) and Bennett (1967)]. Finally, while the econometric methodologies are different and the focus is on only one journey purpose, modal choice studies often confirm important factors influencing the demand for public transport [see Sections 2.5 and 7.2].

In the context of Irish travel demand, this is the first time that public transport use has been estimated at the micro-level in Ireland. McGeehan (1984) undertook a time-series analysis of the demand for inter-urban railway travel in the Republic of Ireland from 1970 to 1983, while Oscar Faber (1998) conducted a survey of taxi use of 1,673 individuals in the Dublin area in 1997/1998 but only asked three questions relating to the socio-economic characteristics of the individual, namely age, gender and socio-economic group and undertook no econometric analysis of the data.

6.3 Data

The data employed in this chapter are micro-data from the 1987, 1994 and 1999 Household Budget Surveys (HBS), both separately and pooled. Section 4.2 contains further information on the conduct of the HBS, the type of variables extracted from the surveys and the preparation of the data for analysis. The dependent variables in the subsequent empirical analyses are household bus and taxi fare expenditures, adjusted for household size and seasonality as described in Section 4.2.2. Expenditure on train fares is not analysed due to the difficulty in distinguishing expenditure on DART or Dublin suburban services from expenditure on inter-city travel (see also Sections 4.2.1 and 4.2.2). As discussed in Section 4.2.1, bus and taxi use are analysed for the two separate samples of non car-owning and car-owning households.[109] The rationale for this division is discussed in Section 6.5.1. Section 4.2.3 describes in detail the various independent variables used in the analyses in this chapter. Variable definitions for the dependent and independent variables are presented in Tables 4.2 and 4.4 respectively while summary statistics for the dependent variables are detailed in Table 4.3 and for the discrete and continuous independent variables in Tables 4.5 and 4.6 respectively.

6.4 Econometric Methodology

6.4.1 Tobit[110]

As the dependent variables are per capita expenditure on bus and taxi fares, traditional regression approaches are inappropriate due to the presence of a significant number of zero observations. The Tobit econometric methodology is therefore used to model bus and taxi use. Section 5.4.2 discusses in detail the derivation of the Tobit model.

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[109] For comparison purposes, Tobit models of bus and taxi use are also estimated for the full sample of households, controlling for household car ownership status.

[110] As discussed in Section 5.4.2, the Tobit model assumes that zero observations are due to corner solutions. In other words, if income were to increase or prices were to fall, expenditure would occur. While this assumption has been criticised as restrictive, it is felt that this is not unduly restrictive in the case of bus and taxi fare expenditures. The consideration of alternative sources of zero observations, which give rise to the infrequency of purchase and double-hurdle models, is beyond the scope of this thesis. Infrequency of purchase is unlikely in the case of bus and taxi expenditure as neither commodity can be stored [Pudney (1989)]. In addition the HBS is conducted over a two-week survey period, an adequate period of time to encompass bus and taxi fare expenditures, especially for an urban area. In terms of non-participation in the market, it is felt that for taxi fare expenditures, economic factors are most important in determining participation in the market while for bus fare expenditures, all areas of the city have access to similar levels of service meaning that non-participation due to non-economic factors such as timetabling is not an issue. However, it is left as an avenue for future research to examine these issues [see also Section 8.3].

Heteroscedasticity and Non-Normality

As discussed in Section 5.4.2, heteroscedasticity and non-normality of the errors can render Tobit estimates inconsistent. Section 6.5.3 details the specification tests for the presence of heteroscedastic and non-normal errors for the Tobit models of bus and taxi use estimated in this chapter. With one exception, the null hypothesis of homoscedastic and normal errors is rejected at the one per cent level of significance meaning that the relevant log-likelihood function that is maximised is that presented in Equation (5.10). However, in the case of taxi fare expenditure in households with one or more cars in 1987, the null hypothesis of a homoscedastic error structure is rejected while the null hypothesis of a normal error structure is not rejected at the one per cent level of significance meaning that the relevant log-likelihood that is maximised is adjusted for heteroscedastic errors only, i.e.,

$$\log L = \sum_{y_i=0} \log\left[1-\Phi\left(\frac{x_i'\beta}{\sigma_i}\right)\right] + \sum_{y_i>0}\left[-\log\sigma + \log\phi\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\right] \qquad (6.1)$$

where Φ and ϕ are the cumulative standard normal distribution and standard normal probability density functions respectively. When $\sigma_i = \sigma$ the log-likelihood reduces to that of the homoscedastic and normal Tobit log-likelihood presented in Equation (5.7).

6.4.2 Pooled Analyses

In order to identify changes in the relationship between the independent variables and the demand for bus and taxi use over the period 1987-1999, the expenditure data from the three surveys are expressed in constant November 1994 prices [see Section 4.2] and Tobit models of bus and taxi fare expenditure are estimated for the samples of non car-owning and car-owning households respectively. As detailed in Section 5.4.3, 1994 is considered the base year and dummy variables for observations recorded in 1987 and 1999 are included to capture changes in the intercepts of the relationships over the period.[111] In addition, each independent variable is interacted with the 1987 and 1999 dummies in order to identify changes in the slope parameters or changes in the magnitude of the relationships between the dependent and independent variables between 1987 and 1999.

Heteroscedasticity and Non-Normality

As detailed in Section 5.4.3, the presence of heteroscedastic and non-normal errors is also a problem in the pooled Tobit models and Section 6.5.3 briefly outlines the testing procedures employed.

6.5 Model Specification

6.5.1 Division of the Samples

As discussed in Section 4.2.1, bus and taxi fare expenditures are analysed for separate samples of households, namely those not owning a car and those owning one or more cars. In order to ascertain whether the effects of the independent variables on average per capita bus and taxi fare expenditures differ depending on whether or not the household owns a car, likelihood ratio tests as applied in Gabriel and Rosenthal (1989) are undertaken to test the null hypotheses of common coefficients on the independent variables for households owning no car and households owning one or more cars. The

[111] In the context of bus use, the intercepts may capture changes in supply such as the introduction of Quality Bus Corridors on certain bus routes in the 1990s [see also Section 5.5.2].

results presented in Table 6.1 indicate that the null hypothesis of common coefficients may be rejected at the one per cent level of significance in all cases. In other words, there are significant differences between households owning no car and households owning one or more cars in the effects of the independent variables on average per capita bus and taxi fare expenditures. The smaller chi-squared test statistics for the taxi use models is reflected in the less distinct differences in the effects of the independent variables on taxi fare expenditures between households not owning cars and households owning one or more cars [see Section 6.6.2].

6.5.2 Choice of Independent Variables

For all four household decisions (bus use and taxi use for non car-owning and car-owning households), the same set of independent variables is employed for comparison purposes. Expenditures on bus and taxi fares are therefore expressed as a linear combination of various household characteristics and an error term.[112] The transport control variables relating to the number of free transport recipients in the household, the number of motorcycles in the household, receipt of motor expenses and the number of household cars are included where appropriate.[113] For household income and the number of adults, children and cars in the household, non-linear terms are included in the specification where they are significant[114] to account for the fact that the effect of these independent variables may differ over the range of the variables [see Kayser (2000), Alperovich *et al.*

[112] We do not consider the possibility of modelling bus and taxi fare expenditures as part of a system, i.e., allowing for substitutions/complementarities between the two decisions. Instead, this is left as an avenue for future research [see also Section 8.3].

[113] For example, the variable indicating the number of free transport recipients is only included in the bus use models as free transport is only available for travel by bus or train in the Dublin area.

[114] Non-linear terms significant in the original Tobit models were also included in the specification of the Tobit models adjusted for heteroscedasticity and non-normality.

(1999), Melenberg and Van Soest (1996), Reynolds and Shonkwiler (1991), Atkinson *et al.* (1990), McCracken and Brandt (1987), Cragg and Uhler (1970) and Bennett (1967)]. Section 4.2.3 contains further details on the choice of independent variables for analysis. All models are estimated using the LIMDEP econometrics package.

6.5.3 Specification Testing

Independent Models for 1987, 1994 and 1999

In allowing for heteroscedasticity, only significant continuous independent variables are included in the heteroscedasticity function [see Yen *et al.* (1996)]. In all of the Tobit models (with one exception), the significance of at least one continuous independent variable in the heteroscedasticity adjustment and of the IHS parameter resulted in the rejection of the null hypotheses of homoscedastic and normal error structures at the one per cent level of significance. However, for the model of taxi fare expenditures in car-owning households in 1987, the null hypothesis of a normal error structure cannot be rejected at the one per cent level of significance and therefore, this model is adjusted for heteroscedasticity only. Tables 6.2 and 6.3 present the results of the three likelihood ratio tests of homoscedastic errors (h=0), normal errors (θ=0) and heteroscedastic and non-normal errors (h=0 and θ=0) for the Tobit models of bus and taxi use respectively.

Pooled Models

Section 5.5.2 details the steps that were taken in order to decide on the most appropriate model specification for the pooled models of household car ownership and use. The same procedure applies to the pooled Tobit models of household bus and taxi use. Tables 6.4

and 6.5 indicate that in all cases, the models with differing intercept terms and significant differing slope coefficients are preferred.[115] These final specifications are further tested for the presence of heteroscedastic errors and non-normal errors.[116] The null hypotheses of homoscedastic errors, normal errors and the joint null hypotheses of homoscedastic and normal errors are rejected at the one per cent level of significance for all pooled Tobit models [see Tables 6.6 and 6.7]. The results of these likelihood ratio tests as well as the significance of at least one of the heteroscedasticity parameters and the IHS parameter guided the final specification of the pooled Tobit models of household bus and taxi use. The pooled Tobit results presented in Tables 6.18 to 6.23 are therefore adjusted for the presence of heteroscedastic and non-normal errors.

6.5.4 Interpretation of Parameter Estimates

Independent Models for 1987, 1994 and 1999

As discussed in Section 5.5.3, the estimated β coefficients in the Tobit model cannot be interpreted in the same way as in a linear regression model. Marginal effects for the continuous independent variables in the models must be calculated by differentiating the expected value of the dependent variable with respect to the independent variable of interest, evaluated at the sample mean of this independent variable. This enables the calculation of elasticities of demand with respect to these continuous independent variables. In order to more accurately identify changes in the value of the elasticities over the period 1987-1999, the elasticities are also calculated at a common reference point,

[115] As with the pooled models of household car ownership and use presented in Chapter 5, the possibility of a model characterised by common intercepts and differing slope coefficients is not considered (see also Section 5.5.2).

[116] The possibility of autocorrelated errors in the pooled Tobit models of bus and taxi fare expenditure is not considered (see also Section 5.5.3).

namely, the 1994 sample means [see Tables 6.16 and 6.17]. The marginal effects for discrete independent variables are calculated as the difference in expected values when the variable takes the value one and when it takes the value zero [see Yen *et al.* (1996)].[117] Section 5A of the Appendix to Chapter 5 contains the formulae for these marginal effects while Section 6A of the Appendix to this chapter contains the marginal effects for the Tobit model of taxi use in car-owning households in 1987 that is adjusted for heteroscedasticity only. In order to ascertain the reliability of all marginal effects in the Tobit models, standard errors for the marginal effects must be calculated. These are approximated using the delta method as presented in Yen *et al.* (1996). Section 5B of the Appendix to Chapter 5 contains the formulae for the standard errors that are employed in the Tobit models adjusted for heteroscedasticity and non-normality while Section 6B of the Appendix to this chapter presents the formulae for the standard errors in the Tobit model of taxi use in car-owning households in 1987 that is adjusted for heteroscedasticity only. For comparison purposes, Tables 6.8 and 6.9 present the estimated coefficients from the Tobit models of bus and taxi use that are not adjusted for heteroscedasticity and non-normality of the errors.

Pooled Models

As we are only interested in the changes over time that have occurred in the relationships between the independent variables and bus and taxi use, marginal effects and elasticities based on the pooled sample are not computed. Tables 6.18 to 6.23 present the estimated coefficients from the pooled Tobit models of bus and taxi use adjusted for heteroscedastic and non-normal errors.

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[117] See also discussion in Section 5.5.3.

6.6 Empirical Results

6.6.1 Bus Use

Income

Table 6.10 indicates that household income, as proxied by per capita weekly household expenditure, has a positive and significant effect on bus use in non car-owning households in all years. The significance of the squared terms in all years indicates that as income increases, expenditure on bus fares increases but at a decreasing rate. The positive income elasticities indicate that for a one per cent increase in household income in 1987, 1994 and 1999, average per capita bus fare expenditures increased by 0.88, 0.69 and 0.53 per cent respectively. Bus travel in non car-owning households may, therefore, be regarded as a necessity, a result similar to that found by Bergantino (1997) for expenditures on public transport using UK Family Expenditure Survey micro-data.

While the above figures suggest that the value of the income elasticity is declining over time, a different conclusion is reached when income elasticities are evaluated at a common reference point, namely the 1994 sample means. When evaluated at 1994 mean values, the income elasticity increases from 0.52 to 0.69 from 1987 to 1994 and declines again to 0.47 in 1999 [see Table 6.16]. The latter interpretation is supported by the results for the pooled regression, which are reported in Table 6.18. The 1987 and 1999 interaction terms have negative signs suggesting that the positive effect of income was smaller in 1987 and 1999 than it was in 1994 with the insignificance of the 1999 interaction term indicating that the largest change in the income effect occurred between 1987 and 1994 rather than between 1994 and 1999.

In car-owning households, the effect of income is positive and only marginally significant in 1999.[118] Once again, the magnitudes of the elasticities suggest that bus use in car-owning households is a necessity. While the income elasticities in Table 6.16 suggest that the elasticity increased in value to 0.39 in 1999, the results from the pooled regression in Table 6.19 indicate no significant difference in the effect of income on average per capita bus fare expenditures in the three years. The magnitude of the elasticities as well as their significance levels would suggest that income is a more important determinant of average per capita bus fare expenditures in households without cars than in households with cars. An increase in the income of the population would therefore change the bus use behaviour of those in households without cars to a greater extent than that of those in households owning one or more cars.[119]

Adults

The number of adults in the household impacts positively on per capita bus fare expenditure in non car-owning households although the effect is insignificant in 1999. The significance of the squared terms in 1987 and 1994 indicate that a non-linear relationship exists. The positive effect of the number of adults in the household on bus use in non car-owning households in the earlier years may be explained by the tendency for non car-owning households with a large number of adults to be composed of third level students or young single workers who would be more mobile than other sectors of

[118] A possible explanation for the reduced significance of income in car-owning households is that the variance of income is smaller in car-owning households. However, this is discounted by an examination of the summary statistics in Table 4.5. In addition, the possibility that income and the number of cars are collinear is rejected by the fact that income remains insignificant when bus use is analysed for the sample of households owning one car only.

[119] Unfortunately, this analysis cannot say anything about the possibility that an increase in income could also lead non car-owning households to acquire a car.

the population. The non-linear effect may capture the tendency for such households to travel together by taxi at times as it may be cheaper than paying individual bus fares. The income elasticities evaluated at the common 1994 sample means indicate that the elasticity increased from 0.51 to 0.65 from 1987 to 1994 and declined to 0.21 in 1999, although the 1999 elasticity is insignificant. The results from the pooled regression in Table 6.18 indicate no significant difference in the effect of the number of adults on bus use in the three years.

For households that own one or more cars, the effect of the number of adults on average per capita bus fare expenditures is positive and significant in all three years, consistent with the results of De Palma and Rochat (2000). The significance of the squared term suggests that as the number of adults in the household increases, average per capita bus fare expenditures increase but at a decreasing rate. The elasticities evaluated at the common 1994 sample means show that bus use in households owning one or more cars in 1994 and 1999 is highly sensitive to the number of adults in the household. In other words, for a one per cent increase in the number of adults in the household in 1994 and 1999, average per capita bus fare expenditures increased by 1.79 and 1.96 per cent respectively. This means that competition for the household car(s) induces some members to choose alternative forms of transport. The lower elasticity in 1987 suggests that the magnitude of the elasticity has been increasing over time although the results from the pooled regression in Table 6.19 report no significant difference between the three years.

Children

In non car-owning households, the effect of the number of children under the age of 17 is negative, although insignificant in 1994. In car-owning households on the other hand, the effect is also negative in all three years, but insignificant in 1987 and 1999. The negative signs of the elasticities as well as the consistently negative and significant marginal effects for children in the full sample results in Table 6.12 are consistent with the results of De Palma and Rochat (2000) and Bergantino (1997), who find that the effect of children on public transport demand is negative. In car-owning households, this may reflect the returns to scale involved in driving children to school. In non car-owning households, there is some evidence to show that the elasticity increased in magnitude between 1987 and 1999 from –0.05 to –0.15 (evaluated at common 1994 sample means) although the results from the pooled regression in Table 6.18 indicate no significant difference between the three years. For car-owning households, the pooled regression results in Table 6.19 also indicate no significant difference in the effect of children on average per capita bus fare expenditures in the three years, although the elasticity estimates in Table 6.16 indicate that the value of the elasticity was slightly higher in 1994 than in 1987 or 1999.

Accommodation Type

In non car-owning households, there are no significant differences in the bus use behaviour of those living in apartments or semi-detached/terraced houses compared to the base category of those living in detached houses in any of the three years. This may be due to the characteristics of the sample with only tiny proportions of the total living in detached houses [see Table 4.6]. For car-owning households, only the effect of living in an apartment in 1987 is significantly different from that of the base category with the positive sign of the marginal effect indicating that households living in apartments spend £0.36 more per capita on bus fares than those living in detached houses. This is consistent with our hypothesis that those living in areas adjacent to, or in, the city centre have better access to public transport services and may face parking difficulties thus leading even households that own cars to choose alternative forms of transport such as the bus. Other studies have confirmed the importance of service quality and restrictions on private car use in encouraging public transport use [see FitzRoy and Smith (1998, 1994)]. Johansson-Stenman (2002) and Bergantino (1997) similarly find that urban location exerts a significant and positive effect on public transport demand. The results from the pooled regression for car-owning households that are reported in Table 6.19 confirm the change in the effect of accommodation type over the period 1987-1999 with significant positive coefficients on the interaction terms for the apartment variable for both 1987 and 1999. The significance of the 1999 term reflects the fact that the sign of the effect changed from negative to positive from 1994 to 1999. Nonetheless, the largest change in effect occurred between 1987 and 1994, a result consistent with the individual regression results. When both samples are examined together however, the effect of accommodation type remains insignificant [see Table 6.12].

Working Status

In both samples, the effect of having at least one person in the household in employment has a positive and significant effect on average per capita bus fare expenditures. This reflects the regular commuting needs of these household types. In car-owning households, the fact that the worker may choose to use the car to travel to work means that other members of the household may use the bus to travel as the car is unavailable for a large part of the day. The results of the pooled regressions in Tables 6.18 and 6.19 suggest no significant difference in the effect of this variable over time for either sample.

Gender

In non car-owning households, the effect of having a single female as the HOH is positive and significant in 1987 and 1994 but insignificant in 1999. For households owning one or more cars, the effect of a single female HOH is positive and significant in 1994 and 1999 but insignificant in 1987. Even when single female households have access to one or more cars, they spent more on bus fares per capita than other car-owning households in the later years (£0.93 and £1.41 respectively), thus reinforcing the point of Mannering (1983) that females select frequencies and types of activities that require less vehicular travel than males. The results of the pooled regressions in Tables 6.18 and 6.19 indicate that a significant difference in the effect of the gender of the HOH occurred between 1987 and 1994 for car-owning households, reflecting the change in sign and significance of the variable that occurred over that period.

Age

In non car-owning households, the effect of being aged 60 years and over has a consistently negative and significant effect on average per capita bus fare expenditures. This result is all the more significant given that the presence of free public transport for pensioners is also controlled for and exerts a negative and significant effect on per capita bus fare expenditures. The negative signs of the marginal effects indicate that in all years, bus use is a declining function of age although the 1994 and 1999 results suggest a non-linear effect with those aged 50-59 years having a less negative effect on bus use than those aged 40-49 years, although these effects are insignificant. The age of HOH variable is generally insignificant in car-owning households although the signs of the effects and the marginal significance of the effect of being aged 30-39 years in 1987 suggests that, in comparison to the base category of those aged 29 years or younger, younger household spend the most per capita on bus fares. These results, while more significant for non car-owning households, are in direct contrast to those of De Palma and Rochat (2000) who find that older people are more likely to use public transport than younger people for the journey to work. The divergence in results may be accounted for by the fact that the HBS data cover all journeys, not just the journey to work. In both the pooled regressions reported in Tables 6.18 and 6.19, the effect of age exhibits no significant difference across the three survey years for either sample.

Education

In non car-owning households, the effect of the education level of the HOH is only significant in 1994 and suggests that, in comparison with those who have a third level education, households with a HOH with a primary and secondary level education spend significantly less on bus fares, with those with a primary level education only spending the least. These effects may be explained by the fact that third level students are included in the third level education category and may be expected to be more mobile than all other categories of individual. The significance of the interaction terms in the pooled regression in Table 6.18 simply indicates the change in sign that occurred between 1987 and 1994 and again between 1994 and 1999.

For households that own one or more cars, the effect of education is only significant in 1987 and is again of opposite sign to the effects in 1994 and 1999. The 1987 results show that households with a HOH with lower levels of education spend more per capita on bus fares than those households with a HOH with a third level education, with households with a primary educated HOH spending the most in comparison with the base category. The significance of the 1987 interaction terms in Table 6.19 reflects this change in sign and significance that occurred between 1987 and 1994. The effect of the education level of the HOH in car-owning households may be capturing the effect of company car provision with those with higher levels of education more likely to be engaged in occupations[120] where company cars are provided. It is expected that those with company cars may be more willing to use them as the costs of doing so are lower than for those who bear the full costs of owning a car.

Transport Control Variables

Entitlement to free travel exerts a negative and significant effect on per capita bus fare expenditures in both samples in all years. This simply reflects the fact that these households do not record bus fare expenditures. Unfortunately, it is not possible to

[120] The occupation of the HOH is not recorded in the data supplied by the CSO. Alternative variables, which indicate broad occupational categories such as socio-economic group and social class, were not considered for inclusion as independent variables due to concerns over multicollinearity with the income variable.

ascertain whether these households use the bus more because of their entitlement to free bus travel. A number of studies have examined the merits of introducing free public transport in an attempt to encourage increased use of public transport but have concluded that public transport use is inelastic with respect to fare levels. On the other hand, FitzRoy and Smith (1998) found that the introduction of an unlimited public transport monthly ticket which effectively reduces the marginal cost of additional trips to zero significantly increased public transport patronage in Geneva. The results of the pooled regressions in Tables 6.18 and 6.19 suggest no significant difference in the effect of this variable over the period 1987-1999. The effect of the number of motorcycles in the household is negative and significant in 1994 but insignificant in 1987 and 1999 in non car-owning households. This may indicate an increasing role for the motorcycle as a faster alternative to the bus or the car for most journeys in 1994 and 1999, as levels of traffic congestion deteriorated. In car-owning households the effect is only significant in 1999 and indicates that as the number of motorcycles increases, average per capita bus fare expenditures decrease. The insignificance of the effects in 1987 and 1994 may again reflect the differing uses of the motorcycle over time.

In car-owning households, entitlement to remuneration for motor expenses has a negative and significant effect on average per capita bus fare expenditures in car-owning households in 1994 and 1999, indicating that if the option of cheaper private transport is available it will be chosen. The results of the pooled regressions in Tables 6.18 and 6.19 suggest no significant difference in the effect of this variable over the period 1987-1999. In car-owning households, the effect of increasing number of household cars is negative and significant in all years. In all years, squared terms were found to be insignificant indicating that as the number of cars increases, average per capita bus fare expenditures decrease at a constant rate. Johansson-Stenman (2002) also finds that ownership of a car significantly reduces both the probability of travelling by public transport and the number of public transport trips. Madan and Groenhaut (1987) similarly find that the number of cars per adult in the household exerts a significantly negative effect on the probability of using public transport to travel to work. While the elasticities in Table 6.16 suggest that the value of the elasticity has been increasing over time, the results of the pooled regression in Table 6.19 indicate no significant difference over the period 1987-1999.

Changes over Time

In households not owning a car, the significance of the intercept terms for 1987 and 1999 indicates that the average level of bus fare expenditure changed significantly between 1987 and 1994 and again between 1994 and 1999. The year interactions suggest that income was a significantly less important factor in explaining variations in household bus use in 1987 than in 1994. With the exception of the education interaction terms, the insignificance of the remaining independent variable interaction terms indicates that no significant changes occurred in the relationships between these variables and bus use over the period 1987-1999. For the sample of households owning one or more cars, only the intercept term for 1987 is significant suggesting that the value of the intercept of the relationship changed significantly between 1987 and 1994 only. The fact that more interaction terms are significant for 1987 than for 1999 indicates that the largest change in the relationship between these independent variables and household bus use in the sample of households owning one or more cars occurred between 1987 and 1994.

6.6.2 Taxi Use

The differences between non car- and car-owning households' taxi fare expenditure patterns are less obvious than for the bus fare expenditure case. This is supported by the smaller chi-squared test statistics for the sub-sample division tests reported in Table 6.1. In other words, there are less obvious differences in average per capita taxi fare expenditure patterns than in average per capita bus fare expenditure patterns between households of differing car ownership status. Nonetheless, the likelihood ratio tests reject the null hypotheses of common coefficients and the results continue to distinguish between households on the basis of their car ownership status. However, reference will be made to the results of the taxi use models based on the full sample of households where appropriate.

Income

Table 6.13 indicates that household income has a positive and significant effect on average per capita taxi fare expenditures in non car-owning households in all years. The elasticities indicate that the income elasticity has been increasing over time and indeed, the results of the pooled regression in Table 6.21 support this claim with the interaction term for 1999 being positive and significant. However, the insignificance of the 1987 interaction term suggests that there was no significant difference in the effect of income over the period 1987-1994. In 1999, the income elasticities evaluated at both the 1994 and 1999 sample means indicate that taxi use in non car-owning households may be considered a luxury with a one per cent increase in income leading to a 1.1 per cent increase in average per capita taxi fare expenditures. As with the case for bus fare expenditures, the public transport behaviour of households without cars is sensitive to income changes with the higher elasticity for taxi use indicating that an increase in income (or a decrease in fares) would lead to a greater increase in the use of taxis than of buses.

In car-owning households, the effect of income is positive in all three years, albeit insignificant in 1994. Once again, there is evidence to show that the magnitude of the income elasticities has increased over time but the results for the pooled regression in Table 6.22 indicate no significant change over the period. As is the case for households without cars, taxis in 1999 are a luxury good with a one per cent increase in average household income leading to a 1.4 per cent increase in taxi use. The higher elasticity of taxi demand than bus demand may be explained by the fact that taxis are a closer substitute for the private car and as such, a change in income will induce a relatively greater increase in taxi use than in bus use in households with one or more cars. These results are in conflict with the results of a survey of 1,673 households in the Dublin area in 1997/1998 by Oscar Faber (1998) who found that taxi use was evenly spread across socio-economic groups. This result may be accounted for by the fact that the survey was carried out over the months October, November and December 1997 and January 1998, i.e., including the Christmas period, when it is expected that taxi use is higher among all groups than at other times of the year.

Adults

In non car-owning households, the effect of the number of adults aged 18 years and over on taxi use is insignificant in all three years. This is not surprising given that taxi fare expenditures have been adjusted for household size. In contrast, the effect is positive and significant in car-owning households in 1987 and 1999, reflecting the competing demands on the households' car(s) in these households, which induce some members to choose alternative forms of transport. The larger elasticity for bus use than for taxi use suggests that an increase in the number of adults in car-owning households has a larger effect on average per capita bus fare expenditures than on average per capita taxi fare expenditures, which may reflect the fact that taxis are often shared whereas the bus is an individual mode of transport.

Children

The effect of the number of children in the household is insignificant in all three years except in 1987 in car-owning households when the effect is negative. This is consistent with the expectation that taxis are almost exclusively a means of transport for adults. The results, therefore, indicate that there are no significant differences between households with and without children in terms of their taxi use behaviour.

Accommodation Type

The effect of accommodation type shows that for non car-owning households, there are no significant differences between those living in apartments and semi detached/terraced houses and those living in detached houses in terms of average per capita taxi fare expenditures. However, as with the bus fare expenditure case, the effect is marginally significant in car-owning households, although in 1994 and not 1987. The marginal effect for those households living in semi-detached/terraced houses in 1994 indicates that these households spent significantly more per capita on taxi fares than households living in detached houses. This result suggests that distance and cost may influence taxi fare expenditure with those living furthest away from the city centre (detached houses) spending least because of cost while those living near the city centre (apartments) can use alternative, cheaper forms of transport such as walking and taking the bus.

Working Status

The presence of at least one working member in the household has a positive and significant effect on taxi fare expenditure in 1987 and 1994 in non car-owning households but is insignificant in 1999. In contrast, the effect is positive and significant in 1994 and 1999 in car-owning households. The increasing significance of this variable in car-owning households may indicate a growing acceptance of taxis as a means of transport for occasional commuting journeys. However, the results for the pooled regression in Table 6.19 indicate no significant difference in the effect of this variable over the period 1987-1999.

Gender

The gender of the HOH is not significant in determining taxi use in non car-owning households and in car-owning households, the effect of a single female HOH is only positive and significant in 1994. While it might be expected that households headed by a single female would spend significantly more on taxis due to increased safety concerns about travelling alone at night, particularly in non car-owning households, these results are consistent with the findings of the Oscar Faber study in 1998, where the same proportion of males as females had taken taxis in the previous six months.

Age

The effect of increasing HOH age on taxi expenditure is negative in both samples with those households with a head aged 60 years and over generally spending the least per person on taxi fares in all three years. However, the insignificance of the age of the HOH in non car-owning households in 1999 indicates that there are no significant differences between households of different generations in their taxi use behaviour. The former result perhaps reflects the difference in activities undertaken by households in different stages of the life-cycle and the general reticence of older people to use taxis. For example, younger households may socialise more than older households and therefore require late night transport, of which taxis are a popular and often necessary form due to poor public transport services late at night. This result is consistent with the findings of the Oscar Faber (1998) study on taxi use among 1,673 Dublin individuals. That survey found that young people aged 15-24 years were most likely to have used a taxi in the previous six months and where the primary purpose of taxi journeys was social/recreational (65 per cent), followed by personal/family business (16 per cent) and then business/work related (6 per cent). The results from the pooled regression in Table 6.21 indicate that for households not owning a car, the effect of being aged 60 years and older was significantly less negative in 1999 in comparison with 1994. This is consistent with the results from Table 6.13 where the age of the HOH becomes insignificant in 1999, in comparison with 1994.

Education

For the sample of non car-owning households, the effect of the education level of the HOH is not significant in any of the three years although the results for the sample of car-owning households in Table 6.14 indicate that those with a primary level education in 1987 spent significantly more per capita on taxi fares relative to those with a third level education. Once again, this may be accounted for by the tendency for third level students to socialise together and therefore travel home together meaning that the costs of taxis can be shared.

Transport Control Variables

The number of motorcycles is only significant in the full sample in 1987 and indicates that as the number of motorcycles in the household increases, average per capita taxi fare expenditures decline, a result similar to that found for the bus fare expenditure case and consistent with the expectation that the motorcycle, where available, will be favoured over the bus or taxi by virtue of its time advantage. The household's entitlement to motor expenses is not significant in explaining variations in taxi use in households with one or more cars in any of the three years. This may indicate that taxis are used more for leisure rather than work trips. The effect of increasing number of household cars is negative and significant in 1987 and 1999 and suggests that if the option of private transport is more easily available, it will be chosen. The insignificance of the squared terms indicates that, similar to the bus use case, expenditure on taxis decreases with increasing number of household cars at a constant rate. While the magnitude of the elasticities in Table 6.17 suggests that the elasticities are increasing over time, the results from the pooled regression in Table 6.22 indicate no significant difference over the period 1987-1999.

Changes over Time

The 1987 and 1999 intercept terms indicate that the major change in the intercept in non car-owning households occurred between 1994 and 1999 whereas the opposite is true for car-owning households. For the sample of households with no car, the insignificance of all the 1987 interaction terms indicates that the major change in the relationship between the socio-economic characteristics and taxi use occurred over the period 1994 to 1999, which reflects the fact that with the exception of household income in 1999, all independent variables are insignificant in explaining variations in taxi use in non car-owning households in 1999. For the sample of households owning one or more cars however, only the relationship between the number of motorcycles and taxi use changed significantly over the period, in comparison to the bus use case where the relationships between accommodation type, gender and education level all changed significantly over the period.

6.7 Summary and Conclusions

In this chapter Household Budget Survey micro-data from 1987, 1994 and 1999 were used to estimate the socio-economic determinants of Dublin households' bus and taxi use decisions. The most significant effects found relate to income (as proxied by per capita weekly household expenditure), the number of adults in the household and the gender and age of the HOH. An examination of income elasticities of demand reveals that while bus use in non car-owning households is consistently classified as a necessity, income is insignificant in explaining variations in bus use in car-owning households in 1987 and 1994 and only marginally significant in 1999. Income is consistently positive and significant in explaining variations in taxi use in both samples and there is some evidence to show that taxis have changed from being necessities to being luxuries over the period 1987-1999, although this may be due to very low average rates of taxi expenditure in 1987. In addition, the income elasticities are higher for taxi use in car-owning households than in non car-owning households, maybe reflecting the fact that taxis are a close substitute for cars. Along with the higher elasticities of demand for taxi fare expenditure, the insignificance of income in explaining variations in per capita bus fares in car-owning households may suggest that factors other than income and price are more important in determining bus fare expenditure, particularly in car-owning households. This is consistent with data for the increase in bus passengers as a result of the introduction of Quality Bus Corridors on certain bus routes in the city over the last number of years [Dublin Bus (2002) and Madden (2001)].

There are significant differences between non car- and car-owning households in terms of the effect of the number of adults. The effect of the number of adults is highly elastic in car-owning households for both bus and taxi use, suggesting that competition for the household car induces some members to choose alternative forms of transport. The gender of the HOH indicates that even in households that own a car, bus use is higher for households that are headed by a single female, a result that has implications for encouraging people out of their cars. The fact that gender is generally insignificant in explaining variations in taxi use[121], while against initial expectations, is consistent with the results of the 1998 Oscar Faber survey on taxi use in the Dublin area. The effects of the age of the HOH on bus and taxi use are consistent with the expectation that younger households are more mobile and are engaged in more activities than older households. The following chapter, Chapter 7, uses a different data source to focus on the modal choice decisions of Dublin individuals for two specific journey purposes, namely, the journeys to work and school/college.

[121] It is significant in car-owning households in 1994.

Table 6.1 Likelihood Ratio Tests of Sample Division based on Household Car Ownership Status

	BUS USE				TAXI USE			
	1987	**1994**	**1999**	**POOL**	**1987**	**1994**	**1999**	**POOL**
Test Statistic	273.006	206.418	96.719	547.200	138.437	139.584	34.466	125.422
Critical Value	$\chi^2_{16,0.01}=$	$\chi^2_{16,0.01}=$	$\chi^2_{16,0.01}=$	$\chi^2_{16,0.01}=$	$\chi^2_{15,0.01}=$	$\chi^2_{15,0.01}=$	$\chi^2_{15,0.01}=$	$\chi^2_{15,0.01}=$
	32.000	32.000	32.000	32.000	30.580	30.580	30.580	30.580
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0

Note: H_0 = Full Sample, i.e., assuming common coefficients for the two sub-samples

H_1 = Division of full sample into two sub-samples of households owning no car and households owning one or more cars, i.e., assuming different coefficients for the two sub-samples

Table 6.2 Likelihood Ratio Tests of Homoscedastic Error Structure, Normal Error Structure and Homoscedastic and Normal Error Structure for Tobit Models of Bus Use

	1987 NO CAR	1987 CAR(S)	1987 ALL	1994 NO CAR	1994 CAR(S)	1994 ALL	1999 NO CAR	1999 CAR(S)	1999 ALL
Homoscedastic Errors*									
Test Statistic	146.194	107.256	279.792	103.834	45.922	172.848	38.960	40.880	82.736
Critical Value	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{2,0.01}$ = 9.210
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0
Normal Errors**									
Test Statistic	104.512	284.204	424.316	94.716	53.626	266.284	28.253	147.692	191.438
Critical Value	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0
Homoscedastic and Normal Errors***									
Test Statistic	172.736	324.388	523.048	146.764	124.718	330.298	56.057	178.462	254.294
Critical Value	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{3,0.01}$ = 11.345
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0

Notes: * H_0 = Homoscedastic Error Structure ($h = 0$); H_1 = Heteroscedastic Error Structure ($h \neq 0$)

** H_0 = Normal Error Structure ($\theta = 0$); H_1 = Non-Normal Error Structure ($\theta \neq 0$)

*** H_0 = Homoscedastic and Normal Error Structure ($h = 0$ and $\theta = 0$); H_1 = Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)

Table 6.3 Likelihood Ratio Tests of Homoscedastic Error Structure, Normal Error Structure and Homoscedastic and Normal Error Structure for Tobit Models of Taxi Use

	1987			1994			1999		
	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL
Homoscedastic Errors*									
Test Statistic	43.485	41.129	190.690	95.512	86.016	223.004	40.446	92.688	119.156
Critical Value	$\chi^2_{2,0.01}$ = 9.210	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{2,0.01}$ = 9.210	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{5,0.01}$ = 15.086
	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0
Normal Errors**									
Test Statistic	54.720	1.034	126.556	73.114	34.092	165.158	44.681	153.628	190.276
Critical Value	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635
	Reject H_0	Do not reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0
Homoscedastic and Normal Errors***									
Test Statistic	78.762		222.894	110.117	104.202	258.154	69.766	193.086	246.468
Critical Value	$\chi^2_{2,0.01}$ = 9.210		$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{5,0.01}$ = 15.086
	Reject H_0		Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0	Reject H_0

Notes: * H_0 = Homoscedastic Error Structure ($h = 0$); H_1 = Heteroscedastic Error Structure ($h \neq 0$)
** H_0 = Normal Error Structure ($\theta = 0$); H_1 = Non-Normal Error Structure ($\theta \neq 0$)
*** H_0 = Homoscedastic and Normal Error Structure ($h = 0$ and $\theta = 0$); H_1 = Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)

Table 6.4 Likelihood Ratio Specification Tests for Pooled Tobit Models of Bus Use

	NO CAR	CAR(S)	ALL
Year Dummies*			
Test Statistic	16.992	14.284	21.720
Critical Value	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{2,0.01} = 9.210$	$\chi^2_{2,0.01} = 9.210$
	Reject H_0	Reject H_0	Reject H_0
Year Dummies and Year Interactions**			
Test Statistic	61.960	66.028	75.642
Critical Value	$\chi^2_{34,0.01} = 56.061$	$\chi^2_{38,0.01} = 63.691$	$\chi^2_{40,0.01} = 63.691$
	Reject H_0	Reject H_0	Reject H_0
Year Dummies and Year Interactions (Best Fit)***			
Test Statistic	38.470	34.348	49.900
Critical Value	$\chi^2_{8,0.01} = 20.090$	$\chi^2_{10,0.01} = 23.209$	$\chi^2_{10,0.01} = 23.209$
	Reject H_0	Reject H_0	Reject H_0

Notes:
* H_0 = Tobit (5.11); H_1 = Tobit + Year Dummies (5.12)
** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (5.13)
*** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (Best Fit), i.e., with insignificant year interactions omitted (5.14)

Table 6.5 Likelihood Ratio Specification Tests for Pooled Tobit Models of Taxi Use

	NO CAR	CAR(S)	ALL
Year Dummies*			
Test Statistic	182.814	330.940	477.632
Critical Value	$\chi^2_{2,0.01}$ = 9.210	$\chi^2_{2,0.01}$ = 9.210	$\chi^2_{2,0.01}$ = 9.210
	Reject H_0	Reject H_0	Reject H_0
Year Dummies and Year Interactions**			
Test Statistic	50.426	52.046	55.948
Critical Value	$\chi^2_{32,0.01}$ = 53.486	$\chi^2_{37,0.01}$ = 59.893	$\chi^2_{36,0.01}$ =58.619
	Do not reject H_0 but reject at 5% & 10%	Do not reject H_0 but reject at 10%	Do not reject H_0 but reject at 5% & 10%
Year Dummies and Year Interactions (Best Fit)***			
Test Statistic	44.380	28.584	30.100
Critical Value	$\chi^2_{18,0.01}$ = 34.805	$\chi^2_{11,0.01}$ = 24.725	$\chi^2_{10,0.01}$ = 23.209
	Reject H_0	Reject H_0	Reject H_0

Notes:
* H_0 = Tobit (5.11); H_1 = Tobit + Year Dummies (5.12)
** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (5.13)
*** H_0 = Tobit + Year Dummies (5.12); H_1 = Tobit + Year Dummies + Year Interactions (Best Fit), i.e., with insignificant year interactions omitted (5.14)

Table 6.6 Likelihood Ratio of Homoscedastic Error Structure, Normal Error Structure and Homoscedastic and Normal Error Structure for Pooled Tobit Models of Bus Use

	NO CAR	CAR(S)	ALL
Homoscedastic Errors*			
Test Statistic	244.442	164.884	499.872
Critical Value	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{3,0.01} = 11.345$
	Reject H_0	Reject H_0	Reject H_0
Normal Errors**			
Test Statistic	255.580	459.716	845.836
Critical Value	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$	$\chi^2_{1,0.01} = 6.635$
	Reject H_0	Reject H_0	Reject H_0
Homoscedastic and Normal Errors***			
Test Statistic	368.576	559.980	1051.064
Critical Value	$\chi^2_{4,0.01} = 13.277$	$\chi^2_{3,0.01} = 11.345$	$\chi^2_{4,0.01} = 13.277$
	Reject H_0	Reject H_0	Reject H_0

Notes: * H_0 = Best Fit + Homoscedastic Error Structure ($h = 0$); H_1 = Best Fit + Heteroscedastic Error Structure ($h \neq 0$)

** H_0 = Best Fit + Normal Error Structure ($\theta = 0$); H_1 = Best Fit + Non-Normal Error Structure ($\theta \neq 0$)

*** Best Fit + Homoscedastic and Normal Error Structure ($h = 0$ and $\theta = 0$); H_1 = Best Fit + Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)

Table 6.7 Likelihood Ratio Tests of Homoscedastic Error Structure, Normal Error Structure and Homoscedastic and Normal Error Structure for Pooled Tobit Models of Taxi Use

	NO CAR	CAR(S)	ALL
Homoscedastic Errors*			
Test Statistic	171.974	171.698	366.608
Critical Value	$\chi^2_{3,0.01}$ = 11.345	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{5,0.01}$ = 15.086
	Reject H_0	Reject H_0	Reject H_0
Normal Errors**			
Test Statistic	192.504	276.586	494.190
Critical Value	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635	$\chi^2_{1,0.01}$ = 6.635
	Reject H_0	Reject H_0	Reject H_0
Homoscedastic and Normal Errors***			
Test Statistic	285.108	427.946	732.494
Critical Value	$\chi^2_{4,0.01}$ = 13.277	$\chi^2_{5,0.01}$ = 15.086	$\chi^2_{6,0.01}$ = 16.812
	Reject H_0	Reject H_0	Reject H_0

Notes: * H_0 = Best Fit + Homoscedastic Error Structure (h = 0); H_1 = Best Fit + Heteroscedastic Error Structure ($h \neq 0$)

** H_0 = Best Fit + Normal Error Structure (θ = 0); H_1 = Best Fit + Non-Normal Error Structure ($\theta \neq 0$)

*** Best Fit + Homoscedastic and Normal Error Structure (h =0 and θ = 0); H_1 = Best Fit + Heteroscedastic and Non-Normal Error Structure ($h \neq 0$ and $\theta \neq 0$)

Table 6.8 Estimated Coefficients from Tobit Models of Bus Use

VARIABLE	1987 NO CAR	1987 CAR(S)	1987 ALL	1994 NO CAR	1994 CAR(S)	1994 ALL	1999 NO CAR	1999 CAR(S)	1999 ALL
Constant	-4.424	-3.460	-3.842	-5.712	-3.958	-4.919	-6.260	-9.400	-8.453
	(1.018)***	(0.685)***	(0.604)***	(1.561)***	(1.141)***	(0.910)***	(2.464)**	(1.740)***	(1.397)***
HHEXP	1.830	0.535	2.255	3.939	0.026	2.498	3.186	1.334	1.983
	(0.295)***	(0.181)***	(0.373)***	(0.675)***	(0.088)	(0.469)***	(0.716)***	(0.340)***	(0.325)***
$HHEXP^2$	-0.165	-0.064	-0.529	-0.671		-0.556	-0.311	-0.136	-0.204
	(0.045)***	(0.026)**	(0.114)***	(0.141)***		(0.123)***	(0.083)***	(0.035)***	(0.035)***
$HHEXP^3$			0.037			0.031			
			(0.010)***			(0.009)***			
ADULTS	2.093	1.796	1.938	2.912	3.277	3.121	1.752	6.117	4.988
	(0.385)***	(0.275)***	(0.243)***	(0.764)***	(0.485)***	(0.441)***	(0.403)***	(0.730)***	(0.657)***
$ADULTS^2$	-0.239	-0.155	-0.175	-0.259	-0.221	-0.197		-0.569	-0.417
	(0.058)***	(0.038)***	(0.035)***	(0.131)**	(0.074)***	(0.071)***		(0.107)***	(0.102)***
CHILDREN	-0.092	-0.009	-0.231	-0.022	-0.012	0.004	-0.353	0.058	-0.117
	(0.076)	(0.051)	(0.098)**	(0.150)	(0.088)	(0.087)	(0.366)	(0.152)	(0.150)
$CHILD^2$			0.038						
			(0.017)**						
APART	0.679	0.790	0.395	0.456	-0.618	0.560	0.163	0.850	0.786
	(0.639)	(0.322)**	(0.258)	(0.947)	(0.469)	(0.397)	(1.746)	(0.791)	(0.657)
SEMI	0.651	0.121	-0.009	0.262	-0.006	0.079	0.648	0.372	0.259
	(0.615)	(0.165)	(0.201)	(0.907)	(0.260)	(0.312)	(1.646)	(0.418)	(0.458)
WORKING	0.724	0.479	0.674	1.660	0.865	1.236	3.105	1.137	2.276
	(0.216)***	(0.202)**	(0.152)***	(0.384)***	(0.321) ***	(0.254)***	(0.822)***	(0.585)*	(0.471)***
SINGLE FEMALE	0.415	-0.497	0.424	1.417	1.505	1.598	0.308	3.234	2.095
	(0.289)	(0.366)	(0.210)**	(0.479)***	(0.432)***	(0.322)***	(0.800)	(0.672)***	(0.522)***
THIRTY	-0.693	-0.551	-0.959	-0.616	-1.118	-1.486	-1.740	-1.656	-1.975
	(0.344)**	(0.413)	(0.257)***	(0.538)	(0.781)	(0.390)***	(1.227)	(0.995)*	(0.737)***
FORTY	-0.865	-0.413	-1.014	-0.989	-0.726	-1.533	-1.881	-1.537	-1.831
	(0.384)**	(0.418)	(0.271)***	(0.603)*	(0.780)	(0.407)***	(1.383)	(0.995)	(0.759)**
FIFTY	-0.777	0.132	-0.577	-0.375	-0.655	-1.030	-0.315	-0.912	-0.787
	(0.392)**	(0.419)	(0.273)**	(0.644)	(0.788)	(0.417)**	(1.379)	(0.972)	(0.738)

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 6.8 continued

VARIABLE		1987			1994			1999	
	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL
SIXTY	-1.047	-0.416	-1.073	-2.178	-0.861	-1.875	-3.745	-1.407	-2.025
	(0.383)***	(0.422)	(0.273)***	(0.642)***	(0.796)	(0.420)***	(1.417)***	(0.973)	(0.752)***
PRIMARY	0.390	0.640	0.556	-1.193	-0.394	-0.732	-0.226	-0.938	-0.971
	(0.381)	(0.176)***	(0.185)***	(0.575)**	(0.306)	(0.298)**	(1.092)	(0.461)**	(0.442)**
SECONDARY	0.556	0.307	0.500	-0.779	-0.185	-0.249	0.523	-0.639	-0.439
	(0.359)	(0.141)**	(0.160)***	(0.539)	(0.219)	(0.242)	(0.974)	(0.327)*	(0.342)
FREETRAV	-1.932	-0.766	-1.445	-2.381	-1.350	-1.952	-2.647	-1.618	-2.123
	(0.213)***	(0.149)***	(0.135)***	(0.379)***	(0.242)	(0.228)***	(0.754)***	(0.348)***	(0.337)***
MOTOR	0.247	-0.666	-0.542	-2.249	-0.192	-0.869	-3.428	-1.209	-1.748
	(0.635)	(0.280)**	(0.302)*	(1.105)**	(0.566)***	(0.585)	(1.360)**	(0.556)**	(0.568)***
EXPENSES		-0.091	-0.150		-0.614	-0.832		-0.494	-0.688
		(0.132)	(0.172)		(0.230)***	(0.289)***		(0.347)	(0.401)*
CARS		-0.677	-1.487		-1.213	-2.329		-2.603	-3.363
		(0.130)***	(0.103)***		(0.214)***	(0.176)***		(0.312)***	(0.254)***
σ	2.367	1.547	2.077	4.078	2.673	3.524	5.958	4.196	4.919
	(0.073)***	(0.046)***	(0.044)***	(0.131)***	(0.081)***	(0.077)***	(0.278)***	(0.131)***	(0.128)***
Number of Observations	979	1,117	2,096	950	1,198	2,148	577	1,212	1,789
Log-Likelihood	-1552.011	-1441.901	-3123.052	-1711.631	-1785.568	-3599.320	-963.037	-1974.280	-2987.169
Het Log-Likelihood	-1478.914	-1388.273	-2983.156	-1659.714	-1762.607	-3434.171	-943.557	-1953.840	-2945.801
IHS Log-Likelihood	-1499.755	-1299.799	-2910.894	-1664.273	-1758.755	-3466.178	-948.910	-1900.434	-2891.450
IHS Het Log-Likelihood	-1465.643	-1279.707	-2861.528	-1638.249	-1723.209	-3434.171	-935.008	-1885.049	-2860.022
Elasticities:									
HHEXP	0.784***	0.394***	0.769***	0.672***	0.026	0.478***	0.570***	0.399***	0.526***
ADULTS	0.903***	1.812***	1.306***	0.817***	1.993***	1.375***	0.451***	2.171***	1.492***
CHILDREN	-0.039	-0.009	-0.087**	-0.004	-0.005	0.001	-0.027	0.014	-0.020
CARS		-0.597***	-0.499***		-0.592***	-0.477***		-0.970***	-0.694***

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.9 Estimated Coefficients from Tobit Models of Taxi Use

VARIABLE	1987			1994			1999		
	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL
Constant	-13.843	-8.634	-13.033	-21.227	-14.477	-20.602	-26.367	-16.593	-18.649
	(2.956)***	(1.480)***	(1.716)***	(3.700)***	(3.106)***	(1.908)***	(4.282)***	(2.481)***	(1.911)***
HHEXP	4.434	1.663	3.371	5.549	3.547	5.878	9.063	2.348	3.890
	(1.006)***	(0.424)***	(0.570)***	(0.497)***	(0.722)***	(0.709)***	(1.063)***	(0.519)***	(0.513)***
$HHEXP^2$	-0.439	-0.178	-0.379		-0.308	-0.487	-0.741	-0.103	-0.242
	(0.149)***	(0.062)***	(0.085)***		(0.090)***	(0.093)***	(0.113)***	(0.046)**	(0.049)***
ADULTS	1.578	2.741	2.885	2.302	5.453	3.490	6.809	3.962	3.500
	(0.332)***	(0.563)***	(0.657)***	(0.525)***	(1.247)***	(0.309)***	(2.091)***	(0.350)***	(0.295)***
$ADULTS^2$		-0.242	-0.183		-0.331		-0.925		
		(0.072)***	(0.087)**		(0.179)*		(0.356)***		
CHILDREN	-0.179	0.103	-0.043	0.544	0.183	0.510	1.233	-0.067	0.093
	(0.280)	(0.106)	(0.145)	(0.380)	(0.253)	(0.238)**	(0.523)***	(0.287)	(0.253)
APART	1.794	-0.386	0.963	3.912	1.558	2.723	-0.213	3.436	2.096
	(2.117)	(0.756)	(0.752)	(2.946)	(1.194)	(1.086)**	(2.323)	(1.390)**	(1.069)**
SEMI	1.174	0.089	-0.017	4.202	1.258	1.965	-0.445	0.451	0.337
	(2.022)	(0.336)	(0.580)	(2.833)	(0.718)*	(0.865)**	(2.177)	(0.774)	(0.739)
WORKING	1.055	0.423	0.981	2.985	1.524	2.621	1.567	3.966	4.073
	(0.750)	(0.462)	(0.463)**	(0.918)***	(0.918)*	(0.668)***	(1.150)	(1.070)***	(0.767)***
SINGLE FEMALE	0.091	1.530	1.262	2.304	3.966	3.454	2.160	2.166	2.080
	(0.857)	(0.732)**	(0.652)*	(1.083)**	(1.166)***	(0.744)***	(1.358)	(1.053)**	(0.757)***
THIRTY	-1.581	-2.291	-2.267	-2.372	-6.189	-3.063	-1.774	-1.906	-1.634
	(1.020)	(0.721)***	(0.672)***	(1.280)*	(1.703)***	(0.964)***	(1.673)	(1.767)	(1.192)
FORTY	-1.793	-2.213	-2.223	-4.143	-7.773	-5.332	-2.614	-3.545	-2.979
	(1.228)	(0.731)***	(0.731)***	(1.502)***	(1.726)***	(1.043)***	(1.930)	(1.779)**	(1.236)**
FIFTY	-0.355	-1.586	-1.121	-4.097	-7.336	-4.314	-2.379	-3.822	-2.929
	(1.155)	(0.713)**	(0.696)*	(1.584)***	(1.745)***	(1.041)***	(1.891)	(1.741)**	(1.196)**
SIXTY	-3.813	-1.976	-2.803	-7.809	-9.014	-6.758	-1.761	-3.644	-2.824
	(1.156)***	(0.707)***	(0.690)***	(1.550)***	(1.769)***	(1.033)***	(1.859)	(1.723)**	(1.189)**

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 6.9 continued

VARIABLE	1987			1994			1999		
	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL	NO CAR	CAR(S)	ALL
PRIMARY	-1.164	0.809	0.432	0.695	1.008	1.170	1.276	1.254	1.459
	(1.133)	(0.359)**	(0.526)	(1.437)	(0.810)	(0.786)	(1.560)	(0.851)	(0.733)**
SECONDARY	-0.541	0.386	0.363	0.352	-0.246	0.608	0.502	0.519	0.752
	(1.024)	(0.295)	(0.447)	(1.286)	(0.581)	(0.621)	(1.383)	(0.607)	(0.561)
MOTOR	-0.101	-1.551	-1.950	0.065	0.962	1.108	-1.483	-0.392	-0.314
	(2.060)	(0.675)**	(0.965)**	(2.696)	(1.340)	(1.402)	(1.694)	(0.920)	(0.830)
EXPENSES		0.112	-0.098		0.094	-0.629		-0.085	-0.274
		(0.266)	(0.492)		(0.588)	(0.723)		(0.633)	(0.639)
CARS		-0.636	-1.835		-2.069	-3.878		-2.320	-2.966
		(0.251)**	(0.295)***		(0.555)***	(0.464)***		(0.565)***	(0.408)***
σ	5.216	2.078	4.016	8.365	5.824	7.600	7.355	7.345	7.545
	(0.355)***	(0.140)***	(0.190)***	(0.416)***	(0.276)***	(0.260)***	(0.428)***	(0.267)***	(0.233)***
Number of Observations	890	1,117	2,096	950	1,198	2,148	577	1,212	1,789
Log-Likelihood	-592.387	-521.933	-1185.942	-1053.625	-1206.440	-2320.783	-713.021	-1871.223	-2615.945
Het Log-Likelihood	-570.644	-501.364	-1090.577	-1005.869	-1163.432	-2209.281	-692.798	-1824.879	-2556.367
IHS Log-Likelihood	-565.027	-521.416	-1122.644	-1017.068	-1189.394	-2238.304	-690.681	-1794.409	-2520.807
IHS Het Log-Likelihood	-553.006		-1074.475	-998.567	-1154.339	-2191.706	-678.138	-1774.680	-2492.711
Elasticities:									
HHEXP	1.030***	0.966***	1.228***	0.929***	1.058***	1.278***	1.381***	0.958***	1.144***
ADULTS	0.663***	1.880***	1.491***	0.504***	1.848***	1.131***	0.774***	1.569***	1.168***
CHILDREN	-0.042	0.075	-0.018	0.057	0.042	0.080**	0.074***	-0.011	0.012
CARS		-0.388**	-0.398***		-0.541***	-0.438***		-0.626***	-0.449***

Notes: (i) Standard Errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.10 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Bus Use (No Car Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-1.974	0.390	-2.051	0.872	-2.619	1.806
	(0.312)***	(0.097)***	(0.762)***	(0.112)***	(0.883)***	(0.132)***
HHEXP	0.870	0.163	1.155	0.218	0.798	
	(0.035)***	(0.047)***	(0.296)***	(0.056)***	(0.250)***	
ADULTS	0.657		0.839	-0.071	0.269	-0.138
	(0.030)***		(0.269)***	(0.034)**	(0.202)	(0.060)**
CHILDREN	-0.142	-0.122	-0.054	-0.056	-0.391	-0.187
	(0.001)***	(0.021)***	(0.059)	(0.022)*	(0.134)***	(0.043)***
APART	0.040		0.083		0.415	
	(0.118)		(0.498)		(0.642)	
SEMI	0.181		0.119		0.534	
	(0.110)		(0.481)		(0.616)	
WORKING	0.191		0.766		1.220	
	(0.009)**		(0.145)***		(0.273)***	
SINGLE FEMALE	0.326		0.631		-0.031	
	(0.022)**		(0.221)***		(0.293)	
THIRTY	-0.271		-0.239		-0.505	
	(0.033)		(0.262)		(0.445)	
FORTY	-0.309		-0.466		-0.640	
	(0.036)*		(0.290)*		(0.480)	
FIFTY	-0.403		-0.315		-0.288	
	(0.039)**		(0.316)		(0.472)	
SIXTY	-0.730		-1.114		-1.479	
	(0.044)***		(0.324)***		(0.519)***	
PRIMARY	0.112		-0.777		0.017	
	(0.050)		(0.277)***		(0.339)	
SECOND	0.179		-0.581		0.370	
	(0.045)		(0.271)**		(0.321)	
FREETRAV	-0.941	0.121	-0.902		-0.833	
	(0.014)***	(0.066)*	(0.145)***		(0.261)***	
MOTOR	0.112		-2.341	-1.128	-1.153	
	(0.048)		(0.435)***	(0.251)***	(1.246)	
θ	0.270		0.211		0.132	
	(0.049)***		(0.033)***		(0.035)***	
Observations	979		950		577	
Non-linear terms	$HHEXP^2$, $ADULTS^2$		$HHEXP^2$, $ADULTS^2$		$HHEXP^2$	
Log-Likelihood	-1465.643		-1638.249		-935.008	
Elasticities:						
HHEXP	0.877***		0.686***		0.527***	
ADULTS	0.856***		0.652***		0.172	
CHILDREN	-0.104***		-0.020		-0.074***	

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.11 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Bus Use (One or More Cars Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-1.573	0.185	-2.344	0.800	-3.924	1.287
	(0.295)***	(0.114)*	(0.515)***	(0.082)***	(0.686)***	(0.107)***
HHEXP	0.098		0.015		0.189	
	(0.063)		(0.040)		(0.114)*	
ADULTS	0.491	-0.062	1.001	-0.073	1.091	-0.164
	(0.097)***	(0.023)***	(0.192)***	(0.026)***	(0.237)***	(0.034)***
CHILDREN	-0.030	-0.108	-0.074	-0.099	-0.024	-0.049
	(0.022)	(0.021)***	(0.036)**	(0.020)***	(0.059)	(0.023)**
APART	0.363		-0.210		0.336	
	(0.138)**		(0.214)		(0.302)	
SEMI	-0.001		0.012		0.077	
	(0.065)		(0.110)		(0.151)	
WORKING	0.164		0.351		0.517	
	(0.080)**		(0.139) ***		(0.221)***	
SINGLE FEMALE	-0.180		0.932		1.406	
	(0.163)		(0.203)***		(0.290)***	
THIRTY	-0.311		-0.305		-0.529	
	(0.183)*		(0.323)		(0.384)	
FORTY	-0.217		-0.106		-0.508	
	(0.184)		(0.320)		(0.384)	
FIFTY	-0.052		-0.083		-0.306	
	(0.185)		(0.324)		(0.373)	
SIXTY	-0.227		-0.251		-0.502	
	(0.184)		(0.325)		(0.375)	
PRIMARY	0.299		-0.127		-0.212	
	(0.071)***		(0.133)		(0.160)	
SECOND	0.143		-0.087		-0.182	
	(0.058)**		(0.096)		(0.120)	
FREETRAV	-0.370		-0.556		-0.637	
	(0.066)***		(0.114) ***		(0.135)***	
MOTOR	-0.195		-0.063		-0.360	
	(0.125)		(0.192)		(0.168)**	
EXPENSES	-0.066		-0.251		-0.227	
	(0.054)		(0.101)***		(0.120)**	
CARS	-0.328	-0.147	-0.472		-0.915	
	(0.064)***	(0.069)**	(0.101)***		(0.124)***	
θ	1.142		0.454		0.390	
	(0.135)***		(0.065)***		(0.050)***	
Observations	1,117		1,198		1,212	
Non-linear terms	$HHEXP^2$, $ADULTS^2$		$ADULTS^2$		$HHEXP^2$, $ADULTS^2$	
Log-Likelihood	-1279.707		-1723.209		-1885.049	
Elasticities:						
HHEXP	0.329		0.032		0.389*	
ADULTS	1.637***		1.794***		1.562***	
CHILDREN	-0.062		-0.065**		-0.014	
CARS	-0.567***		-0.479***		-0.798***	

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.12 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Bus Use (Full Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-1.652	0.259	-2.232	1.010	-3.659	1.508
	(0.280)***	(0.079)***	(0.390)***	(0.061)***	(0.611)***	(0.080)***
HHEXP	0.311	0.075	0.271		0.306	
	(0.131)**	(0.026)***	(0.151)*		(0.107)***	
ADULTS	0.626	-0.034	1.055	-0.058	0.924	-0.175
	(0.092)***	(0.018)*	(0.156)***	(0.021)***	(0.219)***	(0.026)***
CHILDREN	-0.062	-0.079	-0.092	-0.100	-0.116	-0.077
	(0.029)**	(0.015)***	(0.035)***	(0.014)***	(0.052)**	(0.019)***
APART	0.116		0.208		0.315	
	(0.109)		(0.165)		(0.235)	
SEMI	-0.045		0.034		0.033	
	(0.077)		(0.124)		(0.150)	
WORKING	0.178		0.489		0.890	
	(0.064)***		(0.102)***		(0.187)***	
SINGLE FEMALE	0.284		0.980		0.877	
	(0.100)**		(0.147)***		(0.217)***	
THIRTY	-0.432		-0.577		-0.542	
	(0.132)***		(0.186)***		(0.269)**	
FORTY	-0.408		-0.600		-0.561	
	(0.136)***		(0.191)***		(0.276)**	
FIFTY	-0.290		-0.472		-0.269	
	(0.139)**		(0.195)***		(0.264)	
SIXTY	-0.531		-0.870		-0.647	
	(0.179)***		(0.206)***		(0.274)**	
PRIMARY	0.277		-0.265		-0.236	
	(0.079)***		(0.124)**		(0.139)*	
SECOND	0.211		-0.124		-0.074	
	(0.069)***		(0.101)		(0.114)	
FREETRAV	-0.623		-0.759		-0.712	
	(0.060)***		(0.093)***		(0.126)***	
MOTOR	-0.217		-0.207		-0.476	
	(0.126)*		(0.205)		(0.157)***	
EXPENSES	-0.115		-0.322		-0.448	
	(0.069)*		(0.013)***		(0.125)**	
CARS	-0.654	-0.226	-0.909	-0.081	-1.028	
	(0.117)***	(0.062)***	(0.085)***	(0.034)**	(0.117)***	
θ	0.696		0.358		0.286	
	(0.062)***		(0.036)***		(0.031)***	
Observations	2,096		2,148		1,789	
Non-linear terms	$HHEXP^2$, $ADULTS^2$		$HHEXP^2$, $HHEXP^3$, $ADULTS^2$		$HHEXP^2$, $ADULTS^2$	
Log-Likelihood	-2861.528		-3434.171		-2860.022	
Elasticities:						
HHEXP	0.578**		0.324*		0.444***	
ADULTS	1.277***		1.260***		1.005***	
CHILDREN	-0.075**		-0.053***		-0.047**	
CARS	-0.409***		-0.378***		-0.508***	

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.13 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Taxi Use (No Car Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-0.902	1.498	-2.293	1.754	-4.844	2.065
	(0.239)***	(0.160)***	(0.547)***	(0.144)***	(0.945)***	(0.141)***
HHEXP	0.200		0.968	0.179	1.143	
	(0.066)***		(0.157)***	(0.063)***	(0.232)***	
ADULTS	-0.030	-0.205	0.055	-0.163	0.316	-0.220
	(0.934)	(0.045)***	(0.084)	(0.040)***	(0.283)	(0.048)***
CHILDREN	-0.010		-0.041	-0.087	0.082	-0.111
	(0.018)		(0.067)	(0.042)**	(0.108)	(0.063)*
APART	0.080		0.067		0.076	
	(0.155)		(0.309)		(0.373)	
SEMI	0.052		0.307		0.094	
	(0.148)		(0.291)		(0.330)	
WORKING	0.091		0.352		0.188	
	(0.049)*		(0.119)***		(0.194)	
SINGLE FEMALE	-0.079		0.123		0.182	
	(0.070)		(0.156)		(0.255)	
THIRTY	-0.097		-0.234		0.046	
	(0.070)*		(0.183)		(0.295)	
FORTY	-0.115		-0.387		-0.281	
	(0.085)*		(0.200)**		(0.307)	
FIFTY	-0.024		-0.392		-0.127	
	(0.071)		(0.212)**		(0.306)	
SIXTY	-0.218		-0.966		-0.156	
	(0.083)***		(0.241)***		(0.289)	
PRIMARY	-0.022		0.066		0.195	
	(0.078)		(0.217)		(0.232)	
SECOND	0.018		0.048		0.067	
	(0.073)		(0.200)		(0.208)	
MOTOR	0.033		0.059		-0.140	
	(0.126)		(0.357)		(0.298)	
θ	0.369		0.105		0.120	
	(0.105)** *		(0.029)***		(0.032)***	
Observations	890		950		577	
Non-linear terms	$HHEXP^2$				$HHEXP^2$, $ADULTS^2$	
Log-Likelihood	553.006		-998.567		-678.138	
Elasticities:						
HHEXP	0.780***		0.935***		1.125***	
ADULTS	-0.151		0.069		0.301	
CHILDREN	-0.029		-0.025		0.023	

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.14 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Taxi Use (One or More Cars Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-0.658	2.038	-3.132	1.918	-4.101	1.601
	(0.133)***	(0.244)***	(0.619)***	(0.194)***	(0.745)***	(0.137)***
HHEXP	0.060		0.401	0.127	0.483	0.056
	(0.026)**		(0.383)	(0.048)***	(0.168)***	(0.023)**
ADULTS	0.054	-0.234	0.472	-0.196	0.732	-0.109
	(0.033)*	(0.050)***	(0.440)	(0.040)***	(0.147)***	(0.026)***
CHILDREN	-0.089	-0.098	0.021		-0.111	-0.087
	(0.028)***	(0.032)***	(0.037)		(0.084)	(0.032)***
APART	-0.079		0.339		0.516	
	(0.066)		(0.201)		(0.429)	
SEMI	-0.004		0.167		-0.087	
	(0.017)		(0.107)*		(0.187)	
WORKING	0.052		0.276		1.047	
	(0.039)		(0.149)**		(0.342)***	
SINGLE FEMALE	-0.010		0.634		0.368	
	(0.089)		(0.226)**		(0.308)	
THIRTY	-0.268		-0.539		-0.482	
	(0.066)***		(0.311)**		(0.513)	
FORTY	-0.238		-0.753		-0.993	
	(0.057)***		(0.318)***		(0.508)**	
FIFTY	-0.199		-0.607		-0.912	
	(0.050)***		(0.316)***		(0.507)**	
SIXTY	-0.225		-0.810		-0.920	
	(0.053)***		(0.321)***		(0.502)**	
PRIMARY	0.059		0.151		0.353	
	(0.022)**		(0.112)		(0.209)	
SECOND	0.025		0.030		0.135	
	(0.019)		(0.092)		(0.165)	
MOTOR	-0.065		0.128		-0.023	
	(0.041)		(0.152)		(0.274)	
EXPENSES	-0.003		-0.050		-0.055	
	(0.016)		(0.085)		(0.157)	
CARS	-0.108	-0.379	-0.425	-0.203	-0.536	
	(0.033)***	(0.122)***	(0.562)	(0.097)**	(0.143)***	
θ			0.137		0.196	
			(0.039)***		(0.029)***	
Observations	1,117		1,198		1,212	
Non-linear terms	$HHEXP^2$, $ADULTS^2$		$HHEXP^2$, $ADULTS^2$		$HHEXP^2$	
Log-Likelihood	-501.364		-1154.339		-1774.680	
Elasticities:						
HHEXP	0.829**		1.143		0.870***	
ADULTS	0.741*		1.174		0.916***	
CHILDREN	-0.756***		0.025		-0.003	
CARS	-0.775***		-0.599		-0.409***	

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.15 Marginal Effects for Heteroscedastic and Non-Normal Tobit Models of Taxi Use (Full Sample)

VARIABLE	1987	HETERO. TERMS	1994	HETERO. TERMS	1999	HETERO. TERMS
Constant	-0.827	1.550	-2.491	1.641	-4.209	1.685
	(0.131)***	(0.137)***	(0.318)***	(0.105)***	(0.532)***	(0.100)***
HHEXP	0.117	0.069	0.664	0.199	0.686	0.071
	(0.031)***	(0.034)**	(0.115)***	(0.039)***	(0.132)***	(0.020)***
ADULTS	0.058	-0.226	0.249	-0.128	0.582	-0.104
	(0.028)**	(0.030)***	(0.054)***	(0.022)***	(0.098)***	(0.025)***
CHILDREN	0.006		0.037		-0.049	-0.079
	(0.006)		(0.030)		(0.059)	(0.027)***
APART	0.012		0.214		0.243	
	(0.038)		(0.145)		(0.270)	
SEMI	-0.011		0.210		-0.084	
	(0.020)		(0.104)**		(0.152)	
WORKING	0.072		0.357		0.946	
	(0.029)***		(0.097)***		(0.209)***	
SINGLE FEMALE	0.021		0.277		0.316	
	(0.047)		(0.119)**		(0.197)	
THIRTY	-0.147		-0.382		-0.335	
	(0.048)***		(0.144)***		(0.318)	
FORTY	-0.141		-0.553		-0.731	
	(0.046)***		(0.160)***		(0.317)***	
FIFTY	-0.103		-0.420		-0.641	
	(0.039)***		(0.153)***		(0.313)**	
SIXTY	-0.168		-0.735		-0.678	
	(0.042)***		(0.161)***		(0.312)**	
PRIMARY	0.060		0.091		0.408	
	(0.022)**		(0.102)		(0.160)**	
SECOND	0.031		0.054		0.213	
	(0.022)		(0.085)		(0.135)*	
MOTOR	-0.088		0.144		-0.005	
	(0.024)***		(0.172)		(0.223)	
EXPENSES	-0.003		-0.122		-0.092	
	(0.029)		(0.087)		(0.136)	
CARS	-0.162	-0.327	-0.640	-0.276	-0.721	-0.076
	(0.023)***	(0.057)***	(0.079)***	(0.047)***	(0.104)***	(0.038)**
θ	0.313		0.116		0.167	
	(0.074)***		(0.022)***		(0.022)***	
Observations	2,096		2,148		1,789	
Non-linear terms	$HHEXP^2$, $ADULTS^2$		$HHEXP^2$		$HHEXP^2$	
Log-Likelihood	-1074.475		-2191.706		-2492.711	
Elasticities:						
HHEXP	0.864***		1.252***		1.060***	
ADULTS	0.473**		0.452***		0.674***	
CHILDREN	0.031		0.033		-0.021	
CARS	-0.402***		-0.405***		-0.379***	

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) The calculation of elasticities incorporates non-linear terms.
(iv) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.16 Bus Use Elasticities of Demand at 1994 Sample Means[122]

	HHEXP	ADULTS	CHILDREN	CARS
NO CAR				
1987	0.517***	0.511***	-0.053***	
1994	0.686***	0.652***	-0.020	
1999	0.474***	0.209	-0.145***	
CAR(S)				
1987	0.201	0.879***	-0.026	-0.333***
1994	0.032	1.794***	-0.065**	-0.479***
1999	0.388*	1.957***	-0.024	-0.892***
FULL SAMPLE				
1987	0.371**	0.747***	-0.036**	-0.272***
1994	0.324*	1.260***	-0.053***	-0.378***
1999	0.365***	1.103***	-0.067**	-0.428***

Notes: (i) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(ii) The calculation of elasticities incorporates non-linear terms.
(iii) The significance levels of elasticities are those of the underlying marginal effects.

Table 6.17 Taxi Use Elasticities of Demand at 1994 Sample Means[121]

	HHEXP	ADULTS	CHILDREN	CARS
NO CAR				
1987	0.193***	-0.038	-0.006	
1994	0.935***	0.069	-0.025	
1999	1.104***	0.399	0.050	
CAR(S)				
1987	0.170**	0.134*	-0.108***	-0.153***
1994	1.143	1.174	0.025	-0.599
1999	1.376***	1.821***	-0.135	-0.755***
FULL SAMPLE				
1987	0.212***	0.106**	0.006	-0.102***
1994	1.252***	0.452***	0.033	-0.405***
1999	1.241***	1.055***	-0.043	-0.456***

Notes: (i) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(ii) The calculation of elasticities incorporates non-linear terms.
(iii) The significance levels of elasticities are those of the underlying marginal effects.

[122] In contrast to the elasticities reported in Tables 6.8 to 6.15 inclusive, which are calculated using the sample means of the year in question, the elasticties reported in Tables 6.16 and 6.17 are calculated using the 1994 sample means to enable more accurate comparisons over the period 1987-1999.

Table 6.18 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Bus Use (No Car Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-1.681	-2.899	-1.738	1.025
	(0.785)**	(0.764)***	(0.740)**	(0.065)***
HHEXP	-1.041	3.128	-0.606	0.104
	(0.633)*	(0.570)***	(0.700)	(0.031)***
$HHEXP^2$	0.557	-0.771	0.439	
	(0.191)***	(0.181)***	(0.206)**	
ADULTS		2.130		-0.057
		(0.252)***		(0.019)***
$ADULTS^2$		-0.214		
		(0.037)***		
CHILDREN		-0.021		-0.111
		(0.041)		(0.013)***
APART		0.355		
		(0.430)		
SEMI		0.528		
		(0.413)		
WORKING		0.842		
		(0.134)***		
SINGLE FEMALE		0.688		
		(0.196)***		
THIRTY		-0.541		
		(0.247)**		
FORTY		-0.739		
		(0.266)***		
FIFTY		-0.674		
		(0.275)**		
SIXTY		-1.774		
		(0.290)***		
PRIMARY	1.378	-1.138	1.200	
	(0.594)**	(0.347)***	(0.510)**	
SECOND	1.291	-0.906	1.282	
	(0.589)**	(0.337)***	(0.507)**	
FREETRAV		-1.474		
		(0.125)***		
MOTOR		-1.019		
		(0.426)**		
θ		0.220		
		(0.022)***		
Number of Observations		2,506		
Log-Likelihood		-4407.835		
IHS Het Tobit Log-Likelihood		-4223.547		

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 6.19 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Bus Use (One or More Cars Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-0.457 (0.213)**	-3.449 (0.394)***	-0.196 (0.194)	0.763 (0.050)***
HHEXP		0.452 (0.092)***		
$HHEXP^2$		-0.059 (0.013)***		
ADULTS		2.322 (0.141)***		-0.096 (0.014)***
$ADULTS^2$		-0.208 (0.018)***		
CHILDREN		0.081 (0.026)***		-0.100 (0.012)***
APART	0.917 (0.415)**	-0.413 (0.275)	0.737 (0.380)*	
SEMI	-0.142 (0.212)	0.071 (0.143)	0.050 (0.199)	
WORKING		0.490 (0.110)***		
SINGLE FEMALE	-1.031 (0.414)**	0.849 (0.219)***	0.294 (0.262)	
THIRTY		-0.625 (0.244)**		
FORTY		-0.398 (0.244)*		
FIFTY		-0.230 (0.242)		
SIXTY		-0.513 (0.245)**		
PRIMARY	0.433 (0.218)**	-0.034 (0.164)	-0.132 (0.209)	
SECOND	0.293 (0.181)*	-0.047 (0.121)	-0.114 (0.159)	
FREETRAV		-0.723 (0.081)***		
MOTOR		-0.307 (0.119)***		
EXPENSES		-0.237 (0.073)***		
CARS		-0.718 (0.070)***		
θ		0.563 (0.040)***		
Number of Observations		3,527		
Log-Likelihood		-5333.221		
IHS Het Tobit Log-Likelihood		-5053.231		

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 6.20 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Bus Use (Full Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-0.830 (0.279)***	-3.030 (0.339)***	-0.605 (0.275)**	0.992 (0.038)***
HHEXP	0.360 (0.073)***	1.236 (0.153)***	0.239 (0.074)***	
$HHEXP^2$		-0.322 (0.041)***		
$HHEXP^3$		0.019 (0.003)***		
ADULTS	-0.295 (0.061)***	2.283 (0.131)***	-0.064 (0.073)	-0.078 (0.012)***
$ADULTS^2$		-0.176 (0.017)***		
CHILDREN		0.063 (0.044)		-0.100 (0.008)***
$CHILD^2$		-0.003 (0.006)		
APART		0.257 (0.135)*		
SEMI		0.016 (0.096)		
WORKING		0.648 (0.084)***		
SINGLE FEMALE	-0.590 (0.230)**	1.141 (0.167)***	-0.236 (0.230)	
THIRTY		-0.919 (0.157)***		
FORTY		-0.868 (0.161)***		
FIFTY		-0.637 (0.161)***		
SIXTY		-1.128 (0.165)***		
PRIMARY	0.947 (0.218)***	-0.431 (0.152)***	0.230 (0.205)	
SECOND	0.619 (0.193)***	-0.174 (0.127)	0.110 (0.172)	
FREETRAV		-1.062 (0.069)***		
MOTOR		-0.449 (0.123)***		
EXPENSES		-0.329 (0.083)***		
CARS		-1.080 (0.057)***		-0.074 (0.023)***
θ		0.398 (0.023)***		
Number of Observations		6,033		
Log-Likelihood		-9985.170		
IHS Het Tobit Log-Likelihood		-9459.638		

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

Table 6.21 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Taxi Use (No Car Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-1.698	-9.352	-3.595	1.568
	(1.484)	(1.405)***	(1.493)**	(0.096)***
HHEXP	-0.926	3.340	1.935	0.082
	(0.901)	(0.669)***	(0.971)**	(0.039)**
$HHEXP^2$	-0.011	-0.246	-0.326	
	(0.188)	(0.148)*	(0.220)	
ADULTS	0.197	2.494	0.828	-0.232
	(0.718)	(0.676)***	(0.802)	(0.027)***
$ADULTS^2$	0.035	-0.230	-0.164	
	(0.114)	(0.109)**	(0.133)	
CHILDREN	-0.279	0.262	0.437	-0.058
	(0.185)	(0.127)**	(0.260)*	(0.026)**
APART		0.404		
		(0.612)		
SEMI		0.583		
		(0.557)		
WORKING		0.785		
		(0.237)***		
SINGLE FEMALE		0.561		
		(0.375)		
THIRTY	-0.502	-0.436	0.151	
	(0.826)	(0.511)	(0.993)	
FORTY	-0.287	-1.189	0.127	
	(0.861)	(0.521)**	(0.999)	
FIFTY	0.271	-1.202	0.658	
	(0.799)	(0.534)**	(0.984)	
SIXTY	-0.073	-2.534	2.007	
	(0.756)	(0.519)***	(0.848)**	
PRIMARY		0.161		
		(0.389)		
SECOND		0.166		
		(0.353)		
MOTOR		-0.175		
		(0.589)		
θ		0.214		
		(0.030)***		
Number of Observations		2,506		
Log-Likelihood		-2215.476		
IHS Het Tobit Log-Likelihood		-2072.922		

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) Variables that are significant in the unadjusted model are included in the models adjusted for heteroscedasticity and non-normality. This accounts for the fact that all 1987 interactions included in the final specification are insignificant.

Table 6.22 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Taxi Use (One or More Cars Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-2.301 (1.314)*	-9.701 (1.246)***	-0.521 (1.172)	1.545 (0.100)***
HHEXP		1.604 (0.236)***		0.059 (0.024)**
$HHEXP^2$		-0.152 (0.034)***		
ADULTS		3.604 (0.301)***		0.192 (0.023)***
$ADULTS^2$		-0.284 (0.033)***		
CHILDREN		0.213 (0.071)***		-0.064 (0.021)***
APART		0.690 (0.400)*		
SEMI		0.195 (0.181)***		
WORKING		1.390 (0.295)***		
SINGLE FEMALE		1.349 (0.413)**		
THIRTY	-1.381 (1.382)	-2.425 (0.990)***	1.954 (1.239)	
FORTY	0.062 (1.357)	-2.994 (0.979)***	1.388 (1.211)	
FIFTY	0.506 (1.340)	-2.941 (0.980)***	1.360 (1.201)	
SIXTY	0.435 (1.351)	-3.355 (0.988)***	1.770 (1.205)	
PRIMARY		0.742 (0.202)***		
SECOND		0.238 (0.164)		
MOTOR	-1.708 (0.946)*	0.226 (0.558)	-0.405 (0.674)	
EXPENSES		-0.125 (0.150)		
CARS		-0.552 (0.138)***		-0.082 (0.041)**
θ		0.321 (0.032)***		
Number of Observations		3,527		
Log-Likelihood		-3435.164		
IHS Het Tobit Log-Likelihood		-3221.191		

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level
(iii) Variables that are significant in the unadjusted model are included in the models adjusted for heteroscedasticity and non-normality. This accounts for the fact that all the 1999 interaction terms included in the final specification are insignificant.

Table 6.23 Coefficient Estimates for Pooled Heteroscedastic and Non-Normal Tobit Models of Taxi Use (Full Sample)

VARIABLE	1987	1994	1999	HETERO. TERMS
Constant	-2.154 (0.569)***	-10.070 (0.705)***	-0.121 (0.571)	1.498 (0.065)***
HHEXP		2.297 (0.209)***		0.091 (0.019)***
$HHEXP^2$		-0.259 (0.032)***		
ADULTS		3.167 (0.232)***		-0.174 (0.016)***
$ADULTS^2$		-0.238 (0.026)***		
CHILDREN		0.201 (0.059)***		-0.055 (0.016)***
APART		0.646 (0.271)**		
SEMI		0.221 (0.170)		
WORKING		1.254 (0.184)***		
SINGLE FEMALE		1.345 (0.266)***		
THIRTY	-1.270 (0.659)*	-1.293 (0.406)***	0.994 (0.655)	
FORTY	-0.405 (0.643)	-2.124 (0.406)***	0.801 (0.625)	
FIFTY	0.238 (0.617)	-2.092 (0.401)***	0.942 (0.612)	
SIXTY	0.077 (0.627)	-2.788 (0.406)***	1.498 (0.611)**	
PRIMARY		0.683 (0.175)***		
SECOND		0.370 (0.150)**		
MOTOR	-1.560 (0.708)**	0.559 (0.400)	-0.627 (0.447)	-0.156 (0.087)*
EXPENSES		-0.187 (0.146)		
CARS		-0.741 (0.104)***		-0.127 (0.023)***
θ		0.274 (0.022)***		
Number of Observations		6,033		
Log-Likelihood		-5755.732		
IHS Het Tobit Log-Likelihood		-5389.485		

Notes: (i) Standard errors are reported in parentheses.
(ii) * significant at 10% level, ** significant at 5% level, *** significant at 1% level

6B APPENDICES

6A Formulae for the Calculation of Marginal Effects for Tobit Models

Tobit Marginal Effects

$$ME_j = \frac{\partial y_i}{\partial x_{ij}} = \Phi\left(\frac{x_i'\beta}{\sigma}\right).\beta_j \qquad (6A.1)$$

Heteroscedastic Tobit Marginal Effects

$$ME_j = \frac{\partial E(y_i)}{\partial x_{ij}} = \int_0^\infty \left(\begin{array}{l} \frac{y_i}{\sigma_i}\phi\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\times \\ \left(\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\left(\frac{\beta_j}{\sigma_i}\right) + \left(\frac{y_i - x_i'\beta}{\sigma_i}\right)^2 h_j - h_j\right) \end{array} \right) dy_i \qquad (6A.2)$$

where $E(y_i)$ is the expected value of the dependent variable, ϕ is the standard normal density function, Φ is the cumulative standard normal distribution function, σ_i is the estimated standard error, β_j and h_j are the estimated coefficients on the independent variables x_j and the heteroscedasticity terms z_j respectively. All marginal effects are calculated at the sample means of the independent variables.

See Section 5A of the Appendix to Chapter 5 for the formula for the calculation of marginal effects in the Tobit models adjusted for heteroscedasticity and non-normality of the errors.

6B Formulae for the Calculation of Standard Errors for Heteroscedastic Tobit Model

See Section 5B of the Appendix to Chapter 5 for a description of the delta method and for the formulae for the calculation of standard errors in the Tobit models adjusted for heteroscedasticity and non-normality of the errors.

$$\frac{\partial ME_j}{\partial \beta_q} = \int_0^\infty \left(\begin{array}{l} \frac{y_i}{\sigma_i}\phi\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\times \\ \left(\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\left(\frac{x_{iq}}{\sigma_i}\right)\times (.) \right. \\ \left. -\left(\frac{x_{iq}\beta_j}{\sigma_i^2}\right) - 2\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\left(\frac{x_{iq}h_j}{\sigma_i}\right) \right) \end{array} \right) dy_i \qquad (6B.1)$$

$$\frac{\partial ME_j}{\partial \beta_j} = \int_0^\infty \left(\begin{array}{l} \frac{y_i}{\sigma_i}\phi\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\times \\ \left(\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\left(\frac{x_{ij}}{\sigma_i}\right)\times (.) \right. \\ -\left(\frac{x_{ij}\beta_j}{\sigma_i^2}\right) - 2\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\left(\frac{x_{ij}h_j}{\sigma_i}\right) \\ \left. +\left(\frac{y_i - x_i'\beta}{\sigma_i}\right)\left(\frac{1}{\sigma_i}\right) \right) \end{array} \right) dy_i \qquad (6B.2)$$

$$\frac{\partial ME_j}{\partial h_q} = \int_0^{\infty} \left(\begin{array}{l} \frac{y_i}{\sigma_i} \phi \left(\frac{y_i - x_i' \beta}{\sigma_i} \right) \times \\ \left(\begin{array}{l} - z_{iq} \times (.) + \left(\frac{y_i - x_i' \beta}{\sigma_i} \right)^2 z_{iq} \times (.) \\ - \left(\frac{y_i - x_i' \beta}{\sigma_i} \right) \left(\frac{z_{iq} \beta_j}{\sigma_i} \right) \\ - 2 \left(\frac{y_i - x_i' \beta}{\sigma_i} \right)^2 \left(z_{iq} h_k \right) \end{array} \right) \end{array} \right) dy_i \tag{6B.3}$$

$$\frac{\partial ME_j}{\partial h_j} = \int_0^{\infty} \left(\begin{array}{l} \frac{y_i}{\sigma_i} \phi \left(\frac{y_i - x_i' \beta}{\sigma_i} \right) \times \\ \left(\begin{array}{l} - z_{ij} \times (.) + \left(\frac{y_i - x_i' \beta}{\sigma_i} \right)^2 z_{ij} \times (.) \\ - \left(\frac{y_i - x_i' \beta}{\sigma_i} \right) \left(\frac{z_{ij} \beta_j}{\sigma_i} \right) \\ - 2 \left(\frac{y_i - x_i' \beta}{\sigma_i} \right)^2 \left(z_{ij} h_j \right) \\ + \left(\frac{y_i - x_i' \beta}{\sigma_i} \right)^2 - 1 \end{array} \right) \end{array} \right) dy_i \tag{6B.4}$$

where $(.) = \left(\left(\frac{y(\theta) - x_i' \beta}{\sigma_i} \right) \left(\frac{\beta_j}{\sigma_i} \right) + \left(\frac{y(\theta) - x_i' \beta}{\sigma_i} \right)^2 h_j - h_j \right)$

CHAPTER 7

AN ECONOMETRIC ANALYSIS OF CHOICE OF MODE OF TRANSPORT TO WORK AND SCHOOL/COLLEGE IN THE DUBLIN AREA: 1996

7.1 Introduction

The aggregated data presented in Chapter 3 illustrate the large differences that exist between different sectors of the Dublin population in terms of their travel patterns to work, school and college. For example, males cycle, travel by train and drive their cars to work in greater proportions than females who walk, travel by bus and as passengers in a car to work in greater proportions [see Table 3.15]. There are also regional differences in that the most popular mode of transport to school for primary and secondary schoolchildren in Dun Laoghaire-Rathdown is travelling as a passenger in a car. In comparison, the primary mode of transport to school for primary and secondary schoolchildren resident in the other three local authority areas of Dublin is walking [see Tables 3.19 and 3.23]. Unfortunately aggregated Census of Population data do not indicate whether modal shares differ according to other socio-economic characteristics such as socio-economic group, age, level of education or marital status. The availability of a micro-data sample from the 1996 Census of Population enables the construction of more accurate models of modal choice, accounting for a much wider range of explanatory variables that are not possible with aggregated data.

The purpose of this chapter is to follow on from previous research on modal choice by estimating the determinants of modal choice for the journeys to work and school/college in the Dublin area in 1996 using discrete choice econometric methodologies. This is done by using micro-data from the 1996 Census of Population to estimate multinomial logit (MNL) models of the modal choice decisions of workers and students in the Dublin area. In common with the analyses in Chapters 5 and 6, this is the first time that disaggregated data have been used to estimate Irish modal choice decisions and a comparison with the results from Chapters 5 and 6 will indicate the extent to which the effects of the socio-economic characteristics on travel demand are different depending on the type of data employed and also the extent to which travel patterns differ depending on journey purpose. In addition, a comparison with the findings from the aggregated Census of Population data in Chapter 3 will indicate whether the effects of distance, area of residence and gender on choice of mode of transport to work and school/college persist even after additional factors such as income and age are controlled for.

Section 7.2 reviews previous literature in the area of modal choice modelling while Section 7.3 summarises the main features of the data used in the analyses in this chapter. Section 7.4 presents the econometric methodology employed while section 7.5 deals with model specification issues. Section 7.6 presents empirical results and section 7.7 summarises and concludes.

7.2 Previous Literature

While the journey to work accounts for a relatively small proportion of total journeys per person [see Table 7.1], the journey to work is chosen as the focus of most analyses of modal choice decisions for a number of reasons. Firstly, levels of traffic congestion are highest during the morning and evening peaks meaning that work-related journeys cause the greatest challenge to transportation planners. However, due to the routine and repetitive nature of the journey, the potential for targeting individuals to travel by alternative non-car modes is greater than for less routine journeys [Kingham *et al.* (2001) and Pooley and Turnbull (2000)]. Secondly, survey data on commuting journeys are relatively easy to collect as individuals find it easy to recall a journey that is made on a regular basis over the same route, mode and time of day. With two exceptions, all of the studies discussed in Section 2.5 focus on the modal choice decisions of individuals for the journey to work. In addition, Domencich and McFadden (1975) also examine the choice of mode of transport for shopping trips and McGillivray (1972) analyses the choice of mode of transport for a number of additional journey purposes including personal business, visiting friends and relations, shopping and other recreation.

Due to the nature of the decision under consideration, two approaches dominate the literature on modal choice decisions, namely, the multinomial logit (MNL) methodology and the nested multinomial logit (NMNL) methodology.[123] Due to the absence of

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[123] Madan and Groenhaut (1987), Domencich and McFadden (1975), De Donnea (1971) and Lave (1970) use the binary logit methodology but the opportunity afforded by the MNL method to incorporate more than two categories of the dependent variable means that it is 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 [see also Section 7.4].

information on the attributes of the choices as well as information about the household's car ownership status, the COP data preclude the application of a NMNL model to the choice of mode of transport to work and school/college. De Palma and Rochat (2000), Thobani (1984) and Train (1980) all use the NMNL methodology to estimate modal choice for the journeys to work in Geneva, Karachi and San Francisco respectively, conditional on the car ownership status of the individual in question. Hausman and Wise (1978) and Ben-Akiva and Lerman (1975) employ the MNL methodology to the choice between a number of different alternatives for the journey to work in Washington. In addition to the modal choice question, the MNL methodology has been extensively applied to other decisions such as the number of cars to own [Alperovich *et al.* (1999), Bhat and Pulugurtha (1998) and Cragg and Uhler (1970)], the choice of car type [McCarthy (1996) and Lave and Train (1979)], choice of tourist destination [Eymann and Ronning (1997)], choice of occupation [McVicker (2001) and Schmidt and Strauss (1975)] and choice of household location [Gabriel and Rosenthal (1989)].

In the context of modal choice, the majority of the above studies use a combination of individual- and alternative-specific independent variables as explanatory factors. For example, De Palma and Rochat (2000), Madan and Groenhaut (1987), Thobani (1984), Train (1980), Hausman and Wise (1978), Ben-Akiva and Lerman (1975) and Lave (1970) all employ cost and travel time variables in an attempt to explain choice of mode of transport. The socio-economic characteristics of the individual such as age, gender and household location are commonly employed as explanatory variables and explain large variation in modal choice in all studies. The precise effect of income is often difficult to determine in a number of studies as it is interacted with cost variables to illustrate the fact that the effect of price/time differs over different incomes [see Thobani (1984), Train (1980), Hausman and Wise (1978) and Lave (1970)].

In the context of Irish travel demand, the analysis in this chapter complements the research in Chapters 5 and 6 on the income and socio-economic determinants of the demand for car and public transport use using Household Budget Survey data as well as research by Morgenroth (2002)[124] on inter-county commuting patterns in Ireland. As mentioned above, this is the first time that disaggregated data have been used to model the choice of mode of transport to work and it is also the first time that the choice of mode of transport to school/college has been analysed, an important contribution since trips to school/college accounted for nearly 20 per cent of total trips per person in the UK in 2000 [see Table 7.1].

7.3 Data

The data used in this chapter are micro-data from the 1996 Census of Population (COP). Section 4.3 contains further information on the conduct of the COP, the choice of samples and the various dependent and independent variables used in the subsequent analyses. Two samples form the basis of the analyses in this chapter, namely, the sample of persons aged 15+ years in employment (work sample) and the sample of persons aged five years and older in full-time education (school sample). Tables 4.13 and 4.15 define the dependent and independent variables, while Tables 4.14, 4.16 and 4.17 present the

[124] Morgenroth (2002) uses gravity models to analyse the determinants of inter-county commuting flows.

summary statistics for the various dependent and independent variables used in these analyses. As discussed in Sections 4.3.3 and 4.4, a failing of the COP data is the absence of variables relating to the income and/or car ownership status of the individual. Due to the desire to calculate income elasticities and the similarity in variables contained in the COP and HBS, an income variable is constructed using information from the 1994 HBS and this procedure is discussed in further detail in Section 4.3.3 and Section 4C of the Appendix to Chapter 4.

7.4 Econometric Methodology

7.4.1 Multinomial Logit

As the data preclude the application of a NMNL model to the choice of mode of transport to work and school/college, the MNL model is employed to model the choice of mode of transport to work and school/college in the Dublin area in 1996. The MNL model is used to model the choice between a number of mutually exclusive unordered alternatives. It may be viewed as an extension of the binary logit model to situations where the dependent variable has more than two categories. It is usually constructed in a random utility framework where the (unobserved) utility of each alternative is assumed to be a linear function of various independent variables and an error term as follows:

$$U_{ij}^{*} = x_i'\beta_j + \varepsilon_{ij} \tag{7.1}$$

where U_{ij}^{*} is the unobserved utility individual i derives from alternative j, x_i is the vector of individual-specific independent variables, β_j is the vector of estimated parameters and ε_{ij} is the error term. In this case the independent variables are individual-specific but they may also be alternative-specific or a combination of both.[125] 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. This results in the MNL model where the probability of observing alternative j is as follows:

$$P(y_i = j) = \frac{exp(x_i'\beta_j)}{1 + exp(x_i'\beta_1) + exp(x_i'\beta_2) + ... + exp(x_i'\beta_J)}, \; j = 0,1,....,J \qquad (7.2)$$

In order to identify the parameters of the model, usual practice is to set the coefficients on the first alternative (j=0) equal to zero resulting in the probability of observing the first alternative of:

$$P(y_i = 0) = \frac{1}{1 + exp(x_i'\beta_1) + exp(x_i'\beta_2) + ... + exp(x_i'\beta_J)}, \; j = 0,1,....,J \qquad (7.3)$$

With only two alternatives, the model reduces to the binary logit model. The model is estimated by means of the maximum likelihood method of estimation where the following log-likelihood function is maximised with respect to each of the estimated parameters:

$$log\ L = \sum_{i=1}^{n} \sum_{j=1}^{J} d_{ij}\ log\ P(y_i = j) \qquad (7.4)$$

[125] A number of authors distinguish between the "multinomial logit" model, which includes only individual-specific characteristics such as gender as independent variables, the "conditional logit" model which includes only alternative-specific characteristics such as journey time as independent variables and the "mixed logit" model which includes both types of independent variable [see Greene (2000), Kennedy (1998) and Maddala (1983)].

where $d_{ij}=1$ if alternative j is chosen by individual i and 0 otherwise. Unlike the ordered logit model, parameters in the MNL with individual-specific independent variables vary across alternative categories.

Independence from Irrelevant Alternatives

While the assumption of independent and identical errors greatly facilitates model estimation, a consequence of this assumption is the independence from irrelevant alternatives (IIA) property. The IIA property, which 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, is restrictive and unless it holds, the MNL model is incorrectly specified. Section 7.5.2 contains further details on testing for the presence of the IIA property. Despite the strictness of the IIA assumption, the MNL model remains the most popular method for estimating the choice between a number of mutually exclusive unordered alternatives. The multinomial probit methodology, which assumes an alternative normal distribution for the error term, is rarely employed due to computational difficulties, which become severe even for a model with four alternatives [see Greene (2000), Verbeek (2000) and Kennedy (1998)].

7.5 Model Specification

7.5.1 Choice of Dependent Variable Categories

For the work and school samples, the initial choice of categories for the dependent variables (mode of transport to work and school/college respectively) was made on the basis of the available data and intuitive appeal. For the work sample, the initial dependent variable has six categories corresponding to on foot, bicycle, bus, train, car passenger and car driver (the latter being the base category). For the school sample, the dependent variable has six categories corresponding to bicycle, bus, train, car passenger, other[126] and on foot (the latter being the base category). However, it is important to construct the dependent variable categories so that the IIA assumption is satisfied [Eymann and Ronning (1997)]. Section 7.5.2 details the tests involved. On the basis of the test results for IIA, some of the initial dependent variable categories are merged to satisfy the IIA assumption. The final dependent variable for the work sample has four categories, namely, on foot/bicycle, bus/train, car passenger and car driver (the latter being the base category) while for the school sample the final dependent variable also has four categories corresponding to bus/train, car passenger, other and on foot/bicycle (the latter being the base category). Table 7.2 presents the initial and final specifications of the dependent variable categories for the work and school samples.

7.5.2 Testing for Independence from Irrelevant Alternatives[127]

As discussed in section 7.4, the assumption that the error terms in the MNL model are independently and identically distributed gives rise to the IIA property, which implies that the relative probabilities between a pair of alternatives are specified without reference to the nature of the other alternatives. In other words, no allowance is made for the fact that alternatives may be substitutes or complements for each other. This may be a

[126] The "other" category includes car driver, motorcycle, lorry or van.

[127] Following previous literature discussing the multinomial logit methodology, we do not consider the possibility of heteroscedastic errors [see Greene (2000), Kennedy (1998), Maddala (1983) and Amemiya (1981)]. Instead, we concentrate on potentially the most problematic feature of the multinomial logit model, namely, the independence from irrelevant alternatives assumption.

particular problem when two or more alternatives are very similar.[128] It is therefore important to specify the model is such a way that the alternatives can plausibly be assumed to be distinct and independent [Domencich and McFadden (1975)].

The computational complexity of the multinomial probit model does not provide a convenient specification test for IIA [Hausman and McFadden (1984)]. In this chapter, the Hausman and Small-Hsiao likelihood ratio tests are used to test the null hypothesis of IIA. Section 7A of the Appendix presents further details on the test procedures. Both tests involve estimating unrestricted (including the full set of alternatives) and restricted (omitting an alternative choice) forms of the model and comparing the parameter estimates. The intuition behind the tests is that if the IIA property holds, the parameter estimates will be invariant to whether the estimates are obtained from the full or restricted choice sets. As the Hausman test often results in negative test statistics and may be biased towards not rejecting the null hypothesis of IIA [Pagan and Vella (1989) and Small and Hsiao (1985)], the final dependent variable specification includes categories for which the Small-Hsiao test does not reject the null hypothesis of IIA. However, as the Hausman and Small-Hsiao test results often conflict, the models are also estimated with the full choice set of six alternatives, although realising that the results must be treated with caution as the IIA property is rejected on the basis of the Small-Hsiao tests. Tables 7.3 to 7.8 present the results of the Hausman and Small-Hsiao tests for the work and school samples.

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[128] The classic illustration of this problem is the red bus-blue bus example described in Amemiya (1981). If the alternatives in one modal choice model of car, bus and train are replaced by car, red bus and blue bus, it is unreasonable to assume that the unobservables affecting the utility of choosing a red bus are independent of the unobservables affecting the utility of choosing a blue bus.

7.5.3 Choice of Independent Variables

As all independent variables are individual-specific, the same set of independent variables is relevant for each choice. For the work sample, a non-linear specification of the constructed household income variable was considered but was found to be insignificant and was therefore excluded from consideration. Section 4.3 contains further details on the choice of independent variables for the analyses in this chapter. The models are estimated using the LIMDEP econometrics package while the tests for the IIA assumption outlined in Section 7.5.2 are undertaken using STATA.

7.5.4 Interpretation of Parameter Estimates

As in all models with discrete dependent variables, the estimated coefficients cannot be interpreted as the marginal effects of the independent variables on the probabilities of choosing a particular alternative. Tables 7.9 and 7.11 and Tables 7.15 and 7.17 report the estimated coefficients from the MNL models of mode of transport to work and school/college respectively. A positive coefficient for an independent variable implies an increased probability of observing the individual in category j rather than in the base category. A particular problem with the MNL model is that the signs of the estimated coefficients may not correspond with the true effect of the variable on the probability of observing a particular alternative [Greene (2000) and Gabriel and Rosenthal (1989)]. In order to ascertain the absolute effect of the independent variable, marginal effects must be calculated. Marginal effects reflect the absolute effect of the independent variable on the probability of choosing alternative j. Marginal effects in the MNL model are calculated by differentiating the predicted probabilities outlined in Equation (7.2) with respect to the various independent variables of interest. As only one independent variable, namely household income, is continuous, the elasticity of demand with respect to income (proxied by household expenditure) may also be calculated. For the remainder of the independent variables which are all discrete, marginal effects are calculated as the difference in predicted probabilities depending on whether the independent variable takes the value one and the value zero. The formulae for calculating marginal effects and elasticities in the multinomial logit model are presented in Section 7B of the Appendix. Tables 7.10 and 7.12 and Tables 7.16 and 7.18 present the marginal effects for the models of mode of transport to work and school/college respectively while Tables 7.13 and 7.14 present the estimated income elasticities for the work sample.

7.6 Empirical Results

7.6.1 The Journey to Work

Tables 7.9 and 7.10 present the estimated coefficients and the marginal effects respectively for the model with four alternatives, namely car driver (base category), on foot/bicycle, bus/train and other. As discussed in Section 7.5.4, the estimated coefficients represent the probability of being observed in category *j* relative to the base category while the marginal effects reflect the change in the absolute probability of being observed in category *j*. This means that significance levels and signs may differ between coefficients and marginal effects. As the Small-Hsiao tests reject the null hypothesis of independent alternatives for the six-alternative model, the estimated coefficients and marginal effects of the four-alternative model (for which the Small-Hsiao IIA tests are not rejected) form the basis of the following discussion. The estimated coefficients and marginal effects from the initial model with six alternatives, namely car driver (base category), on foot, bicycle, bus, train and car passenger are also presented in Tables 7.11 and 7.12 and reference will be made to these results where significant differences arise. However, the rejection of the IIA assumption for the six-alternative model on the basis of the Small-Hsiao tests means that the results must be treated with caution.

Income

The effect of household income, as proxied by per capita weekly household expenditure, enters as a significant factor in explaining choice of mode of transport to work. The effect of increasing household income reduces the probability of walking or cycling, travelling by public transport or travelling as a passenger in a car in comparison with the base category of driving a car to work. De Palma and Rochat (2000) also find that income exerts a negative effect on the probability of using public transport to travel to work in comparison with choosing to drive a car. Similarly, Madan and Groenhaut (1987) report positive and negative income elasticities for the choice of car and public transport to work respectively. An examination of the income elasticities in Table 7.13 indicates that a 1 per cent increase in household income increases the probability of being a car driver by 1.28 per cent and consequently reduces the probability of walking or cycling to work by 1.53 per cent, travelling by public transport by 2.28 per cent and travelling as a passenger in a car by 1.77 per cent.[129] This reflects the increasing probability of household car ownership as incomes increase as well as the increased value of time that accompanies an increase in income, leading individuals to choose faster modes of

[129] However, it must be remembered that since information about the car ownership status of the individual is not available in the 1996 COP, these income effects are likely to be overstated.

transport. The results for the six-alternative model presented in Table 7.12 confirm the above results with one exception: the effect of merging the bus and train categories is to mask the fact that household income has no significant effect on the probability of choosing the train as a mode of transport. In other words, as household income increases, while the individual may be expected to shift from walking, cycling, travelling by bus and as a passenger in a car to driving a car, there is no significant change in the probability of travelling by train. This may indicate a role for modes of transport such as the train that can compete with the private car in terms of journey times.

Distance

Increasing distance exerts a negative effect on the probability of walking or cycling to work with those travelling the shortest distances being much more likely to walk or cycle than drive a car to work. On the other hand, those travelling three miles or less to work are significantly less likely to travel by bus or train than to drive a car, while those travelling four to nine miles are more likely to travel by public transport than travel by car. The effect of increasing distance is generally positive on the probability of being a car passenger, although the effects for the two miles and five to nine miles categories indicate that there are no significant differences in the probability of travelling as a passenger in a car and driving a car for these distances. The marginal effects in Table 7.10 confirm that while the probability of driving a car and travelling by public transport to work are increasing functions of distance, the probability of walking or cycling is a negative function of distance. The insignificance of the longer distance categories in explaining the probability of travelling by public transport indicates that there are no significant differences between those travelling four or five to nine miles and those travelling ten miles or more (the base category). The results for the car passenger category indicate that distance exerts no significant effect on the probability of travelling as a passenger in a car to work. An examination of the disaggregated categories in Table 7.12 illustrates that there are significant differences in the effect of distance on the probabilities of travelling by bus and train respectively. For distances of three to nine miles, increasing distance exerts a declining negative effect on the probability of taking the train and a positive effect on the probability of taking the bus. This discrepancy may account for the insignificance of the longer distance terms in explaining the probability of travelling by public transport in the four-alternative model. The negative effect of distance on the probability of travelling by bus and the corresponding positive effect on the probability of travelling by train and car may indicate an absence of bus services that can compete with the train and private car in terms of time for longer distances in Dublin. These results support the findings from the aggregated data presented in Chapter 3 where those travelling short distances favour walking and cycling, those travelling medium distances choose the bus and those travelling the longest distances choose the car or train.

Area of Residence

Relative to the base category of driving a car to work, living in Dun Laoghaire-Rathdown, Fingal or South Dublin exerts a negative effect on the probability of travelling on foot or by bicycle and by public transport to work. An examination of Table 3.13 supports these results. As Dublin County Borough roughly corresponds to the city centre, these results support those of Madan and Groenhaut (1987) and McGillivray (1972) where the probability of driving a car to work is significantly increased for those residing in areas where employment density is low and for those living further away from the city centre respectively. The marginal effects in Table 7.10 indicate that living in Dun Laoghaire-Rathdown exerts the largest positive effect on the probability of driving a car and the largest negative effect on the probability of walking and cycling relative to the base category of those living in Dublin County Borough. Living in South Dublin has the strongest negative effect on the probability of travelling by public transport relative to the base category. This may be explained by the absence of rail links in the South Dublin area meaning that the negative effect on the probability of travelling by train dominates this effect. This is confirmed by an examination of the marginal effects for the six-alternative case presented in Table 7.12 where the effect of living in South Dublin is consistently negative for the probability of travelling by bus and train but the effect of residing in Dun Laoghaire-Rathdown or Fingal is positive for the probability of travelling by train but negative for the probability of travelling by bus. Even after distance travelled to work has been controlled for, it is significant that area of residence still exerts an influence on mode of transport to work. Some differences may be due to differences in transport mode availability with the significant negative marginal effect on the probability of travel by train in South Dublin reflecting the absence of a rail service in the area. The marginal significance of area of residence on the probability of travelling as a passenger in a car indicates that those living in the Fingal area are most likely to travel as a passenger in a car to work. An examination of Table 3.13 supports this result with little difference in the proportion of workers travelling as a passenger in a car to work in Dun Laoghaire-Rathdown and Dublin County Borough and a slightly higher proportion in

Fingal and South Dublin. This is in comparison with the larger differences in share for other modes between the four different areas of Dublin.

Gender

The effect of being female increases significantly the probability of travelling by public transport or as a passenger in a car relative to driving a car to work. The marginal effects in Table 7.10 indicate that gender is consistently significant in explaining choice of mode of transport to work. Females are less likely to drive and walk or cycle to work than males while they are more likely to travel by public transport or as a passenger in a car. The result that females are more likely to choose public transport than private is supported by the work of Mannering (1983) and by the results of Chapters 5 and 6, which indicate a significant gender effect on car ownership, car use and public transport use, in particular bus use. The results for the six-alternative model in Table 7.12 confirm the positive effect of being female on the probability of travelling by bus or train or as a passenger in a car. However, the effect on the probability of walking is positive while the effect on the probability of cycling is negative, divergent effects that are masked by the aggregation of the categories. Pooley and Turnbull (2000), who examine changes in mode of transport to work in Britain since 1890 and also find that females are significantly less likely to cycle than males, explain this trend by arguing that females are more conscious of safety risks associated with cycling in urban traffic, they are more conscious of looking smart for work and because they often have to undertake other tasks after work such as shopping or collecting children which would be difficult to accomplish by bicycle. These results are in agreement with the findings presented in Table 3.15

where females walk, use the bus and train and travel as a passenger in a car in greater proportions than males.

Age

The effects of age indicate that those aged 30 years and older are less likely to walk or cycle, travel by public transport or travel as a passenger in a car than drive a car to work. The marginal effects in Table 7.10 confirm that age exerts a positive effect on the probability of driving a car to work with the effect found to be non-linear, namely, those aged 40-49 years are most likely to drive to work relative to the base category of those aged 29 years or younger. This is consistent with the results from Chapter 5 where in 1994, car ownership was found to be an increasing function of age but car use was found to be a decreasing function. Train (1980) and Lave (1970) also find that age exerts a positive effect on car driving. On the other hand, De Palma and Rochat (2000) find that those aged 50+ years and under 30 years are less and more likely respectively to drive their cars to work. Consistent with expectations, those aged 60 years and older are significantly less likely to walk or cycle to work and the results in Table 7.12 for the disaggregated categories confirm the expectation that this effect is driven by a significant negative effect on the probability of cycling to work. The insignificance of the marginal effect of being aged 30-39 years shows that there are no significant differences between those aged 29 years or younger and those aged 30-39 years in the probability that they will walk or cycle to work. The insignificance of the marginal effect for those aged 60 years and over on the probability of using public transport indicates that there are no significant differences between this category and the base category of those aged 29 years or younger.[130] This result is in direct contrast to that of Chapter 6 where the effect of being 60 years or older had a significantly negative effect on bus fare expenditure, although it must be remembered that this result refers to expenditure on bus fares for all purposes, not just the work journey. De Palma and Rochat (2000) and Bergantino (1997) also find that older people are more favourable towards public transport.

Education Level

In comparison with those driving to work, having a lower level of education reduces the probability that an individual will walk or cycle, travel by public transport or travel as a passenger in a car. The marginal effects show that, in comparison with having a third level education, having a primary or secondary school education increases the probability of driving to work with the effect of having a secondary level education exerting the largest positive effect. This is in direct contrast to the effect of education on car ownership probability in Chapter 5 where those with the highest levels of education were most likely to own cars. Consequently, those with a secondary school education are significantly less likely to choose walking or cycling or public transport as a mode of transport to work. A possible explanation for this result is that those with higher levels of education may be more aware of the detrimental environmental effects of car driving and seek to modify it by choosing more environmentally friendly methods of transport. Johansson-Stenman (2002) includes membership of an environmental organisation as an independent variable but finds it insignificant. On the other hand, it is expected that those with higher levels of education are more likely to be engaged in occupations that need a

[130] Free travel on public transport services at off-peak times in Dublin is only granted to those aged 65 years and over who are retired.

car as part of their work and are more likely to have company cars which would reduce the cost of driving a car to work in comparison with other modes of transport.

Marital Status

Marital status is included as an independent variable to proxy household type. It is expected that individuals that are married are more likely to live in households with children and thus have extra responsibilities. The results support this hypothesis with the effect on the probability of driving a car being positive suggesting that individuals may use the car for purposes other than purely to travel to work, e.g., to transport children to and from school. The effect of being married has no significant effect on the probability of travelling as a passenger in a car but the effect of being widowed or divorced is significantly negative reflecting the reduced opportunities for car-sharing in households with only one adult member. De Palma and Rochat (2000) and Bergantino (1999) similarly find that the effect of having children on the probability of driving to work and spending on public transport are positive and negative respectively, although the former finds an insignificant effect.

Type of Work

The type of work variable is included to capture the fact that journeys to work are not made at the same time of day. The results indicate that individuals with a part time job are more likely to choose walking or cycling and public transport than driving a car to work, which may suggest that more flexible forms of transport are preferred by those in part-time work. Examining the disaggregated categories in Table 7.12 indicates that while the effect of part-time employment on the probability of using the bus is positive, the effect on the probability of using the train is insignificant, divergent effects that are disguised by the aggregation of these two categories. As discussed in Section 4.3, it is difficult to predict the effect of this variable. While part-time workers may be more likely to travel by car if one is available due to less congestion, they may also be more likely to use public transport as it too is less congested at off-peak times. These results support the latter interpretation. De Palma and Rochat (2000) include a similar variable, namely, whether the individual works flexible work hours, but find no significant effect on the choice between car and public transport for the journey to work.

7.6.2 The Journey to School/College

Tables 7.15 and 7.16 present the estimated coefficients and the marginal effects respectively for the model with four alternatives, namely on foot/bicycle (base category), bus/train, car passenger and other. As discussed in section 7.5.4, the estimated coefficients represent the probability of being observed in category j relative to the base category while the marginal effects reflect the change in the absolute probability of being observed in category j. As the Small-Hsiao tests reject the null hypothesis of independent alternatives for the six-alternative model, the estimated coefficients and marginal effects of the four-alternative model (for which the Small-Hsiao independence tests are not rejected) form the basis of the following discussion. The estimated coefficients and marginal effects from the initial model with six alternatives, namely on foot (base category), bicycle, bus, train, car passenger and other are also presented in Tables 7.17 and 7.18 and reference will be made to these results where significant differences arise.

However, the rejection of the IIA assumption for the six-alternative model on the basis of the Small-Hsiao tests means that the results must be treated with caution.

Socio-Economic Group

In comparison with the base category of walking or cycling, those students in the ABC socio-economic category are more likely to travel as a passenger in a car or by other means (principally driving a car) to school/college. However, the coefficients in Table 7.15 indicate there is no significant difference in the probability of travelling by public transport and walking or cycling to school/college for those of differing socio-economic status. The marginal effects in Table 7.16 on the other hand indicate that the effect of moving into the ABC socio-economic category is to reduce the probability of walking or cycling to school/college, to reduce the probability of travelling by public transport and to increase the probability of travelling as a passenger in a car. This obviously reflects the increasing probability of household car ownership as income (or socio-economic status as a proxy for income) increases, meaning that students shift away from walking and cycling and public transport towards travelling as a passenger in a car as the economic resources and consequently car ownership level of the household increase.

The marginal effects for the six-alternative model in Table 7.18 indicate differences in the effect of socio-economic group on the probability of walking compared with cycling and travelling by bus compared with train, i.e., the merged categories mask differences in the effects of the socio-economic group variable on the different components of these categories. While moving into the ABC socio-economic group increases significantly the probability of cycling, the probability of walking is significantly reduced and while moving into the ABC socio-economic group reduces the probability of travelling by bus, the effect on the probability of taking the train to school/college is insignificant. It is difficult to explain why the probability of cycling is higher for those in the ABC socio-economic group except to indicate that those in higher socio-economic groups are better able to afford the costs of providing children with a bicycle and associated equipment.

Distance

For those students travelling nine miles or less to school/college, the probability of travelling by public transport, as a passenger in a car or by other means is significantly lower than the probability of walking or cycling. These results are consistent with expectations and with the aggregated patterns presented in Chapter 3 where among those travelling short distances to school/college, walking and cycling are the dominant modes of transport. The marginal effects in Table 7.16 confirm that travelling nine miles or less increases the probability that the student will walk or cycle but reduces the probability that the student will travel by public transport, as a passenger in a car or by other means. The higher negative marginal effects for the bus/train category in comparison with the car passenger category indicate that those travelling short distances are even less likely to travel by bus or train than as a passenger in a car.

Once again, the marginal effects for the six-alternative model, which are presented in Table 7.18, are slightly different. While the effect of increasing distance reduces the probability of walking to school/college, the effect of increasing distance first increases and then decreases the probability that a student will cycle to school/college. In comparison with the base category of travelling ten miles or more to school/college, while walking is favoured by those travelling distances of one mile or less, cycling is favoured by those travelling distances of two miles. The effect of walking dominates however in the merged category results in Table 7.16.

Area of Residence

Even after distance to school/college has been controlled for, there exist significant differences in the effect of area of residence on the choice of mode of transport to school/college. Those living in Dun Laoghaire-Rathdown are significantly more likely to travel as a passenger in a car but significantly less likely to travel by public transport. For those living in South Dublin, travelling by public transport is significantly less likely than walking. The marginal effects in Table 7.16 confirm that residing in Dun Laoghaire-Rathdown reduces the probability of walking or cycling and travelling by public transport to school/college but increases the probability of travelling as a passenger in a car by the greatest amount. This is consistent with the aggregated data presented in Tables 3.19, 3.23 and 3.27 where the proportions being driven to school/college are highest in Dun Laoghaire-Rathdown, particularly for primary schoolchildren. The effects of living in Fingal are of similar signs and magnitudes, although the effect on the probability of taking public transport to school/college is insignificant. In other words, there is no significant difference between those living in Dublin County Borough and those living in Fingal in terms of the probability of taking public transport to school/college. In contrast to the effects for Dun Laoghaire-Rathdown and Fingal, the effect of living in South

Dublin on the probability of walking or cycling to school/college is positive and significant but in common with the results for Dun Laoghaire-Rathdown and Fingal, the marginal effects on the probability of travelling by public transport and as a passenger in a car are significantly negative and positive respectively.

The marginal effects from the six-alternative model presented in Table 7.18 indicate once again that the merging of categories so as to satisfy the IIA axiom masks differences in the effects of the independent variables on the different components of these categories. The marginal effects for the four-alternative model indicate that those living in Dun Laoghaire-Rathdown are significantly less likely to walk or cycle or travel by public transport than those living in Dublin County Borough. However, the marginal effects in Table 7.18 show that while the marginal effect of living in Dun Laoghaire-Rathdown on the probability of walking is negative and significant, the effect on the probability of cycling is insignificant. Therefore, the walking effect dominates. Similarly, the overall negative marginal effect on the probability of travelling by public transport for Dun Laoghaire-Rathdown masks the fact that the effect on the probability of taking the bus is negative while the effect on the probability of taking the train is in fact positive and significant, albeit only marginally so. Similarly, the effect of living in South Dublin on the probability of walking is found to be positive while the effect on the probability of cycling is negative even though when the categories are merged, the effect of South Dublin residence is positive, i.e., the walking effect dominates.

Gender

It is expected that the gender of the student will not be as important an explanatory factor in explaining mode of transport to school/college as it is in explaining mode of transport to work. However, the coefficient estimates in Table 7.15 indicate that female students are more likely to travel by bus or train or travel as a passenger in a car than walk or cycle to school/college. The marginal effects in Table 7.16 indicate that being female increases the probability of travelling by public transport or as a passenger in a car but reduces the probability of walking or cycling. It is difficult to explain why these patterns exist except where it may indicate increased safety concerns on the part of female students, and in particular on the part of their parents. The marginal effects from the six-alternative model in Table 7.18 confirm the negative effect of gender on the probability of cycling but indicate that there are no significant differences between male and female students in their probability of walking to school/college. Similarly, while the effect of being female increases the probability of taking the bus, there are no significant differences between males and females in terms of the probability of travelling by train.

Age

The age of the student exerts a consistently significant effect on modal choice for the journey to school/college. While being a younger student increases the probability of travelling by public transport or as a passenger in a car in comparison with walking or cycling, it reduces the probability of choosing other modes, principally driving by car. The marginal effects in Table 7.16 confirm that the probability of walking or cycling and travelling by other means increases with the age of the student while the probability of travelling as a passenger in a car declines as the age of the student increases. This effect reflects the car availability of households but may also indicate the increased safety concerns involved in letting young children walk or cycle to school. For the public transport category, students aged 11-15 years have the highest probability of travelling by public transport in comparison with the base category of those aged 20 years and older.

The marginal effects for the more disaggregated categories presented in Table 7.18 confirm the increasing probability of walking or cycling to school/college as the age of the student increases. In other words, the aggregation of this category is not disguising any different effects on the probability of choosing the two different modes. However, the effect of age on the probability of travelling by public transport in the six-alternative model was found to be positive but at a decreasing rate whereas in the four-alternative model, age exerts no significant effect on the probability of choosing the bus but exerts a negative and declining effect on the probability of choosing the train.

7.7 Summary and Conclusions

Despite the limitations associated with using COP data to examine modal choice decisions [see Section 4.4], the results highlight the importance of individual socio-economic characteristics in explaining modal choice for the journeys to work and school/college in Dublin in 1996. The income elasticities indicate that a one per cent increase in household income increases the probability of driving a car to work by 1.28 per cent although it is likely that this elasticity value is also capturing the effect of increasing income on increased car ownership probability. The fact that increasing income increases the probability of driving a car to work but reduces the probability of travelling by more sustainable modes of transport such as walking, cycling, public transport and as a passenger in a car is supported by the aggregated data in Table 3.10 where the proportions driving a car to work increased greatly over the period 1986 to 2000, a period of rapid economic growth in Ireland. The fact that the proportions travelling by train stayed relatively constant at approximately 4 per cent over the period is supported by the fact that the effect of income on the probability of travelling by train is insignificant, reflecting the attractiveness of a mode that can compete with the private car in terms of journey times. This has important policy implications in terms of identifying areas to target if a decrease in car use is to be achieved [see Section 8.2].

The effects of distance, area of residence and gender on choice of mode of transport to work are also highly significant and are in broad agreement with the aggregated results presented in Tables 3.11, 3.13 and 3.15. It was expected that the effect of area of residence was unlikely to be as significant a predictor of modal choice using disaggregated data after income and distance had been controlled for. However, the significance of area of residence in explaining modal choice may indicate that residents of different areas have different tastes or attitudes towards certain forms of transport. It also indicates differences in levels of public transport provision, with residents of Dun Laoghaire-Rathdown and Fingal, which are well served by train services, having higher probabilities of using the train. The effects of gender and age are consistent with the results presented in Chapters 5 and 6 where households headed by young females used their cars the least and consequently spent the most per capita on bus fares. The results in this chapter indicate that in addition, females are more likely to travel as passengers in a car (consistent with the aggregate patterns in Table 3.15). The fact that the effect of increasing age reduces the probability of travelling by public transport to work but only up to the age of 60 years is in direct contrast, however, to the result in Chapter 6 that older households spend the least per capita on bus and taxi fares compared to younger households. However, it must be remembered that the expenditure data employed in Chapter 6 covers trips for all purposes, not just the journey to work.

For the journey to school/college, the results reflect the aggregated patterns of travel to school and college presented in Tables 3.17, 3.21 and 3.25. Once again, the effect of area of residence suggests that public transport availability affects modal choice but also that there may be additional factors such as the levels of female employment and car ownership that are important in determining mode of transport to school/college. An interesting finding is that female students are significantly less likely to cycle to school/college, a pattern of behaviour that persists into adulthood. The significant effects of the age of the student suggest that safety concerns lead the parents of young schoolchildren to drive them to school rather than walk, cycle or use public transport. These results have important implications for identifying areas in need of reform and categories of the population that need to be targeted if an increase in the use of more sustainable forms of transport is to be achieved [see Section 8.2].

7A TABLES

Table 7.1 Journeys for Commuting, Education and Shopping as a Proportion of Total Journeys per Person in the UK: 1996, 1998 and 2000

	COMMUTING	EDUCATION	SHOPPING
1996	15.8	19.1	21.1
1998	15.6	19.0	21.0
2000	15.3	19.2	21.0

Sources: UK DETR (2002). Transport Statistics Bulletin National Travel Survey: 1999/2000 Update.
UK DETR (2001e). Transport Statistics Bulletin National Travel Survey: 1998/2000 Update.
UK DETR (1999). Transport Statistics Bulletin National Travel Survey: 1996/1998 Update.

Note: (i) Education includes escort education and other escort trips.

Table 7.2 Initial and Final Dependent Variable Categories for Work and School Samples

WORK	SCHOOL
Initial Specification	**Initial Specification**
Car Driver (Base Category)	On Foot (Base Category)
On Foot	Bicycle
Bicycle	Bus
Bus	Train
Train	Car Passenger
Car Passenger	Other
Final Specification	**Final Specification**
Car Driver (Base Category)	On Foot and Bicycle (Base Category)
On Foot and Bicycle	Bus and Train
Bus and Train	Car Passenger
Car Passenger	Other

Notes: (i) The car driver category for the work sample includes car driver, motorcycle, lorry or van.
(ii) The other category for the school sample includes car driver, motorcycle, lorry or van.

Table 7.3 Hausman Tests of Independence from Irrelevant Alternatives in Work Sample with Six Alternatives

OMITTED CATEGORY	TEST STATISTIC	DECISION RULE
On Foot	35.132	Do not reject H_0
Bicycle	-4.641	Inconclusive
Bus	-160.471	Inconclusive
Train	16.864	Do not reject H_0
Car Passenger	-29.457	Inconclusive

Notes: (i) Base Category is car driver, motorcycle, lorry or van.
(ii) H_0: IIA; H_0: IIA does not hold
(iii) The test is distributed as chi-squared with degrees of freedom equal to the difference in the number of estimated parameters under the null and alternative hypotheses, i.e., 80.
(iv) The χ^2 critical value with 80 degrees of freedom is 112.329.

Table 7.4 Small-Hsiao Tests of Independence from Irrelevant Alternatives in Work Sample with Six Alternatives

OMITTED CATEGORY	TEST STATISTIC	DECISION RULE
On Foot	83.600	Reject H_0
Bicycle	84.631	Reject H_0
Bus	91.471	Reject H_0
Train	89.093	Reject H_0
Car Passenger	89.267	Reject H_0

Notes: (i) Base Category is car driver, motorcycle, lorry or van.
(ii) H_0: IIA; H_0: IIA does not hold
(iii) The test is distributed as chi-squared with degrees of freedom equal to the difference in the number of estimated parameters under the null and alternative hypotheses, i.e., 20.
(iv) The χ^2 critical value with 20 degrees of freedom is 37.566.

Table 7.5 Small-Hsiao Tests of Independence from Irrelevant Alternatives in Work Sample with Four Alternatives

OMITTED CATEGORY	TEST STATISTIC	DECISION RULE
On Foot/Bicycle	26.322	Do not reject H_0
Bus/Train	36.822	Do not reject H_0
Car Passenger	33.278	Do not reject H_0

Notes: (i) Base Category is car driver, motorcycle, lorry or van
(ii) H_0: IIA; H_0: IIA does not hold
(iii) The test is distributed as chi-squared with degrees of freedom equal to the difference in the number of estimated parameters under the null and alternative hypotheses, i.e., 20.
(iv) The χ^2 critical value with 20 degrees of freedom is 37.566.

Table 7.6 Hausman Tests of Independence from Irrelevant Alternatives in School Sample with Six Alternatives

OMITTED CATEGORY	TEST STATISTIC	DECISION RULE
Bicycle	-35.953	Inconclusive
Bus	-12.418	Inconclusive
Train	-18.106	Inconclusive
Car Passenger	99.334	Reject H_0
Other	-2.466	Inconclusive

Notes: (i) Base Category is on foot/bicycle; Other includes car driver, motorcycle, lorry or van.
(ii) H_0: IIA; H_0: IIA does not hold
(iii) The test is distributed as chi-squared with degrees of freedom equal to the difference in the number of estimated parameters under the null and alternative hypotheses, i.e., 56.
(iv) The χ^2 critical value with 56 degrees of freedom is 83.514.

Table 7.7 Small-Hsiao Tests of Independence from Irrelevant Alternatives in School Sample with Six Alternatives

OMITTED CATEGORY	TEST STATISTIC	DECISION RULE
Bicycle	90.346	Reject H_0
Bus	86.793	Reject H_0
Train	93.581	Reject H_0
Car Passenger	87.550	Reject H_0
Other	70.237	Reject H_0

Notes: (i) Base Category is on foot/bicycle; Other includes car driver, motorcycle, lorry or van.
(ii) H_0: IIA; H_0: IIA does not hold
(iii) The test is distributed as chi-squared with degrees of freedom equal to the difference in the number of estimated parameters under the null and alternative hypotheses, i.e., 14.
(iv) The χ^2 critical value with 14 degrees of freedom is 29.141.

Table 7.8 Small-Hsiao Tests of Independence from Irrelevant Alternatives in School Sample with Four Alternatives

OMITTED CATEGORY	TEST STATISTIC	DECISION RULE
Bus/Train	23.158	Do not reject H_0
Car Passenger	25.442	Do not reject H_0
Other	22.219	Do not reject H_0

Notes: (i) Base Category is on foot/bicycle; Other includes car driver, motorcycle, lorry or van.
(ii) H_0: IIA; H_0: IIA does not hold
(iii) The test is distributed as chi-squared with degrees of freedom equal to the difference in the number of estimated parameters under the null and alternative hypotheses, i.e., 14.
(iv) The χ^2 critical value with 14 degrees of freedom is 29.141.

Table 7.9 Four-Alternative Multinomial Logit Model of Mode of Transport to Work (Estimated Coefficients)

VARIABLE	ON FOOT/BICYCLE	BUS/TRAIN	CAR PASSENGER
Constant	0.318	3.941	1.215
	(0.504)	(0.375)***	(0.562)**
HHEXP[131]	-1.101	-1.397	-1.193
	(0.150)***	(0.121)***	(0.181)***
ONELESS	4.773	-0.798	0.245
	(0.210)***	(0.106)***	(0.132)*
TWO	3.604	-0.160	0.135
	(0.211)***	(0.087)*	(0.129)
THREE	2.824	0.082	0.293
	(0.214)***	(0.080)	(0.118)**
FOUR	2.316	0.219	0.336
	(0.221)***	(0.082)***	(0.122)***
FIVE	1.614	0.235	0.114
	(0.214)***	(0.063)***	(0.096)
DLR	-0.911	-0.565	-0.082
	(0.079)***	(0.061)***	(0.091)
FINGAL	-0.813	-0.373	0.049
	(0.093)***	(0.065)***	(0.096)
SCD	-0.749	-0.554	-0.003
	(0.073)***	(0.058)***	(0.084)
FEMALE	0.054	0.815	1.231
	(0.058)	(0.047)***	(0.071)***
THIRTY	-0.266	-0.365	-0.390
	(0.108)**	(0.087)***	(0.129)***
FORTY	-0.684	-0.761	-1.025
	(0.101)***	(0.082)***	(0.124)***
FIFTY	-0.549	-0.582	-0.747
	(0.138)***	(0.113)***	(0.169)***

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van.

[131] The models for the work sample were also estimated with SEGABC replacing HHEXP. While the results for the models with SEGABC are not presented, the results are the same in both sign and significance levels for all variables.

Table 7.9 continued

VARIABLE	ON FOOT/BICYCLE	BUS/TRAIN	CAR PASSENGER
SIXTY	-0.671	-0.309	-0.691
	(0.181)***	(0.153)**	(0.248)***
PRIMARY	-0.391	-0.469	-0.594
	(0.231)*	(0.187)**	(0.283)**
SECONDARY	-0.601	-0.552	-0.381
	(0.145)***	(0.116)***	(0.174)**
MARRIED	-1.135	-1.559	-0.388
	(0.095)***	(0.077)***	(0.112)***
OTHERMAR	-1.068	-1.115	-0.931
	(0.143)***	(0.115)***	(0.200)***
PART	0.546	0.588	0.064
	(0.076)***	(0.064)***	(0.095)
Number of Observations		16,912	
Log-Likelihood		-15,367.700	
McFadden's R-squared[132]		21.909	

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(ii) Base Category is car driver, motorcycle, lorry or van.

[132] McFadden's R-squared is a common measure of goodness-of-fit in MNL models [see Greene (2000), Verbeek (2000) and Amemiya (1984)]. It is calculated as $1\text{-LogL}_{UR}/\text{LogL}_{R}$ where LogL_{UR} is the log-likelihood value of the estimated model and LogL_{R} is the log-likelihood value from the model when all the parameters, except the intercept, are set to zero.

Table 7.10 Four-Alternative Multinomial Logit Model of Mode of Transport to Work (Marginal Effects)

VARIABLE	CAR DRIVER	ON FOOT/BICYCLE	BUS/TRAIN	CAR PASSENGER
Constant	-0.602	-0.063	0.648	0.018
	(0.074)***	(0.041)	(0.062)***	(0.039)
HHEXP	0.306	-0.056	-0.196	-0.053
	(0.024)***	(0.012)***	(0.020)***	(0.012)***
ONELESS	-0.178	0.421	-0.239	-0.004
	(0.019)***	(0.013)***	(0.017)***	(0.009)
TWO	-0.191	0.309	-0.104	-0.014
	(0.018)***	(0.013)***	(0.014)***	(0.009)
THREE	-0.186	0.237	-0.049	-0.001
	(0.018)**	(0.014)***	(0.013)***	(0.008)
FOUR	-0.178	0.190	-0.016	0.003
	(0.019)***	(0.015)***	(0.014)	(0.008)
FIVE	-0.129	0.132	0.005	-0.008
	(0.016)***	(0.016)***	(0.011)	(0.007)
DLR	0.132	-0.065	-0.077	0.010
	(0.012)***	(0.007)***	(0.010)***	(0.006)*
FINGAL	0.094	-0.062	-0.048	0.016
	(0.013)***	(0.008)***	(0.011)***	(0.007)**
SCD	0.117	-0.052	-0.079	0.015
	(0.012)***	(0.006)***	(0.009)***	(0.006)**
FEMALE	-0.170	-0.021	0.118	0.073
	(0.009)***	(0.005)***	(0.007)***	(0.005)***
THIRTY	0.082	-0.012	-0.050	-0.020
	(0.017)***	(0.009)	(0.014)***	(0.009)**
FORTY	0.189	-0.035	-0.099	-0.055
	(0.016)***	(0.008)***	(0.013)***	(0.009)***
FIFTY	0.144	-0.029	-0.076	-0.039
	(0.022)***	(0.011)**	(0.019)***	(0.012)***
SIXTY	0.112	-0.046	-0.027	-0.039
	(0.030)***	(0.015)***	(0.025)	(0.017)**

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van

Table 7.10 continued

VARIABLE	CAR DRIVER	ON FOOT/BICYCLE	BUS/TRAIN	CAR PASSENGER
PRIMARY	0.113	-0.019	-0.062	-0.032
	(0.037)***	(0.019)	(0.031)**	(0.020)*
SECONDARY	0.126	-0.037	-0.076	-0.013
	(0.023)***	(0.012)***	(0.019)***	(0.012)
MARRIED	0.292	-0.062	-0.237	0.007
	(0.015)***	(0.008)***	(0.012)***	(0.008)
OTHERMAR	0.254	-0.061	-0.153	-0.040
	(0.023)***	(0.012)***	(0.019)***	(0.014)***
PART	-0.113	0.034	0.088	-0.009
	(0.013)***	(0.006)***	(0.010)***	(0.006)
Number of Observations		16,912		
Log-Likelihood		-15,367.700		
McFadden's R-squared		21.909		

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van.

Table 7.11 Six-Alternative Multinomial Logit Model of Mode of Transport to Work (Estimated Coefficients)

VARIABLE	ON FOOT	BICYCLE	BUS	TRAIN	CAR PASSENGER
Constant	-3.321	0.977	4.042	1.183	1.195
	(1.159)***	(0.651)	(0.422)***	(0.640)*	(0.560)**
HHEXP	-1.018	-1.311	-1.650	-0.759	-1.193
	(0.190)***	(0.201)***	(0.136)***	(0.207)***	(0.180)***
ONELESS	7.827	2.875	-0.182	-3.149	0.344
	(1.002)***	(0.225)***	(0.115)	(0.456)***	(0.132)***
TWO	6.303	2.805	0.390	-2.227	0.181
	(1.003)***	(0.223)***	(0.096)***	(0.265)***	(0.129)
THREE	4.956	2.552	0.594	-1.547	0.323
	(1.006)***	(0.222)***	(0.090)***	(0.181)***	(0.118)***
FOUR	3.768	2.252	0.708	-1.184	0.362
	(1.019)***	(0.228)***	(0.092)***	(0.173)**	(0.122)***
FIVE	2.322	1.617	0.522	-0.208	0.127
	(1.026)**	(0.219)***	(0.075)***	(0.089)	(0.096)
DLR	-1.114	-0.780	-0.927	0.152	-0.111
	(0.105)***	(0.102)***	(0.073)***	(0.097)	(0.091)
FINGAL	-0.763	-0.945	-0.624	0.125	0.035
	(0.118)***	(0.133)***	(0.076)***	(0.102)	(0.096)
SCD	-0.692	-0.736	-0.338	-3.030	0.015
	(0.094)***	(0.082)***	(0.061)***	(0.310)***	(0.085)
FEMALE	0.587	-0.579	0.892	0.536	1.232
	(0.073)***	(0.082)***	(0.051)***	(0.083)***	(0.071)***
THIRTY	-0.269	-0.246	-0.295	-0.507	-0.392
	(0.137)**	(0.144)*	(0.097)***	(0.154)***	(0.129)***
FORTY	-0.619	-0.781	-0.825	-0.577	-1.030
	(0.128)***	(0.136)***	(0.092)***	(0.143)***	(0.124)***
FIFTY	-0.535	-0.567	-0.604	-0.460	-0.756
	(0.175)***	(0.185)***	(0.128)***	(0.199)**	(0.169)***
SIXTY	-0.570	-0.849	-0.290	-0.281	-0.698
	(0.223)**	(0.263)***	(0.171)*	(0.283)	(0.248)***

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van.

Table 7.11 continued

VARIABLE	ON FOOT	BICYCLE	BUS	TRAIN	CAR PASSENGER
PRIMARY	-0.176	-0.686	-0.421	-1.007	-0.566
	(0.291)	(0.309)**	(0.209)**	(0.347)***	(0.283)**
SECONDARY	-0.516	-0.727	-0.577	-0.492	-0.371
	(0.184)***	(0.194)***	(0.130)***	(0.198)**	(0.173)**
MARRIED	-1.381	-0.975	-1.811	-0.900	-0.403
	(0.121)***	(0.127)***	(0.087)***	(0.133)***	(0.112)***
OTHERMAR	-1.202	-1.016	-1.313	-0.583	-0.940
	(0.175)***	(0.210)***	(0.128)***	(0.210)***	(0.200)***
PART	0.597	0.498	0.647	0.310	0.068
	(0.091)***	(0.109)***	(0.069)***	(0.125)**	(0.095)
Number of Observations			16,912		
Log-Likelihood			-17,969.370		
McFadden's R-squared			23.617		

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van.

Table 7.12 Six-Alternative Multinomial Logit Model of Mode of Transport to Work (Marginal Effects)

VARIABLE	CAR DRIVER	ON FOOT	BICYCLE	BUS	TRAIN	CAR PASSENGER
Constant	-0.527	-0.068	0.009	0.544	0.009	0.033
	(0.073)***	(0.012)***	(0.033)	(0.057)***	(0.014)	(0.042)
HHEXP	0.316	-0.009	-0.045	-0.196	-0.006	-0.059
	(0.023)***	(0.003)***	(0.010)***	(0.018)***	(0.005)	(0.013)***
ONELESS	-0.140	0.126	0.146	-0.067	-0.076	0.011
	(0.021)***	(0.011)***	(0.010)***	(0.015)***	(0.008)***	(0.010)
TWO	-0.189	0.099	0.138	0.017	-0.057	-0.009
	(0.019)***	(0.008)***	(0.009)***	(0.013)	(0.007)***	(0.010)
THREE	-0.205	0.077	0.123	0.047	-0.042	0.001
	(0.017)***	(0.008)***	(0.010)***	(0.012)***	(0.005)***	(0.009)
FOUR	-0.202	0.057	0.107	0.067	-0.034	0.005
	(0.018)***	(0.009)***	(0.010)***	(0.012)***	(0.005)***	(0.009)
FIVE	-0.144	0.035	0.077	0.051	-0.010	-0.008
	(0.016)***	(0.012)***	(0.010)***	(0.010)***	(0.002)***	(0.007)
DLR	0.146	-0.015	-0.031	-0.118	0.009	0.009
	(0.012)***	(0.003)***	(0.005)***	(0.010)***	(0.002)***	(0.007)
FINGAL	0.107	-0.010	-0.043	-0.077	0.007	0.017
	(0.013)***	(0.003)***	(0.007)***	(0.010)***	(0.002)***	(0.007)**
SCD	0.115	-0.009	-0.031	-0.027	-0.065	0.016
	(0.012)**	(0.002)***	(0.005)***	(0.008)***	(0.006)***	(0.006)**
FEMALE	-0.159	0.006	-0.045	0.109	0.007	0.083
	(0.009)***	(0.001)***	(0.004)***	(0.007)***	(0.002)***	(0.005)***
THIRTY	0.073	-0.003	-0.007	-0.031	-0.009	-0.023
	(0.017)***	(0.002)	(0.007)	(0.013)**	(0.003)***	(0.010)**
FORTY	0.190	-0.005	-0.027	-0.090	-0.007	-0.062
	(0.016)***	(0.002)**	(0.007)***	(0.012)***	(0.003)**	(0.009)***
FIFTY	0.141	-0.005	-0.019	-0.065	-0.006	-0.045
	(0.022)***	(0.003)*	(0.009)**	(0.017)***	(0.004)	(0.013)***
SIXTY	0.111	-0.007	-0.037	-0.020	-0.003	-0.044
	(0.030)***	(0.004)*	(0.013)***	(0.023)	(0.006)	(0.019)**

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van.

Table 7.12 continued

VARIABLE	CAR DRIVER	ON FOOT	BICYCLE	BUS	TRAIN	CAR PASSENGER
PRIMARY	0.119	0.000	-0.028	-0.040	-0.019	-0.032
	(0.036)***	(0.005)	(0.016)*	(0.028)	(0.008)**	(0.021)
SECONDARY	0.123	-0.005	-0.030	-0.065	-0.007	-0.015
	(0.023)***	(0.003)*	(0.010)***	(0.017)***	(0.004)	(0.013)
MARRIED	0.284	-0.016	-0.030	-0.231	-0.011	0.003
	(0.015)***	(0.003)***	(0.006)***	(0.011)***	(0.003)***	(0.008)
OTHERMAR	0.254	-0.013	-0.035	-0.155	-0.004	-0.046
	(0.023)***	(0.004)***	(0.011)***	(0.017)***	(0.005)	(0.015)***
PART	-0.104	0.007	0.019	0.082	0.003	-0.008
	(0.013)***	(0.002)***	(0.006)***	(0.009)***	(0.003)	(0.007)
Number of Observations			16,912			
Log-Likelihood			-17,969.370			
McFadden's R-squared			23.617			

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is car driver, motorcycle, lorry or van.

Table 7.13 Income Elasticities for Four-Alternative Model of Mode of Transport to Work

	CAR DRIVER	FOOT/BICYCLE	BUS/TRAIN	CAR PASSENGER
INCOME ELASTICITY	1.278***	-1.526***	-2.284***	-1.765***

Notes: (i) *** significant at 1% level; *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(ii) Significance levels of elasticities are those of the underlying marginal effects.

Table 7.14 Income Elasticities for Six-Alternative Model of Mode of Transport to Work

	CAR DRIVER	FOOT	BICYCLE	BUS	TRAIN	CAR PASSENGER
INCOME ELASTICITY	1.230***	-1.323***	-2.106***	-2.974***	-0.694	-1.817***

Notes: (i) *** significant at 1% level; *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(ii) Significance levels of elasticities are those of the underlying marginal effects.

Table 7.15 Four-Alternative Multinomial Logit Model of Mode of Transport to School (Estimated Coefficients)

VARIABLE	BUS/TRAIN	CAR PASSENGER	OTHER
Constant	4.185	0.356	2.116
	(0.585)***	(0.612)	(0.642)***
SEGABC	-0.039	1.113	0.478
	(0.072)	(0.062)***	(0.191)**
ONELESS	-8.377	-6.330	-6.707
	(0.590)***	(0.605)***	(0.698)***
TWO	-5.554	-4.290	-5.012
	(0.589)***	(0.605)***	(0.673)***
THREE	-4.451	-3.176	-3.981
	(0.590)***	(0.608)***	(0.660)***
FOUR	-3.182	-2.644	-2.861
	(0.602)***	(0.624)***	(0.670)***
FIVE	-2.548	-2.055	-2.767
	(0.595)***	(0.614)***	(0.643)***
DLR	-0.158	0.852	0.339
	(0.093)*	(0.084)***	(0.238)
FINGAL	-0.029	0.329	0.053
	(0.095)	(0.086)***	(0.308)
SCD	-0.442	-0.012	-0.097
	(0.086)***	(0.080)	(0.270)
FEMALE	0.499	0.382	0.267
	(0.064)***	(0.059)***	(0.182)
PRIME	1.760	4.394	-2.287
	(0.132)***	(0.180)***	(0.630)***
SEC1	1.570	3.387	-1.717
	(0.124)***	(0.178)***	(0.397)***
SEC2	1.065	2.033	-1.257
	(0.116)***	(0.175)***	(0.250)***
Number of Observations		10,610	
Log-Likelihood		-7,661.858	
McFadden's R-squared		33.436	

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is on foot/bicycle; Other includes car driver, motorcycle, lorry or van.

Table 7.16 Four-Alternative Multinomial Logit Model of Mode of Transport to School (Marginal Effects)

VARIABLE	ON FOOT/BICYCLE	BUS/TRAIN	CAR PASSENGER	OTHER
Constant	-0.565	0.736	-0.178	0.006
	(0.147)***	(0.081)***	(0.075)**	(0.003)**
SEGABC	-0.135	-0.071	0.205	0.001
	(0.014)***	(0.012)***	(0.010)***	(0.001)
ONELESS	1.833	-1.148	-0.666	-0.020
	(0.149)***	(0.079)***	(0.077)***	(0.005)***
TWO	1.229	-0.755	-0.458	-0.017
	(0.148)***	(0.077)***	(0.078)***	(0.005)***
THREE	0.952	-0.620	-0.319	-0.013
	(0.149)***	(0.077)***	(0.078)***	(0.004)***
FOUR	0.727	-0.422	-0.296	-0.009
	(0.152)***	(0.077)***	(0.081)***	(0.003)***
FIVE	0.576	-0.341	-0.225	-0.010
	(0.150)***	(0.075)***	(0.079)***	(0.003)***
DLR	-0.087	-0.078	0.164	0.001
	(0.019)***	(0.015)***	(0.014)***	(0.001)
FINGAL	-0.037	-0.024	0.062	0.000
	(0.019)*	(0.016)	(0.014)***	(0.002)
SCD	0.056	-0.079	0.023	0.000
	(0.017)***	(0.014)***	(0.013)***	(0.002)
FEMALE	-0.109	0.068	0.041	0.000
	(0.013)***	(0.011)***	(0.010)*	(0.001)
PRIME	-0.752	0.071	0.705	-0.024
	(0.033)***	(0.021)***	(0.029)***	(0.004)***
SEC1	-0.606	0.094	0.531	-0.018
	(0.032)***	(0.019)***	(0.028)***	(0.004)***
SEC2	-0.378	0.079	0.312	-0.013
	(0.031)***	(0.018)***	(0.029)***	(0.003)***
Number of Observations		10,610		
Log-Likelihood		-7,661.858		
McFadden's R-squared		33.436		

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is on foot/bicycle; Other includes car driver, motorcycle, lorry or van.

Table 7.17 Six-Alternative Multinomial Logit Model of Mode of Transport to School (Estimated Coefficients)

VARIABLE	BICYCLE	BUS	TRAIN	CAR PASSENGER	OTHER
Constant	1.456	5.050	4.762	1.793	3.626
	(1.230)	(1.007)***	(1.020)***	(1.021)*	(1.041)***
SEGABC	0.615	0.100	0.656	1.244	0.758
	(0.097)***	(0.078)	(0.146)***	(0.066)***	(0.194)***
ONELESS	-2.691	-8.579	-12.101	-6.974	-7.622
	(1.231)**	(1.009)***	(1.169)***	(1.016)***	(1.072)***
TWO	-0.726	-5.435	-8.481	-4.614	-5.461
	(1.232)	(1.008)***	(1.058)***	(1.017)***	(1.060)***
THREE	0.123	-3.888	-6.098	-3.030	-3.906
	(1.238)	(1.014)***	(1.040)***	(1.023)***	(1.057)***
FOUR	0.634	-2.210	-4.064	-2.061	-2.358
	(1.278)	(1.054)**	(1.074)***	(1.065)*	(1.094)**
FIVE	1.531	-0.884	-2.117	-0.704	-1.478
	(1.299)	(1.084)	(1.090)*	(1.093)	(1.111)
DLR	0.484	-0.043	0.739	1.013	0.644
	(0.117)***	(0.103)	(0.190)***	(0.089)***	(0.242)***
FINGAL	-0.869	-0.197	-0.045	0.216	-0.101
	(0.164)***	(0.101)*	(0.200)	(0.089)**	(0.310)
SCD	-0.573	-0.514	-3.606	-0.124	-0.401
	(0.121)***	(0.091)***	(0.528)***	(0.083)	(0.276)
FEMALE	-1.310	0.181	-0.097	0.135	-0.214
	(0.098)***	(0.070)***	(0.141)	(0.062)**	(0.186)
PRIME	-3.024	1.241	-2.318	3.670	-2.798
	(0.276)***	(0.154)***	(1.021)**	(0.195)***	(0.625)***
SEC1	-0.907	1.125	0.450	2.778	-2.158
	(0.148)***	(0.148)***	(0.254)*	(0.193)***	(0.396)***
SEC2	-0.382	0.771	0.641	1.653	-1.570
	(0.139)***	(0.144)***	(0.196)***	(0.192)***	(0.261)***
Number of Observations			10,610		
Log-Likelihood			-9,683.077		
McFadden's R-squared			34.159		

Notes: (i) Standard errors are reported in parentheses.
(ii) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(iii) Base Category is on foot; Other includes car driver, motorcycle, lorry or van.

Table 7.18 Six-Alternative Multinomial Logit Model of Mode of Transport to School (Marginal Effects)

VARIABLE	ON FOOT	BICYCLE	BUS	TRAIN	CAR PASS.	OTHER
Constant	-0.733	-0.033	0.831	0.005	-0.082	0.012
	(0.222)***	(0.040)	(0.108)***	(0.002)**	(0.107)	(0.004)***
SEGABC	-0.158	0.009	-0.096	0.000	0.242	0.002
	(0.014)***	(0.005)**	(0.014)***	(0.000)	(0.012)***	(0.001)*
ONELESS	1.678	0.111	-1.072	-0.015	-0.680	-0.021
	(0.212)***	(0.038)***	(0.100)***	(0.006)**	(0.105)***	(0.005)***
TWO	1.067	0.124	-0.676	-0.011	-0.486	-0.018
	(0.219)***	(0.038)***	(0.101)***	(0.005)**	(0.109)***	(0.005)***
THREE	0.722	0.117	-0.516	-0.008	-0.301	-0.014
	(0.224)***	(0.039)***	(0.103)***	(0.004)**	(0.111)***	(0.005)***
FOUR	0.437	0.101	-0.273	-0.006	-0.251	-0.008
	(0.237)*	(0.040)**	(0.106)**	(0.003)**	(0.119)**	(0.004)**
FIVE	0.139	0.105	-0.137	-0.003	-0.095	-0.008
	(0.248)	(0.041)**	(0.110)	(0.002)**	(0.122)	(0.004)**
DLR	-0.116	0.009	-0.103	0.001	0.208	0.002
	(0.019)***	(0.005)	(0.018)***	(0.000)*	(0.016)***	(0.002)
FINGAL	0.013	-0.045	-0.044	0.000	0.077	0.000
	(0.018)	(0.009)***	(0.017)**	(0.000)	(0.016)***	(0.002)
SCD	0.079	-0.019	-0.081	-0.007	0.030	-0.001
	(0.016)***	(0.006)***	(0.016)***	(0.003)**	(0.016)*	(0.002)
FEMALE	-0.007	-0.072	0.045	0.000	0.035	-0.002
	(0.013)	(0.007)***	(0.012)***	(0.000)	(0.011)***	(0.001)
PRIME	-0.450	-0.234	-0.007	-0.007	0.728	-0.030
	(0.034)***	(0.015)***	(0.025)	(0.002)***	(0.034)***	(0.005)***
SEC1	-0.387	-0.109	0.010	-0.001	0.511	-0.024
	(0.034)***	(0.011)***	(0.024)	(0.001)*	(0.033)***	(0.005)***
SEC2	-0.243	-0.058	0.024	0.000	0.293	-0.017
	(0.033)***	(0.008)***	(0.022)	(0.000)	(0.034)***	(0.004)***
Number of Observations			10,610			
Log-Likelihood			-9,683.077			
McFadden's R-squared			34.159			

Notes: (i) Standard errors are reported in parentheses.
(i) *** significant at 1% level; ** significant at 5% level; * significant at 10% level
(ii) Base Category is on foot; Other includes car driver, motorcycle, lorry or van.

7B APPENDICES

7A Specification Tests for Independence from Irrelevant Alternatives

The Hausman likelihood ratio test is outlined in Hausman and McFadden (1984) and involves comparing parameter estimates under a restricted specification (omitting an alternative choice) and an unrestricted specification (including the full set of alternatives), i.e.,

$$\chi^2 = \left(\beta_r - \beta_{ur}\right)' \left(V_r - V_{ur}\right)' \left(\beta_r - \beta_{ur}\right) \quad (7A.1)$$

where β_r represent the parameter estimates based on the restricted sub-set of choices, β_{ur} represents the parameter estimates based on the unrestricted full set of choices and V_r and V_{ur} are the estimated variance-covariance matrices for the restricted and unrestricted models respectively. The test statistic is distributed as chi-squared with the number of degrees of freedom equal to the difference in the number of estimated parameters.

The Small-Hsiao likelihood ratio test is outlined in Small and Hsiao (1985) and involves randomly dividing the sample into two sub-sets, A and B. The model is then estimated in each sub-sample using the full choice set, C. Using the parameter estimates β_C^A and β_C^B, β_C^{AB} is formed as follows:

$$\beta_C^{AB} = \frac{1}{\sqrt{2}}\beta_C^A + \left(1 - \frac{1}{\sqrt{2}}\right)\beta_C^B \quad (7A.2)$$

The first sub-sample A is then discarded and the model is estimated for the restricted choice set, D, in sub-sample B giving rise to parameter estimates β_D^B. The Small-Hsiao test statistic is then constructed as:

$$SH = -2\left[log\ L\left(\beta_C^{AB}\right) - log\ L\left(\beta_D^B\right)\right] \quad (7A.3)$$

where $log\ L\left(\beta_C^{AB}\right)$ is the log-likelihood evaluated at the weighted average of the full choice set of estimates β_C^{AB} defined above [Fry and Harris (1998)]. The test statistic is also distributed as chi-squared with the number of degrees of freedom equal to the difference in the number of estimated parameters.

For the choice of mode of transport to work and school/college, five restricted choice sets are constructed by eliminating one choice at a time as well as the individuals that have made that choice.[133] Tables 7.3 and 7.4 present the results of the Hausman and Small-Hsiao IIA tests for the work sample with six alternatives, while Tables 7.6 and 7.7 present the Hausman and Small-Hsiao test results for the school sample with six alternatives. A failing of the Hausman test is that it often reports negative chi-squared test statistics. This results from the fact that even though all models may converge and the estimated variance-covariance matrices are non-singular, taking the inverse of the matrix $\left(V_r - V_{ur}\right)$ may result in singularity [see Small and Hsiao (1985) and Hausman and McFadden (1984)].

[133] This is carried out automatically in STATA.

While Fry and Harris (1998) and Hausman and McFadden (1984) interpret a negative test statistic as evidence for support of the null hypothesis of IIA, Small and Hsiao (1985) and Pagan and Vella (1989) favour the application of the Small-Hsiao test as it overcomes the problem of possible negative test statistics as well as overcoming the bias towards not rejecting the null hypothesis of IIA that is associated with the Hausman test. Tables 7.4 and 7.7 show that the Small-Hsiao tests of IIA are rejected for all alternatives in the work and school samples with six alternatives. Based on intuition, some alternatives are merged and Tables 7.5 and 7.8 present the results of the Small-Hsiao tests on the final dependent variable specifications. As the Small-Hsiao tests of IIA are not rejected for any of the alternatives, the final dependent variable categories for the work and school samples may be considered as distinct alternatives. The final choice sets (presented in Table 7.2) therefore comprise the sets of alternatives for which the IIA assumption cannot be rejected on the basis of the Small-Hsiao tests.

7B Formulae for the Calculation of Marginal Effects and Elasticities in the Multinomial Logit Model

Marginal effects for continuous independent variables in the MNL model are calculated by differentiating the predicated probabilities given in (7B.1) below with respect to each independent variable of interest x_k:

$$P(y_i = j) = \frac{exp(x_i{'}\beta_j)}{1 + exp(x_i{'}\beta_1) + exp(x_i{'}\beta_2) + ... + exp(x_i{'}\beta_J)},\ j = 0,1,....,J \tag{7B.1}$$

$$\frac{\partial P_j}{\partial x_k} = P_j\left[\beta_{jk} - \sum_{j=1}^{J-1} P_j.\beta_{jk}\right] \tag{7B.2}$$

where β_{jk} is the parameter estimate for variable *k*. This enables the calculation of elasticities for the independent variables in the model as follows:

$$e = \frac{\partial P_j}{\partial x_k}.\frac{x_k}{P_j} = x_k\left[\beta_{jk} - \sum_{j=1}^{J-1} P_j.\beta_{jk}\right] \tag{7B.3}$$

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Overview

This thesis was concerned with examining the income and socio-economic determinants of transport demand, using Dublin as a case study. Chapter 1 set the context and detailed the aims and structure of the thesis. The problem of excessive car use in urban areas was discussed and the increasing movement away from earlier policies concerned with expanding road capacity towards a more integrated solution encompassing investment in public transport and complementary measures, such as improved cycle and bus lanes and road pricing, was documented. In this context, the need for a better understanding of the income and socio-economic factors influencing urban transport decisions was highlighted.

Chapter 2 discussed previous literature relevant to the analyses in this thesis, grouped into the three broad areas that form the basis of the core chapters, namely car ownership and use (Chapter 5), public transport use (Chapter 6) and modal choice (Chapter 7). Chapter 3 motivated the use of Dublin as a case study by documenting the rapid economic and demographic changes that have occurred in Dublin over the last fifteen years and assessed the implications for patterns of travel to work, school and college. Chapter 4 introduced the two micro-data sets that are employed in this thesis, namely the 1987/1988, 1994/1995 and 1999/2000 Household Budget Surveys and the 1996 Census of Population. Issues such as sample sizes and the choice of dependent and independent variables were discussed and broad relationships between the dependent and independent variables were presented. This chapter also described the procedure whereby information from the 1994/1995 Household Budget Survey was used to supplement data from the 1996 Census of Population for use in the analysis in Chapter 7.

In Chapter 5, the issues of household car ownership and use and changes in the relationship between these issues and the income and socio-economic characteristics of the household over the period 1987-1999 were examined using probit and Tobit econometric methodologies. Chapter 6 extended the analysis in Chapter 5 to incorporate household decisions about bus and taxi use. This was the first time in published research that public transport was decomposed into its separate components, as well as the first time that public transport use was analysed for separate samples of households, namely, non car-owning and car-owning households. Chapter 7 estimated multinomial logit models of the modal choice decisions of workers and students in an attempt to ascertain whether the factors influencing overall levels of transport use found in Chapters 5 and 6 were any different to those influencing travel for two specific purposes, i.e., the journeys to work and school/college. A new development was the extension of the analysis to incorporate the journey to school/college, a journey purpose overlooked in previous papers that have modelled modal choice; these papers have primarily concentrated on the journey to work.

Section 8.2 summarises the main findings and discusses the policy implications that arise from the research. Section 8.3 concludes and suggests areas for future research.

8.2 Summary and Policy Implications

8.2.1 Car Ownership and Use

In common with previous research discussed in Section 2.3, income was found to have positive and significant effects on car ownership and use. The result that cars were luxury items in 1987 and 1994 but that by 1999, they had become necessities is in agreement with trends in private car registrations in Dublin over the last fifteen years where the major growth in car registrations occurred over the latter part of the 1990s, but slowed after 2000. This would suggest that as car ownership increases to levels found in other European countries, the importance of income in determining differences in car ownership levels is decreasing. In terms of forecasting future levels of growth, this implies that an increase in income will lead to a smaller proportionate change in car ownership levels, reflecting the already high rates of car ownership in the Dublin area. In addition, our results suggest that, since 1994, car ownership has become more prevalent among other family types, such as households headed by a single female, with no working members and with lower levels of education.

In contrast to the changing effect of income on the probability of car ownership over time, car use was consistently found to be a necessity. Once the expense of acquiring a car has been undertaken, economic considerations are, therefore, less important in determining variations in car use. This would suggest that non-economic measures, such as parking restrictions and priority on road space for public transport vehicles, may be just as effective in reducing car use as economic measures, such as increased car parking charges or road pricing. The results for the additional socio-economic characteristics indicate that households that own and use cars are most likely to be traditional family types, i.e., headed by a middle-aged male with children and with at least one person in employment. The socio-economic composition of car owners and users suggest that these households would be most affected by measures such as parking restrictions, road pricing or tolling. The importance of country-specific factors is highlighted by the divergent effects of age on car ownership and use with older households most likely to own cars yet using their cars the least. Higher insurance costs for young people in Ireland may explain the former result, which is in direct contrast to many studies in the area [see Section 2.3].

8.2.2 Public Transport Use

In terms of bus use, income was found to be an insignificant factor in determining variations in use among households that own one or more cars.[134] In contrast, income had a positive and significant, albeit inelastic, effect on bus use in households that do not own a car. In terms of public transport use, most studies of public transport demand find that income has a significantly positive effect on public transport use [Bergantino (1997) and FitzRoy and Smith (1998, 1994)] but our findings suggest that an increase in incomes will only lead to an increase in bus use among the population of households that do not own a car.[135] With ever increasing rates of car ownership, this does not bode well for

[134] With the exception of 1999 where income was significant at the 10 per cent level.
[135] While we cannot infer anything about the effect of increasing income on the possibility that non car-owning households will acquire a car, this possibility would further reduce the potential for increased bus use in the future.

future modal split between car and bus use. This result highlights the importance of our analysis of bus use decisions for two separate samples of households.

In terms of taxi use, the effect of income was positive and significant in all years for both non car-owning and car-owing households, with evidence to show that the income elasticity has been increasing over time to the extent that by 1999, taxis were luxuries. The increasing significance of income in explaining variations in taxi use is consistent with aggregate trends in taxi use in Dublin, where taxi use has increased significantly in recent years due to economic growth, parking restrictions in the city centre, a strengthening of the drink driving legislation [Oscar Faber (1998)] and the deregulation of the market in 2000, which substantially increased supply. In addition, the insignificance of income in determining bus use in households with one or more cars, as well as the higher elasticities for taxi use in comparison with those for bus use, suggest that changes in income will lead to much greater changes in taxi use than in bus use. This result is consistent with the fact that taxis are considered a closer substitute for the car than buses, meaning that as car ownership increases and restrictions on car use in the city centre strengthen, the shift will be towards taxis rather than towards buses. This has key implications for urban transport planning and the regulation of the bus and taxi markets in the future. Households with high levels of taxi use have similar socio-economic characteristics to households that have a high level of bus use (i.e., no children, young, at least one working member) except that there is no significant gender difference. In addition, the fact that single females are still more likely to use the bus even when they have access to a car suggests that males should be targeted in promotional campaigns to encourage increased use of the bus.

8.2.3 Modal Choice

In Chapter 7, it was found that an increase in household income leads to an increase in the probability of travelling by car to work and consequently reduces the probability that the individual will travel on foot or by bicycle, by public transport or as a passenger in a car. The largest decrease in probability occurs for the public transport category. While this income effect obviously includes the effect of increased car ownership probability, the results indicate that future rises in income in the Dublin area are likely to perpetuate the shift away from walking, cycling and public transport towards the private car. The results from the six-alternative model (while they must be interpreted with caution since the IIA axiom is rejected), suggest that an increase in income would not significantly change the probability of travelling by train, reflecting the ability of the train to compete with the private car in terms of speed. These results are consistent with travel patterns to work from 1996-2000 [presented in Table 3.10] where the proportions driving to work increased substantially at the expense of those cycling, using the bus and travelling as a passenger in a car. The fact that the proportions travelling by train increased slightly is in agreement with the forecasts from our model where increases in income would have no significant effect on the probability of travelling by train. This may reflect the fact that the train generally has a better image than the bus [Webster and Bly (1980)], perhaps due to its comparative time and comfort advantages. These results, along with the results for distance, highlight the potential that exists to attract car drivers to modes that have similar speed and comfort characteristics. This would suggest continuing investment in measures such as QBCs and express bus services for commuters, which can significantly improve the attractiveness of the bus, as well as improved park and ride facilities at train stations.

While income data were unavailable for students, the effect of socio-economic group on modal choice for students mirrors that of income for workers with the probability of travelling as a passenger in a car increasing with socio-economic group at the expense of walking, cycling and using public transport. While data for travel patterns to school/college since 1996 are not yet available, it expected that this prediction for modal choice for students is an accurate reflection of changes since 1996. For the journey to school/college, safety concerns are most evident in the significantly reduced probability of young schoolchildren walking or cycling to school. This highlights the need to allay parental concerns with safety through the provision of dedicated bus routes to school and more assistance at road crossings. A final area in need of reform is the urgent need to increase the attractiveness of cycling. Measures to increase safety such as improved cycle lanes as well as measures to ease practical difficulties associated with cycling such as changing and washing facilities at work and more secure parking facilities are necessary if the substantial shift away from cycling is to be halted or reversed.

8.3 Concluding Comments and Future Research

In this thesis, the income and socio-economic determinants of the demand for car ownership, car use and public transport use as well as the choice of mode of transport to work and school/college were examined in detail. This was the first time that the demand for transport has been analysed at the micro-level in Ireland. In addition, it was the first time that public transport use as proxied by expenditure has been disaggregated into more detailed categories (i.e., bus vs. taxi). In addition, the examination of public transport expenditure for households of differing car ownership status highlighted significant differences in behaviour, in particular for the bus use case. In terms of modal choice, while international literature has tended to focus on the journey to work, this thesis exploits the availability of data on the journey to school/college and consequently examines choice of mode of transport for this journey.

In terms of future work, the release of the 2002 Census of Population will aid in examining the substantial changes that have occurred in recent times in the income and socio-economic influences on modal choice for the journeys to work and school/college. In addition, the availability of household car ownership status in the 2002 Census is a significant development and will enable household car ownership status to be explicitly included in future models of modal choice. An extension to the Tobit models in Chapters 5 and 6 may consider the possibility that there are alternative explanations for zero observations on transport expenditures and examine the appropriateness of applying methodologies such as the double hurdle and infrequency of purchase to these decisions. In addition, an extension to the analysis in Chapter 6 might consider the possibility of examining bus and taxi fare expenditures as part of a system, thus allowing for substitutions/complementarities between the two decisions. Finally, it would be useful to examine the travel decisions of all those living in the Greater Dublin Area (i.e., including residents of Kildare, Meath and Wicklow), as it is these areas that experienced the most rapid economic and demographic change over the period 1986-2000.

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