CAPPING TRANSPORT EMISSIONS:
A WELFARE ANALYSIS OF A PERSONAL CARBON TRADING SCHEME

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DECLARATION

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university. I further declare that, except where reference is given, it is entirely my own work.

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SUMMARY

This thesis presents the findings of a study to determine the welfare effects of a personal carbon trading scheme (PCTS) for the transport sector. A PCTS sets a limit on carbon and allocates free permits to all participants. Individuals are then free to trade permits with others in a carbon market creating a monetary incentive to reduce emissions so as to profit from the prevailing market price. The research focused on three areas of interest in determining the welfare effects of a PCTS. The first area estimated carbon emissions associated with road transportation in Ireland. An analysis of the socio-economic characteristics of individuals within a scheme using a logistic regression analysis followed. The second area of the research estimated welfare changes across population density and social deprivation levels. A second logistic regression model determined the socio-economic characteristics of individuals with varying welfare changes and the impact of the aforementioned density and deprivation variables on these welfare outcomes. The final area of research outlined a framework of the potential structure of a PCTS. Based on this structure, the outcomes of an initial phase of trading were also predicted.

Binary and multinomial logistic regression models were used to determine the important socio-economic factors associated with higher emitters and individuals with varying welfare changes in the thesis. The welfare model utilised a consumer surplus analysis to determine welfare changes arising from carbon price changes. The main data source used to complete these analyses was a travel survey taken from the Irish Census of Population, 2006. A number of supplementary data sources were also used in the logistic regression and welfare models. Throughout the thesis, two study areas were chosen as comparative regions in presenting the findings of this research; Dublin and the Western and Border Region (WBR). The regions were chosen as a means of comparing the outcomes of the PCTS in an urban and rural environment.

An initial study of the Census data detailing travel-to-work trips found that 58% of all trips were by private vehicle. Public transport trips accounted for 9% of trips. Consequently, driving private vehicles accounted for the bulk of carbon emissions associated with work trips. Taking all modes into account, the average national trip length was found to be 16 kilometres with average trip emissions of 2.5kg of carbon.

A cap was set at this level and a second level was chosen 20% below the average emissions level in line with Ireland's reduction targets.

The resulting binary logistic regression determined the characteristics of individuals above both carbon caps nationally and in each study region. Owning a car and driving longer distances to work were identified as the main characteristics of individuals who fell above the cap. Family status was also an important factor as individuals with dependent children were also likely to be above the cap. These individuals would likely be constrained to using private vehicles in travelling to work due to the trip chaining associated with school and work trips. The findings were more pronounced in the WBR than Dublin due to the higher prevalence of private vehicle usage in the region.

The welfare model found a significant divergence in the changes in consumer surplus between both study regions. This analysis was based on low, medium and high carbon price scenarios. While welfare changes were minimal in the low price scenario, divergences occurred in the medium and high price scenarios as individuals using more sustainable modes in urban areas benefited from the higher market price. Large welfare losses were found in the WBR whilst most areas in Dublin were found to experience a welfare gain. Losses were also found to be greater in sparsely populated and socially deprived areas. A multinomial logistic regression confirmed the importance of living in these area types as a major factor in welfare losses.

Finally, a detailed description of a potential PCTS was presented. The scheme's main principles were based on a free and equal allocation of permits to all, an initial fixed price of carbon to guard against fluctuations and an independent regulatory body to maintain integrity of the system. The number of permit transactions and associated costs for the initial phase of trading were also estimated. This analysis found the only region which would attain a net surplus of permits would be the Dublin region. The largest net deficit of permits was found in the WBR and Midland regions.

The results presented in this thesis demonstrate the inequity of introducing a PCTS on rural and socially deprived persons. The introduction of any scheme would require compensation to those constrained to using less sustainable modes of transport through tax breaks, energy subsidies, or more generous carbon allocations.

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LIST OF ABBREVIATIONS

AUD	Australian Dollar
BLR	Binary Logistic Regression
CO_2	Carbon Dioxide
CLEAR	Consolidated Land, Energy and Aquatic Resources
CPRS	Carbon Pollution Reduction Scheme
CS	Consumer Surplus
CSO	Central Statistics Office
DART	Dublin Area Rapid Transit
DED	District Electoral Division
DEFRA	Department for the Environment (UK)
EF	Ecological Footprint
EPA	Environmental Protection Agency
ETS	Emissions Trading Scheme
EU	European Union
EUA	European Union Allowance
EV	Electric Vehicle
GDA	Greater Dublin Area
GDP	Gross Domestic Product
GHG	Green House Gas
GIS	Geographical Information System

HWAY	Highway
Kg	Kilogram
KM	Kilometres
LL	Log Likelihood
LNC	Large Negative Change
MAC	Market Advisory Committee
MNC	Marginal Negative Change
MNL	Multinomial Logistic
MPC	Marginal Positive Change
NAEI	National Atmospheric Emissions Inventory
NAP	National Allocation Plan
NDP	National Development Plan
NSS	National Spatial Strategy
NTA	National Transport Authority
NTS	National Travel Survey
NZ	New Zealand
NZU	New Zealand Unit
PC	Positive Change
PCA	Personal Carbon Allocation
PCTS	Personal Carbon Trading Scheme
POWCAR	Place of Work Census of Anonymised Records
POWSAR	Place of Work Sample of Anonymised Records
PPS	Personal Public Service

PT	Public Transport
QBC	Quality Bus Lane
RPA	Railway Procurement Agency
SAPS	Small Area Population Statistics
UK	United Kingdom
US	United States
VKM	Vehicle Kilometres
VOT	Value of Time
WBR	Western and Border Region

1. INTRODUCTION

The signing of the Kyoto Protocol in December, 1997 heralded a new direction in environmental policy. This treaty, for the first time, recognised climate change as a global problem and created legally binding reduction targets for participating nations.

> *'The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases....do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed....and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012'*
>
> Article 3, Kyoto Protocol (1998)

Annex I countries are defined as developed industrialised countries of which the European Union (EU) participates as one entity. The use of emissions trading as a mechanism to meet Kyoto target was provided for in the Treaty and was implemented by the EU in 2005. The EU Emissions Trading Scheme (ETS) set a centralised cap on carbon (CO_2) emissions in the heavy polluting energy and industrial sectors across each member state. This also created an energy market in which participants trade excess permits as required.

Under Kyoto guidelines Ireland's share of EU green house gas (GHG) emissions must not exceed 1990 levels by 13% by 2012 (Department of the Environment, 2000). However, recent Environmental Protection Agency (EPA) studies have shown levels to be above Kyoto targets in 2010 (EPA, 2010). In addition to participating in the EU ETS the Irish Government has instituted a number of domestic policies to reduce emissions. As the transport sector accounts for over 20% of Ireland's annual emissions (EPA, 2010), policies have mainly focused on the promotion of sustainable transportation and the reduction of private vehicle use as a mechanism to reduce overall emissions (Dept. of Transport, 2009). A carbon tax on transportation fuel, home heating oil and natural gas has also come into effect since 2010 levied at a rate of €15 per tonne of CO_2.

However, research has shown the imposition of a direct tax to be a regressive measure (Tol et al., 2008, Callan et al., 2009). A flat rate penalises individuals in lower income groups more than those in higher income groups. Moreover, the environmental benefits of a carbon tax are ambiguous (Tol et al., 2008). Recent research has suggested the application of an ETS-type scheme on the end users of energy in an attempt to effect behavioural change. This scheme would also potentially provide a direct financial incentive to reduce CO_2 through the trading mechanism. This type of scheme would allocate a free and equal quota to all individuals, creating a market for carbon in which individuals below their quota can sell surplus permits to individuals above the cap. A central regulatory authority would manage the scheme and the market, progressively lowering the CO_2 cap in line with emission targets. This approach is known as a 'downstream' scheme. An EU ETS type scheme limited to a small number of energy intensive industries is a form of 'upstream' trading. Research has focused on the merits of each form of implementation of a scheme as a policy to reduce CO_2 emissions.

While it is clear that an efficiently designed trading scheme can reduce CO_2 emissions (Fleming, 1997, Fawcett, 2005), the welfare effects of these schemes on society remains an area requiring further research (Brand and Preston, 2010). This thesis will investigate the potential welfare effects of a downstream personal carbon trading scheme (PCTS) on individuals who undertake travel-to-work trips.

While the upstream approach has been advocated by a number of authors (Millard-Ball, 2008, Stavins, 2007, Cramton and Kerr, 2002), the rationale for doing so has been the relative administrative simplicity of regulating a smaller number of entities compared to a complex downstream scheme. However, this upstream approach can be perceived as a quasi carbon tax. This is because individuals experience an increase in energy prices without the financial incentives of a purely downstream scheme - a similar outcome to a carbon tax. This erodes the potential for substantial emissions reductions from behavioural changes (Fleming, 1997).

This research also focuses on the relative welfare changes between urban and rural regions in Ireland. Individuals in rural regions are primarily constrained to using private vehicles as their primary form of transport. This reliance on private vehicles is much greater than in urban areas well served by public transport. With this in mind, a downstream PCTS has the potential to penalise individuals constrained to these modes (Wadud et al., 2008, Fawcett, 2010). Therefore, a research requirement arises in quantifying the relative welfare loss to individuals in rural regions compared to urban regions.

The means of introducing a carbon trading scheme have been researched widely in Ireland and internationally (Fawcett et al., 2007, DEFRA, 2008, Comhar, 2008a). Fawcett (2008) recommend a phased introduction of a downstream scheme to acclimatise individuals to using CO_2 as a new currency. Comhar (2008a) evaluated a number of upstream and downstream type schemes. However, the potential implementation process of a hybrid scheme was the only policy chosen for an in-depth analysis. Alternatively, this thesis will research the implementation of a downstream scheme. It will outline the potential implementation process of a PCTS using evidence and findings from international downstream trading research (DEFRA, 2008, Fawcett et al., 2007).

To summarise, gaps in the research exist in determining i) the socio-economic characteristics of individuals within a downstream PCTS, ii) the welfare change arising from introducing a scheme and iii) the potential implementation and structure of a PCTS. This thesis attempts to address the lack of research in these areas. To address these research questions, a number of regression and welfare modelling techniques will be utilised to analyse census travel data. As a precursor to these analyses, an estimation of individual CO_2 emissions will be determined to gauge the initial impact of a introducing a PCTS.

Therefore the objectives of this research are:

1. To conduct a detailed literature review in the following areas: i) the use of census data in quantitative transport research, ii) emissions calculation studies, iii) carbon reduction policies, iv) carbon trading schemes v) welfare and deprivation issues and vi) the current state of implementation of carbon trading schemes.
2. Estimate CO_2 emissions associated with travel-to-work trip and determine a potential cap in a PCTS.
3. Develop a behavioural model to determine the socio-economic factors affecting individual's propensity to be above the CO_2 cap in a PCTS.
4. Conduct an analysis to determine the relative welfare changes between various socio-economic groups with particularly focus on rural regions.

5. Investigate the potential framework and outcomes of a PCTS.

The remainder of this thesis is structured as follows. The research to date relating to the implementation, structure, regulation and scope of carbon trading schemes is investigated in ***Chapter 2***. The underlying demographic trends and transportation issues in Ireland are also discussed as a precursor to this review. This process will identify the areas of research which require further investigation.

The application of the modelling techniques discussed in Chapter 2 is detailed in the methodology presented in ***Chapter 3***. This chapter outlines the data sources and techniques used to conduct the research presented in this thesis. The methodologies of the two main quantitative research techniques are presented in this chapter: a logistic regression analysis and a welfare analysis of individuals within a PCTS.

Chapter 4 reports the results of the emissions estimated for individual travel-to-work trips. Based on the estimated emissions and Irelands reduction commitments, a prospective CO_2 cap will be set on individuals who undertake travel-to-work trips. A logistic regression analysis will then identify the socio-economic characteristics of those who fall above the cap.

Chapter 5 presents the findings of an analysis used to determine the change in welfare of individuals within a PCTS. This chapter uses a scenario analysis to compare welfare changes across three CO_2 price scenarios.

Chapter 6 outlines the research to date relating to the implementation of a PCTS scheme. A potential framework for a PCTS scheme is recommended based on this review. The number of CO_2 transactions and associated costs required in the initial phase of trading are also estimated. Finally, the effects of a modal switch away from private vehicles to public transport on emissions and permit allocation in the scheme is investigated using a scenario analysis.

The final chapter, ***Chapter 7*** concludes the thesis with a discussion of the key findings of the research and the contribution to knowledge. This chapter also discusses the shortcomings of the research and identify the topics which require further investigation.

2. REVIEW AND APPRAISAL OF CARBON TRADING SCHEMES

2.1 INTRODUCTION

This chapter introduces and defines the concept of carbon trading. Methods of implementing such a scheme, its benefits and its drawbacks are discussed. Section 2.2 details the current population and demography statistics in Ireland as per the Census of Population, 2011 and introduces the study areas examined in this thesis. The current state of transportation in Ireland in relation to modal share, private vehicle usage and public transport availability are discussed in section 2.3. The primary data source used in this thesis is taken from the Census of Population, 2006 and consequently the use of census data in relevant transportation literature is examined in section 2.4. Chapter 4 will present estimations of travel-to-work CO_2 emissions for Ireland, of which a number of studies have previously been published. The research relating to CO_2 emissions estimation is presented in section 2.5.

Alternative carbon reduction policies using fiscal measures have been researched and implemented internationally; these policies are described in section 2.6. Section 2.7 will discuss the literature relating to carbon trading schemes. Section 2.8 will detail existing deprivation levels in Ireland in the context of a potential increase in the cost of carbon. In addition, the literature relating to economic models of welfare is discussed. Section 2.9 presents an analysis of the current status and structure of carbon trading schemes internationally. Section 2.10 will summarise the chapter.

2.1.1 Concept of Carbon Trading

Carbon trading schemes set a limit on the quantity of CO_2 which can be emitted annually in an economy. Commercial entities and/or individuals are allocated a quota of CO_2 in the form of permits. These permits are tradable within a market, providing a monetary incentive to reduce emissions so as to profit from the prevailing market price and sustainable transport behaviour. The methods of implementation and regulation of such a scheme are discussed in sections 2.7 and 2.9.

2.2 POPULATION AND DEMOGRAPHY

According to the most recent Census of Population, Ireland has a population of 4.25 million people (CSO, 2011). A sizeable proportion of this population (38%) reside on the eastern seaboard in the capital city of Dublin and the surrounding counties of Meath, Kildare and Wicklow which encompass the Greater Dublin Area (GDA). The Dublin region will be an important study area in this thesis. Rural areas in the west and north-west of the country are less densely populated than Dublin. An additional study area in this thesis is the predominately rural Western and Border Region (WBR). This region encompasses counties Mayo, Galway, Roscommon, Sligo, Leitrim, Donegal, Monaghan and Cavan. While much larger geographically than the Dublin, it has a smaller proportion of the nation's population at 18%. This study area does not include Galway City as its inclusion would skew any findings for this rural region.

While disparities in population densities and access to transport differ greatly between the two regions, the most marked contrast between Dublin and WBR is in terms of income and deprivation. Haase and Pratschke (2005) presented a comprehensive report on the extent of income disparity and deprivation in Ireland using census data. This research was updated in 2008 to determine deprivation levels based on 2006 Census data (Haase and Pratschke, 2008). The spatial distribution of deprivation in Ireland was found to have a substantial urban-rural divide with districts in major urban centres having much higher levels of affluence relative to isolated rural areas. The measures of deprivation utilised as part of the research presented in this thesis are discussed in section 2.8.1 and Chapter 3.

In light of the regional disparities which exist in Ireland, the Government of the day instigated the National Spatial Strategy (NSS), 2002-2020. The aim of the policy was to achieve a 'better balance of social, economic, physical development and population growth between regions' (Irish Government, 2002). This was to be achieved through the selection of 'gateway' cities and towns as centres of population and economic growth in tandem with Dublin. The NSS is based on a central goal of stimulating social and economic activity in rural regions outside of the GDA. Another facet of this strategy was the improvement of transport and communication links between centres of population identified in the NSS. This process of improvement was articulated further in the National Development Plan (NDP) 2007 – 2013 and the Transport 21 initiative. These national policies are reviewed in section 2.3. Despite the ambitious plans laid out in the NSS, disparities have remained static between regions and have widened in some cases (Haase and Pratschke, 2005).

2.3 TRANSPORT IN IRELAND

In Ireland the main mode of transport is the private car. Nationally, driving alone accounts for 58% of all commute trips, whereas just 9% of trips are by public transport. This percentage share is greater in Dublin where public transport trips accounts for 22% of all commuting trips. This is due to the availability of a greater number of public transport options in the city in comparison to other regions. Table 2-1 presents the National, Dublin and WBR modal split. These regions will be used as the main study regions in Chapters 4 and 5.

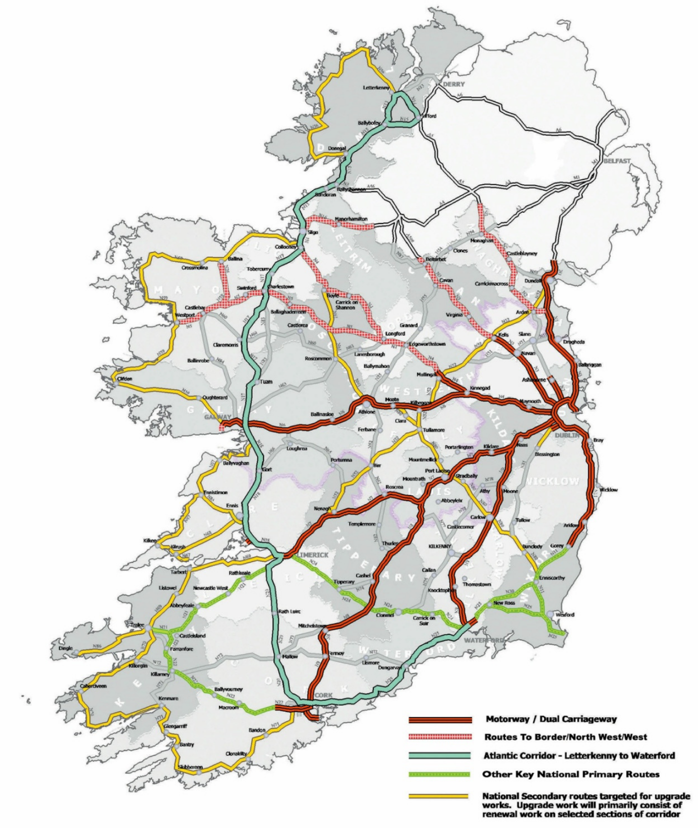
Table 2-1: Modal Split of travel-to-work trips

	National		**Dublin**		**WBR**	
Mode	**N**	**%**	**N**	**%**	**N**	**%**
Walk	197,517	10.9	70,044	13.2	23,415	8.3
Cycle	35,291	1.9	20,588	3.9	1,901	0.7
Bus	110,932	6.1	76,785	14.4	4,279	1.5
Rail	53,063	2.9	39,510	7.4	319	0.1
Motorcycle	12,673	0.7	6,607	1.2	707	0.3
Drive - Alone	1,052,324	58.1	260,630	49	174,570	61.9
Drive - Passenger	102,438	5.7	19,969	3.8	18,632	6.6
Lorry or van	138,164	7.6	19,232	3.6	34,112	12.1
Other means	6,222	0.3	1,027	0.2	1,455	0.5
Work from home	56,862	3.1	8,213	1.5	11,857	4.2
NA	45,620	2.5	9,362	1.8	10,675	3.8
Total	1,811,106	100	531,967	100	281,922	100.0

2.3.1 Road transportation

Ireland is served by an extensive road network consisting of motorway, dual carriageway and single carriageway routes. As part of the NDP (2007-2013), the nation's inter-urban motorway network linking major cities was completed by the end of 2010. These major arterial routes focus on the capital, Dublin. Dual carriageway and single carriageway national primary routes also link other major urban centres across the country. Other secondary and regional routes link smaller centres of population particularly in rural areas. The main national routes are illustrated in Figure 2-1. While road transportation is well developed in the urban regions particularly in the GDA, it is underdeveloped in the western and north-western regions of Ireland. This disparity is being redressed somewhat with the implementation of a number of schemes within the current NDP. As was previously discussed the road network is the primary means of transportation for both commuters and freight transportation and thus has been the primary focus of infrastructural funding in recent years.

Figure 2-1: Road network in Ireland



Source: (Irish Government, 2011)

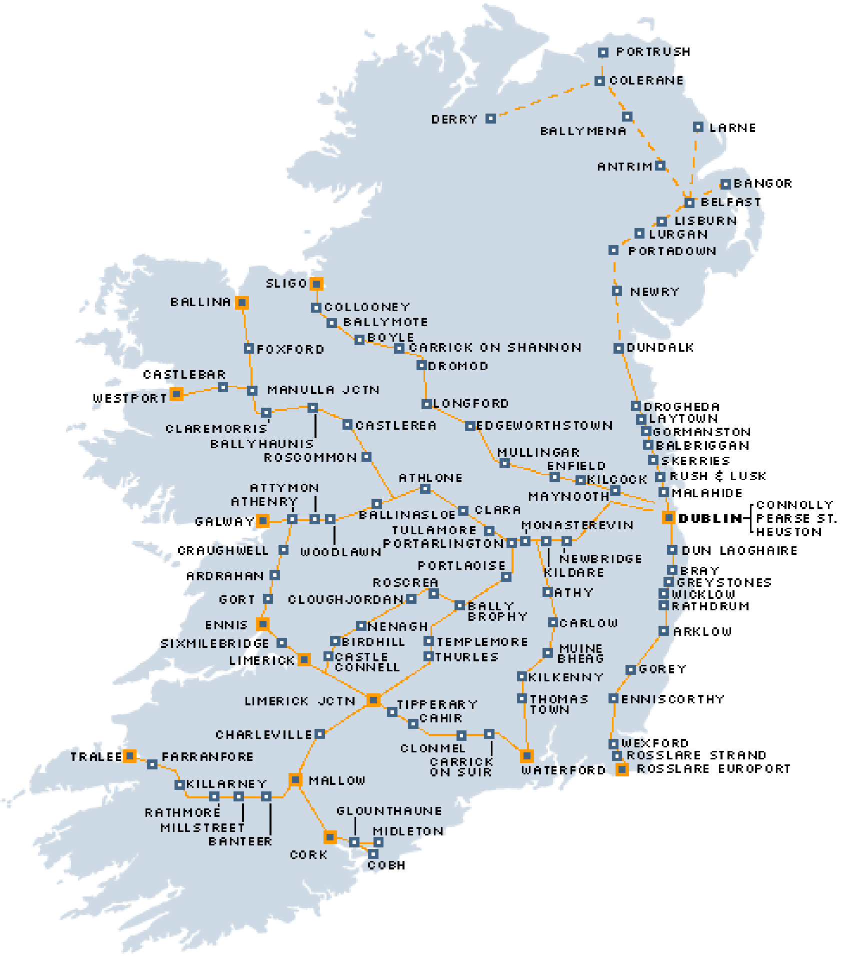
2.3.2 Bus network in Ireland

Bus Eireann operate the bulk of all bus services outside of Dublin. The company provides express services between large urban areas and also socially important local services in major cities and rural areas. Bus Eireann reported 84,640 trips on its scheduled services in its most recent report in 2009, a drop of 12.3% attributable mainly to the economic downturn (Bus Eireann, 2010). In Dublin, services are operated by another public service operator, Dublin Bus. It operates the largest public transport network in the city. The company has a fleet of 1,020 buses operating over 160 routes and in 2009 reported 128 million passenger trips (Dublin Bus, 2010). Dublin Bus services are currently undergoing substantial redesign as part of the company's 'Network Direct' plan to deliver more efficient services in the city (Dublin Bus, 2010). This strategy has been articulated in the most recent policy document produced by the National Transport Authority (NTA) named '2030 Vision' (NTA, 2010). This document details the envisaged transport network in Dublin City by 2030. Plans for bus services include: increased connections between the city and surrounding hinterlands, the provision of more Quality Bus Corridors (QBC) and development of Bus Rapid Transit along existing QBC routes to provide high frequency and reliable bus services in areas not served by railways (NTA, 2010).

2.3.3 Rail Network in Ireland

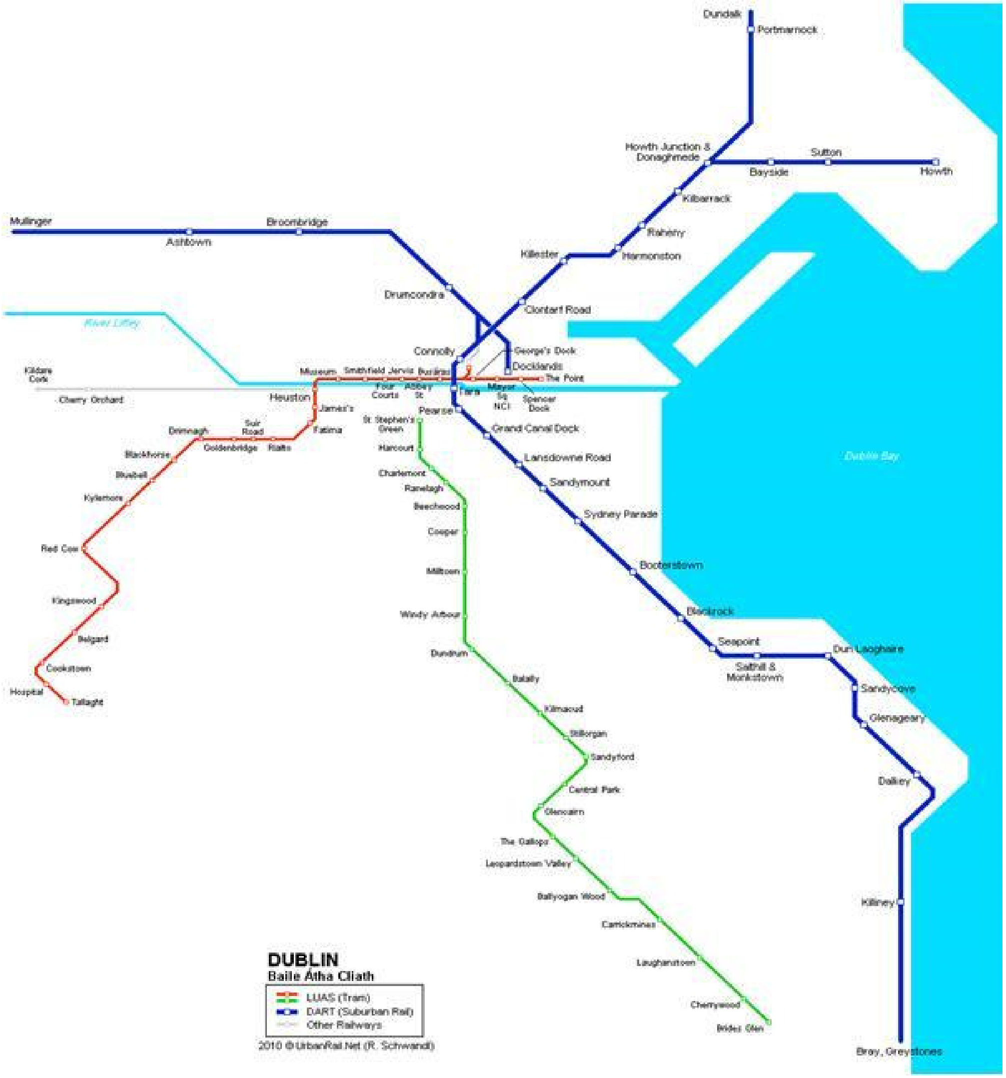
Rail services in Ireland are operated by Iarnrod Eireann. As is the case with the motorway network the majority of rail lines converge on Dublin. Dublin has both a heavy and light rail network. Outside of Dublin a new Western Rail Corridor between Limerick and Galway was opened in 2009. Iarnrod Eireann carried 38.8 million passengers in 2009, a drop of 13% on the previous year (Iarnrod Eireann, 2010). National rail routes are illustrated in Figure 2-2. Rail services in Dublin operate across three modes. The Railway Procurement Agency (RPA) operates two tram lines in conjunction with a private operator. This service is called 'Luas'. In 2010, Luas accounted for 27.4 million trips in the city. Dublin Area Rapid Transit (DART) and suburban rail services are operated by Iarnrod Eireann and also provide rail services from the city centre. DART connects Malahide and Howth in the north of the city to Greystones, Wicklow to the south of the city. Suburban rail provides services to Mullingar and Kildare in the west, Dundalk to the north and Arklow to the south of the city. Plans are afoot to connect the existing Luas lines as well as extending the network, while an underground metro service is at an advanced planning stage to connect the city centre and North Dublin. An additional project to create an underground loop line connecting DART services to one of the main railway stations, Hueston is also at an initial planning stage. The Dublin rail network is illustrated in Figure 2-3.

Figure 2-2: National Rail Network



Source: Iarnrod Eireann (2010)

Figure 2-3: Dublin rail network



Source: (Iarnrod Eireann, 2010)

2.4 CENSUS DATA RESEARCH

The use of census data in transportation research internationally is widespread. A subset of the Irish Census named Place of Work Census of Anonymised Records (POWCAR), collated in 2006, is used in this thesis. This dataset contains information on 1.8 million trips in Ireland as well as socio-economic information associated with each trip. The composition of this dataset and its application in this thesis is explained in more detail in the methodology chapter (Chapter 3). This dataset is the second iteration of its kind in Ireland. The Census of 2002 also contained a smaller dataset detailing travel behaviour named Place of Work Sample of Anonymised Records (POWSAR). This dataset is not as detailed as POWCAR as it only records a sample of approximately 20% of the population. The Central Office (CSO) of Ireland is responsible for tabulating these datasets. An additional dataset of population statistics tabulated by the CSO is the Small Area Population Statistics (SAPS). This dataset breaks down tracts of the census data into fifteen separate subsets containing distinct socio-economic information such as marital status, age, gender, employment group etc. This dataset can be further isolated into each District Electoral Division (DED) or council boundaries and is useful for micro analysis of small geographical areas. DED statistics are the most localised level of population statistics in Ireland. One important omission from these datasets is a lack of income information for each individual. This omission will be compensated for somewhat by combing national deprivation statistics with POWCAR. These deprivation statistics will be discussed in section 2.8.1. The subsequent sections will review the existing census research in the transportation field and the techniques used to assimilate the data.

2.4.1 Irish Research

Irish research has used the POWCAR and POWSAR datasets to research various topics in the past decade. Vega and Reynolds-Feighan (2009) used data from the POWSAR dataset to demonstrate how spatial distribution affects travel choices. The results illustrated the varying effects that travel attributes such as travel time and travel costs have on the choice of travel mode across employment destinations. The research also highlights the role of trip destination as a main driver of travel behaviour in the Dublin region. A previous paper by the same authors also utilised POWSAR in determining employment sub-centres and travel-to-work patterns in the Dublin region (Vega and Reynolds-Feighan, 2008). The authors used Geographical Information Systems (GIS) and regression analysis to determine a small number of employment sub-centres and the associated factors determining mode choice when travelling to work. Carty and Ahern (2010) also used POWCAR in spatial analyis, focusing on the influence of urban form on transsport energy consumption. The authors recommended the use of high density, mixed use developments with proximity to public transport as major drivers in increasing sustainable travel. These factors were found to have a significant relationship with transport energy consumption. The authors have also determined a CO_2 vulnerability index for the GDA using POWCAR data and GIS techniques (Carty and Ahern, 2011). This index will be discussed in section 2.5.

McNamara and Caulfield (2009) utilised regression analysis in determining the socio-economic characteristics of individuals who travel-to-work in the Dublin region. Rather than using a travel mode choice regression model as was used by Vega and Reynolds-Feighan (2009), this paper focused on CO_2 emissions associated with work trips. POWCAR trips were grouped into three tranches representing low, medium and high emitters and the socio-economic differences between each group observed using a logistic regression model. The results indicated that age and household composition are important factors in determining an individual's propensity to emit CO_2. McNamara and Caulfield (2011a) also used a similar regression analysis to determine the socio-economic characteristics of individuals falling above a carbon cap in a PCTS. Individuals above the cap were likely to own more than one car, have dependent children and travel over 10 kilometres (km) to work. The results presented in Chapter 4 are mainly based on this research.

Browne et al. (2008) measured the ecological footprint (EF) of the energy and electricity consumption of residents in an Irish metropolitan region. The research used SAPS data to determine an EF. The authors also estimated a carbon footprint as part of an overall EF to study different policy scenarios. It was found that an absolute reduction in CO_2 and demand management should be prioritised over renewables substitution based on a scenario analysis. Farrell et al. (2010) assessed the benefits of travel demand management in a small town in Ireland. The environmental benefits of a modal shift from private vehicles to sustainable forms of transport were studied using the emissions estimation program COPERT. A mix of soft measures was found to provide be the optimal result in achieving a modal shift. Walsh et al (2008) used census data ranging from 1986 to 2006 in determining the emissions generated from cycling in comparison to motorised modes. The conclusions drawn from this research would suggest that cycling can emit the same levels of CO_2 as peak time travel by public transport taking into account human metabolic rates. Data on commuting distances contained in historical census records were used to determine average trip times and distance as part of this research. The emissions estimation methodology used in Walsh et al. (2008) will be discussed in section 2.5.

POWCAR has also been used in assessing the benefits of sustainable forms of transport (Caulfield, 2009, Smith, 2010, Brady and O'Mahony, 2011). Caulfield (2009) used regression analysis and COPERT to quantify the environmental benefits of ride sharing. Individuals who travel early in the morning (7AM-8AM), younger age groups, couples and households owning only one car were found to be the most likely groups to ride-share. The environmental benefits of ride-sharing also result in a significant reduction in annual CO_2 emissions in a 5-day working week (Caulfield, 2009). Smith (2010) studied the potential benefits of switching from fossil-fuelled vehicles to electric vehicles (EV). The benefits of switching to EV's were found to be significant with annual reductions in CO_2 of 25-40% for private cars. Brady and O'Mahony (2011) also assessed the environmental benefits of EV's. This study was based on a more realistic EV target of a 10% share of the total fleet by 2020. This 10% target is a policy priority outlined in the Irish Government's 'Smarter Travel' document (Department of Transport, 2009). The results predicted a more modest decrease than Smith (2010) of 3% in CO_2 emissions in comparison to a business-as-usual scenario. The time frame required for the introduction of EV's into the fleet suggests the short to medium term reductions in emissions would be quite minimal.

2.4.2 International Research

Internationally, census data is an important data source in transport research. McGuckin and Srinivasan (2003) used historical census data (1960-2000) to determine trends in travel patterns amongst commuters, particularly in metropolitan regions of the United States (US). A time series model of changes to commuting patterns was created to inform policy decisions, particularly with respect to public transportation provision. Reuscher et al. (2002) outlined the development of system to assimilate local and regional travel behaviour census data. This involved grouping data into tracts or clusters. These tracts or clusters were based on a number of socio-economic factors such as household income, employment rate, number of household vehicles, and area type. The authors found that these tracts predicted travel behaviour better than other aggregated methods.

2.4.3 Travel Surveys

Smaller dedicated travel surveys are also useful indicators of overall travel pattern in addition to census records. Kunert et al. (2002) described the design characteristics of ten international travel surveys in Britain, Switzerland and the US. The results noted that the design and scope of the surveys are important factors in maintaining the rigour and continuity of the results in each iteration of a survey. A national travel survey (NTS) in Ireland is also tabulated by the CSO. The NTS surveyed 7,221 individuals in their daily travel movements over a 7-day period. This research found work and education trips to account for 28% of all trips (CSO, 2011). Individuals surveyed undertook 2.4 trips of 13km each on average. Distances were found to be higher in rural regions with fewer separate trips being taken. Based on the NTS findings and allowing for a margin of error in terms of the sample size and the different time periods in which the NTS and POWCAR were collected, it can be postulated that POWCAR would account for 25 - 30% of all trips based on NTS estimations.

It is clear having reviewed transportation research using census data, the body of work is skewed towards researching transport issues within the urban regions. A research requirement arises in studying other less densely populated regions with respect to a carbon trading scheme.

2.5 EMISSIONS ESTIMATION TECHNIQUES

In Ireland, the transport sector has become one of the major sources of GHG emissions growth in recent years. In 2009, transport emissions accounted for 21.1% of Ireland’s GHG’s (EPA, 2010). This was a 176% increase on 1990 levels, second only to Cyprus amongst the 27 EU countries (EPA, 2010). Road transport emissions accounted for 97% of transport emissions. Substantial reductions of road transport emissions as part of overall GHG emissions is required in meeting Ireland's Kyoto targets.

Research relating to CO_2 emissions is widespread in all sectors of the economy, particularly transport emissions. In Europe, one of the most utilised emissions calculation models is the COPERT model (Federico et al. 2007; Caulfield, 2009, Ryan and Caulfield, 2010). This model is currently in its fourth generation of development since its inception in the 1980's and is funded by the European Union. The model estimates a variety of GHG's associated with road transportation. Studies have used alternative activity based data similar to the dataset in using COPERT to determine emissions (Caulfield, 2009; Farrell et al. 2010), while others have estimated emissions using data from numerous sources. Burón et al. (2004) used fuel data, temperature distribution, emission regulations, a study of average vehicle speeds and fuel consumption to estimate emissions. Walsh et al. (2008) also used a number of sources in calculating emissions. This paper focused on CO_2 emissions associated with cycling while also estimating emission factors for various forms of motorised transport in Ireland. Emission factors were calculated taking into account occupancy rates, engine size, fuel consumption and journey length. Rail travel emissions factors were calculated based on electricity consumption per km and occupancy rates at peak times. The results of this research found that a cycling to work releases a similar amount of CO_2 as travelling by an electrically propelled train at full occupancy. The authors caveat this result stating that it is based on a number of assumptions in relation to rail occupancy rates and frequencies on rail lines at peak times in addition to a number of factors relating to cycling.

These emission factors estimated in Walsh et al. (2008) are used to estimate daily travel-to-work emissions for 1.8 million individuals tabulated in the POWCAR dataset used in this thesis. Carty and Ahern (2011) also used POWCAR data to determine a CO_2 vulnerability index for the GDA. This research estimated CO_2 emissions and determined the average CO_2 per person in each DED. The results found a higher vulnerability to CO_2 in areas outside of Dublin city and along major motorways which converge on the city. Urban areas with more accessibility to public transport and higher instances of walking and cycling were found to have lower levels of CO_2 vulnerability. This study also utilised emission factors similar to those used in Walsh et al (2008).

Emissions in the UK are tabulated by the National Atmospheric Emissions Inventory (NAEI) which calculates emissions from a number of sectors of the economy including the transport sector (Bush et al. 2006). To date in Ireland no such national dataset exists. These UK factors cover emissions generated from all road and rail transport across numerous GHG's. Factors tabulated in the NAEI database have been used in previous research to estimate GHG emissions (McNamara and Caulfield, 2009). While these factors are the most comprehensive available in the UK and can be applied to Irish data, utilising Irish factors when using such data is a more appropriate course of action. The factor utilised in Walsh et al. (2008) will be used in this thesis and discussed in Chapter 3.

2.6 CARBON REDUCTION POLICIES

A number of supply-side and demand-side policies have been advocated to reduce CO_2 emissions. Research has mainly focused on fiscal measures such the carbon taxation. These measures will be discussed in the following sections.

2.6.1 Carbon Tax

In 2010, a carbon tax on fuel and gas was introduced in Ireland. This tax was levied on transport and home heating fuels as well as natural gas. In 2011, the cost of carbon was levied at a rate of €15 per tonne of CO_2. This tax is due to be doubled by 2014 under the previous Government's National Recovery Plan. The new Government has not opposed this increase as of October 2011, although it will exempt farm diesel from any increases in the tax if implemented.

The idea of reducing CO_2 emissions by imposing a tax is not a new concept. The idea of negating an externality using taxation was first suggested by Pigou (1952). Pigou (1952) argued that the agents who create the benefits or costs in an economy do not always have to bear the outcomes. A tax would internalise any negative outcomes while incentivising agents to reduce activities which would incur a tax. This type of tax is known as a Pigouvian tax.

Using a Pigouvian type tax to reduce CO_2 has become a popular policy tool subsequent to the signing of the Kyoto protocol in 1997. This treaty provided flexibility to implement a number of policies to share the burden of reduction amongst nation such as trading schemes. While the EU created the Emissions Trading Scheme (ETS) to provide a pan-European mechanism to reduce CO_2, many countries have implemented carbon taxes within each state as the primary policy tool for reduction. One of the reasons for the popularity of taxation is the relative simplicity of levying a tax as opposed to designing and implementing a complex trading scheme. To date in Europe, Norway, Sweden, Finland, Switzerland, Netherlands and Ireland have all implemented various forms of carbon related taxation.

Early studies investigating measures to mitigate climate change have advocated the use of carbon taxation (Symons et al., 1994, Baumol, 1972, Pearce, 1991). Baumol (1972) built on the work of Pigou in investigating the effectiveness of Pigouvian type taxes in reducing emissions. This approach also suggested using subsidies as a supplementary measure to incentivise polluters to reduce their emissions. Baumol (1972) suggested a persuasive case could be made for the use of taxation, although in reality the environmental outcomes would be less optimal than predicted. Pearse (1991) and Symons et al. (1994) both studied the potential effects of a carbon tax levied across the UK economy. Their conclusions endorsed the view that carbon taxes can effectively reduce emissions at a minimum cost to the economy. Another benefit cited is the ‘double dividend’ effect (Goulder, 1995). This is the concept that the tax will reduce emissions while substituting for revenues from so-called ‘good’ sources such as income tax.

Tol et al. (2008) modelled the effects of a carbon tax in Ireland as proposed in the Programme for Government 2007-2012. More specifically they addressed ten questions relating to the implementation of a carbon tax in Ireland. A uniform tax across all sectors of the economy was modelled, setting the marginal cost of emissions equal for every source. The authors concluded that the level of this tax should equal the futures price of EU ETS permits. Crucially however, a carbon tax was also found to be mildly regressive while the predicted reduction in emissions would be in the order of a 0.5%. Reductions in emissions would be negated by emissions increases in other sectors not covered by the tax. Tol et al. (2008) also concluded that if a similar tax were to be introduced across the EU the reductions in emissions would be more substantial than the predicted 0.5%. Sovacool (2010) conducted a study of carbon taxation while comparing it to carbon trading in the US. This article advocates using carbon taxes over other mechanisms such as carbon trading due to the price stability it provides, net benefits up to 16 times greater than other schemes, simplicity of implementation and a minimisation of transaction costs.

While the majority of the research to date has focused on potential emissions reductions, recent studies have investigated equity. Ekins and Dresner (2004) modelled the equity effects of a carbon tax in the UK. The findings emphasise the importance of compensating the lowest income earners, who were found to be the largest net losers in the event of taxation being introduced. Despite including for measures to compensate low income individuals in their model, some low-earners still remained the largest net losers. Callan et al. (2009) also studied the equity effects of a carbon tax in Ireland concluding that a tax would be regressive, costing the poorest households €3 euro per week while only costing the richest €4 per week. Compensation through social welfare payments was cited as a mechanism of redress.

Public Acceptability of carbon taxation has also been researched in recent years (Agrawal et al., 2010, Bristow et al., 2010). Agrawal (2010) found that up to 50% would support some form of environmental taxation. Individuals with pro-environment or pro-government attitudes tended to be most likely to support these measures. This is a very high acceptance rate, taking into account most individual's aversion to new forms of taxation. Bristow et al. (2010) carried out similar research to determine societal attitudes towards carbon taxation in the UK. This paper used a stated preference model to determine individual's attitudes to carbon taxation and carbon trading. This study predicted up to 70% acceptability of taxation under a number conditions. Acceptability of carbon taxation falls to under 50% when the proceeds of the tax are not explicitly stated by Government. In contrast, acceptability of carbon trading was found to be as high as 80% is some cases in this study. This finding will be discussed in section 2.7.

While some authors suggest that carbon taxes are the most efficient means of reducing emissions, the common thread from the literature reviewed in this section is one of a justification for taxation based on grounds of efficiency and cost effectiveness. However, research has shown that a flat carbon tax is an inherently regressive measure without compensatory mechanisms for lower income groups. Moreover, the environmental dividend is ambiguous.

2.6.2 Incentives

Incentives are ‘soft’ measures which can be implemented to encourage individuals and industry to reduce CO_2 emissions. Examples of such incentives are: subsidies for insulating homes, tax breaks for public transport tickets and subsidised travel-to-work bicycle schemes. Other measures such as ‘green’ banks or investment funds incentivise individuals to invest in and create employment in sustainable industries. This measure has recently been introduced in the UK and is proposed in the new Irish Governments Programme for Government (Irish Government, 2011).

Non fiscal policies have also been examined in reducing emissions. (Bristow, 2010) emphasised the use of behavioural measures in reducing CO_2 emissions and reviewed current carbon reduction policies in the UK. These policies include smarter travel choice initiatives such as marketing campaigns and travel awareness campaigns to increase public transport use. Cairns et al. (2004) found that interventions in travel choices such as school travel plans, car pooling schemes and teleworking yielded significant reductions in car travel of up to 30% in some cases. Sustainable travel demonstration towns are also cited as useful initiatives achieving reductions in car use ranging from 4 – 9% (Bristow, 2010). Similar initiatives have also been implemented in Ireland with the advent of the Smarter Travel Policy (Department of Transport, 2009). Nine smarter travel areas have also been shortlisted from medium to large urban areas around the country to compete for funding of up to €50 million over 5 years to transform these urban areas into smarter travel demonstration zones. This policy has particularly has focused on incentivising walking and cycling to work. The initiation of the cycle-to-work scheme is one such incentive, providing a tax break on the purchase of bicycles used to travel to work trips. Caulfield and Leahy (2011), found a substantial percentage of participants in the scheme who were previously non cyclists have changed their perceptions of cycling and improved accessibility to the mode since the inception of the scheme.

2.7 CARBON TRADING

Literature relating to carbon trading has demonstrated that such a scheme can effectively reduce CO_2 emissions and is less regressive than a carbon tax (Starkey and Anderson, 2005). Two distinct methods of implementing a carbon trading scheme have been researched; an upstream approach and a downstream approach. An upstream scheme issues permits to producers and importers of energy i.e. oil refineries, fuel importers etc, who then pass on the cost of maintaining emissions under the cap to the consumers who purchase that energy in its various forms. These entities can also trade any permits they do not use with other entities that may require them.

A downstream approach bypasses the producers and importers of energy and issues permits to the end users of energy who trade these permits as they require creating a much larger market than an upstream cap. Fleming (1997) was one of the first authors to advocate the use of 'tradable quotas' in reducing CO_2 emissions. The scheme distributed free allowances to end users creating an auction process for businesses and public sector bodies to purchase quotas. This approach is an example of a downstream scheme. Wadud et al. (2008) and Brand and Preston (2010) also advocated the use of a downstream cap in the form of a personal tradable CO_2 permits as a less regressive policy than direct taxation of CO_2. It is this type of scheme, namely a PCTS for the purpose of this thesis that that will be evaluated in this thesis. The various types of carbon trading schemes are outlined in Table 2-2. Strengths and weakness of each approach are listed based on research to date.

2.7.1 Upstream vs. Downstream

Advocates of a downstream scheme argue that durable reductions in CO_2 emissions can only be achieved through the behavioural changes associated with a downstream scheme on consumers (Fleming, 1997, Fawcett, 2005, Fawcett et al., 2010, Niemeier et al., 2008). A downstream scheme applied to each individual provides a direct monetary incentive to reduce emissions and reward low-emitting individuals with a monetary amount. The potential outcome of an upstream scheme is increased fuel and utility prices which would be in effect a tax on consumers creating inequitable results (Fleming, 1997). Niemeier et al. (2008) proposed a household carbon trading scheme which would target consumers with four key elements: a state allocation to households, household to household trading, households to utility company credit transfers, and utility companies to government credit transfers. The proposed system augmented Fleming's (1997) model in allocating free allowances to consumers while granting regulation of the scheme to energy and utility companies. This system was found to be more equitable than carbon taxes and an upstream cap.

Subsequent studies have advocated an upstream cap (Ellerman, 2000, Tietenberg, 2002, Millard-Ball, 2008). Millard-Ball (2008) recommended the use of such a scheme due to its administrative simplicity and complete coverage of a small group of energy importers. This is a view shared by California's Market Advisory Committee (MAC). The California MAC was created to study market-based mechanisms to reduce GHG emissions in the state. The California MAC recommended an upstream cap due to reduced administrative costs in comparison to a downstream cap and the presence of fewer agents in the market (California Market Advisory Committee, 2007). While the simplicity of regulation of an upstream scheme is an advantage over a downstream scheme the behavioural changes required to reduce emissions are perhaps only possible by applying the cap downstream on each individual agent in the economy (Raux and Marlot, 2005). Cramton and Kerr (2002) also advocate the introduction of an upstream cap scheme for reasons of administrative simplicity and efficiency while discussing the auction process involved in regulating and operating such a scheme.

Table 2-2: Carbon trading schemes – strength and weaknesses

Name	Appliance	Description	Strengths	Weaknesses
Upstream Trading (Cap-and-Trade)	Upstream	Entities which produce or import fossil fuels are allocated free permits directly and a market for carbon is created.	Appliance upstream on a small number of entities creates administrative and regulatory simplicity.	Public do not engage with policy, perceiving it as another form of taxation on energy. Availability of offsets has potential to diminish emission reductions.
Cap-and-Share	Upstream	Individuals allocated permits, sell to upstream entities, which pass on increased costs to consumers.	Appliance upstream on a small number of entities creates administrative and regulatory simplicity.	Public do not engage with policy, perceiving it as another form of taxation on energy.
Personal Carbon Trading Scheme (PCTS)	Downstream	Each individual allocated permits, trade these permits with other individuals.	Appliance directly to each citizen incentivises sustainable practises. Individuals who emit below the cap level profit from trading surplus leading to positive welfare outcomes.	Costly and complex implementation of a system which must account for millions of individuals.
Cap-and-Dividend	Upstream	Government auctions permits upstream and distributes the proceeds to the people on an equal per capita basis.	Appliance upstream on a small number of entities creates administrative and regulatory simplicity. Individuals receive direct compensation in response to increased costs.	Lack of engagement with public in changing behaviour to reduce emissions. Payments to citizens of proceeds risks politically motivated interventions in the scheme.
Tradable Energy Quota	Downstream	Individuals allocated % of permits and remainder auctioned to industry. Both sectors free to trade amongst each other.	Encourages individuals and industry to collectively change behaviour. Auction proceeds can be used to support 'green' initiatives.	Costly and complex implementation of a system which must account for millions of individuals and companies.

2.8 WELFARE MODELLING

This section of the thesis discusses the literature relating to regional deprivation in Ireland and the use of econometric models in determining the welfare effects of environmental policies.

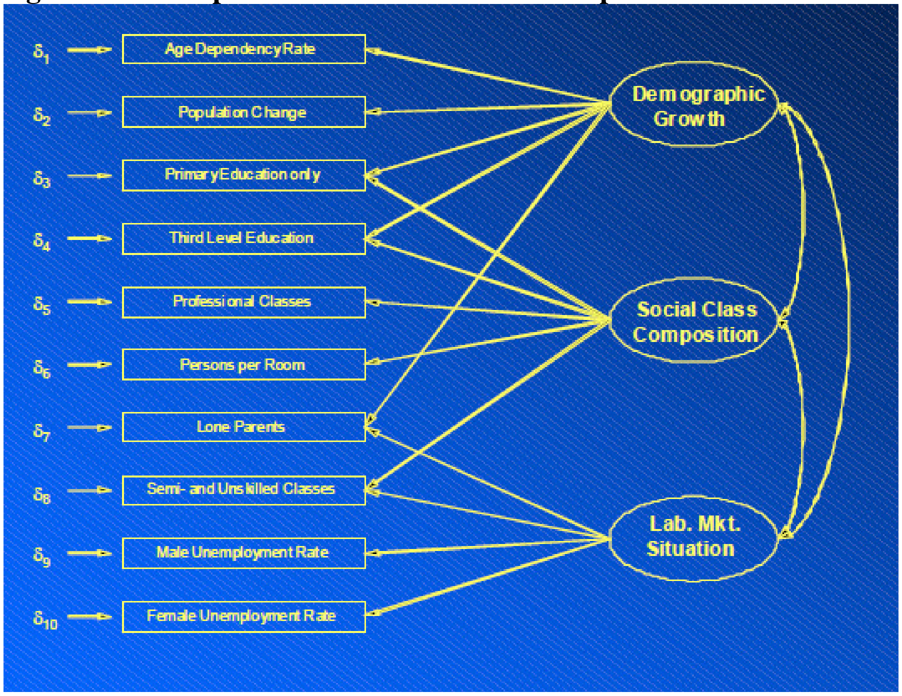
2.8.1 Rural Deprivation in Ireland

Applying a national carbon cap has the potential to result in inequitable outcomes for individuals unable to reduce their emissions. Comhar (2008a) found a minority of lower income households were predicted to be worse off from such a scheme and inequities between rural and urban dwellers were predicted to arise. Recent literature has suggested research is needed in the area of carbon trading and associated energy poverty and equity issues (Brand and Preston, 2010).

McNamara and Caulfield (2011b) used a welfare model to determine the distribution of the loss borne by rural dwellers in comparison with urban dwellers in the event of a PCTS being introduced. The results of this research are presented in Chapter 5. Research has also found existing transportation policy in Ireland to be more advantageous to urban dwellers (McDonagh, 2006). This paper highlighted the GDA-centric policy stance of the NDP and the social exclusion derived from underdeveloped rural transport systems.

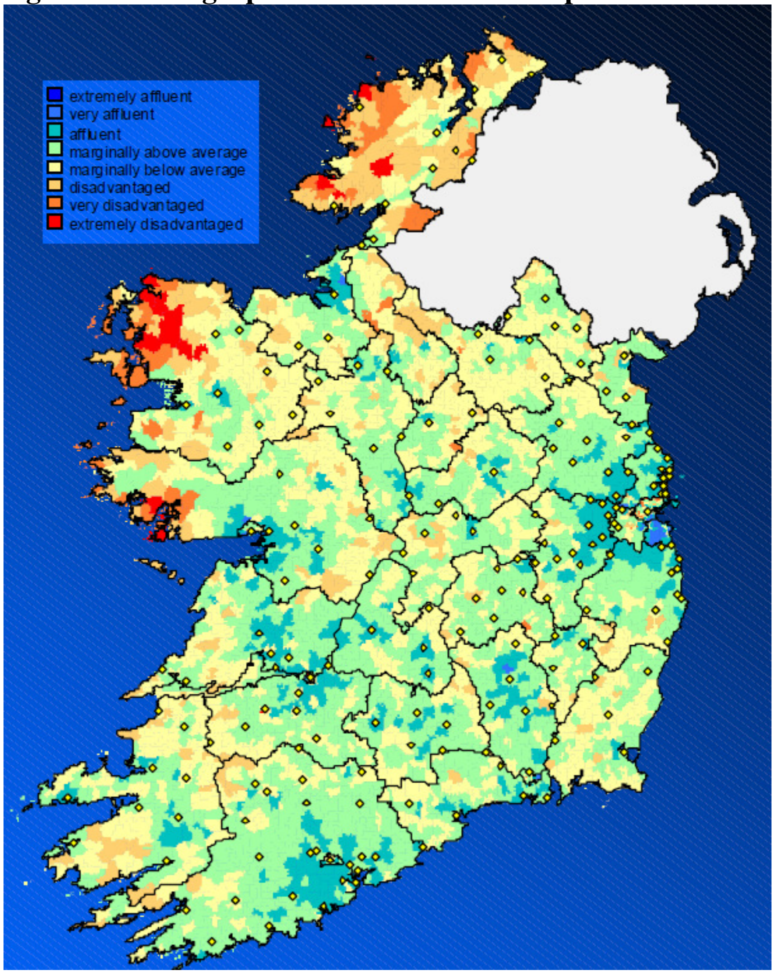
Haase and Pratschke (2005) conducted a detailed study on levels of deprivation in Ireland over the past twenty years. The clear conclusion from this research is that of an urban-rural divide in terms of deprivation and affluence levels. Indicators of deprivation used included unemployment levels, age dependency rates (number of individuals under 16 and over 65), the lone parent ratio, the proportion of population with only a primary education and the rates of population decline. These measures were combined to provide a simple scale of deprivation ranging from extremely deprived to extremely affluent. While this data loosely follows a normal distribution, outliers representing the most deprived areas were found to occur mainly in isolated rural regions. To date it is the most comprehensive study of deprivation available in Ireland and the only study which breaks down the measures of deprivation to a localised DED level. Some of the data associated with the findings from that study are used as part of the research. This data measures the relative deprivation of DED’s in Ireland. The methodological process and the composite variables used to determine the deprivation index are outlined in Figure 2-4. The geographical distribution of relative deprivation and affluence in Ireland is presented in Figure 2-5. This illustrates aggregate deprivation or affluence levels in each DED. The most affluent DED’s are in urban areas, particularly in Dublin, Kildare, Wicklow, Cork, Galway and Limerick. The most deprived DED’s are to be found in the WBR in counties May, Galway, and Donegal.

Figure 2-4: Composite variables included in deprivation index



Source: Haase and Pratschke (2008)

Figure 2-5: Geographical Distribution of Deprivation in Ireland



Source: Haase and Pratschke (2008)

Recent studies have somewhat dealt with socio-economic and welfare issues. Wadud (2011) found that the majority of CO_2 permit allocation strategies were progressive. Rural household could not incur negative welfare changes in some instances. Raux and Marlot (2005) stressed the importance of a free allocation of CO_2 permits to mitigate equity issues together with a tailored allocation of permits based on socio-economic characteristics. It can be concluded that a free allocation would be the most equitable approach in any form of downstream carbon trading.

2.8.2 Consumer Surplus as a Welfare Indicator

In light of the welfare issues highlighted in section 2.8.1, this thesis seeks to determine the welfare loss, if any, to rural commuters in the event of a downstream PCTS being introduced. The analysis in Chapter 5 will employ a similar consumer surplus model used in Wadud et al (2008).

A consumer surplus analysis will be utilised as a means of measuring the change in welfare arising from the implementation of a PCTS. Consumer surplus is defined as the difference between what a consumer is willing to pay and what is actually paid for a good. If the price that is paid is below what an individual was willing to pay, the individual attains a consumer surplus. The introduction of a permit price on CO_2 could reduce the consumer surplus of some individuals, with the resulting loss used as a proxy for welfare loss. Others may experience a gain in consumer surplus as the allocation of permits is free and tradable, thus providing a potential income stream. The outcome depends on the sustainability of individual travel movements. Consumer surplus is the most widely used welfare measure in economics (Slesnick, 1998). It can be thought of as a measure of utility (satisfaction derived from consuming a good) or an individual's purchasing power (Slesnick, 1998). Harberger (1971) recommended the use of consumer surplus as the appropriate measure of welfare in response to price changes and the imposition of taxation. A PCTS can also be thought of as a price CO_2 to be decided by market forces rather than a flat levy. It is therefore applicable to a consumer surplus analysis.

Some have contested the usefulness of consumer surplus as a welfare indicator as it does not take into account income effects as well as price effects (Hausman and Newey, 1995, Slesnick, 1998). Willig (1976) concluded that consumer surplus can be rigorously utilised to account for the income and price effects of a welfare change. Ju (2000) noted that consumer surplus can also be an adequate measure of welfare in the absence of income effects. This thesis does not take income levels into account as this is not tabulated in the POWCAR dataset, but uses price movements of CO_2. Consequently a consumer surplus analysis can be used as an indicator of the welfare changes arising from price effects in isolation.

Wadud (2011) applied a consumer surplus analysis to a downstream tradable permit scheme based on gasoline usage in the US. This research allocated permits on a per-person and per-vehicle basis, concluding that each allocation scenario to more progressive than traditional taxation. Further research into the design and implementation of a scheme was also recommended by Wadud (2011) and will be researched in Chapter 6 of this thesis.

2.9 CURRENT STATUS OF CARBON TRADING SCHEMES

Various forms of carbon trading schemes have been researched and implemented in a number of regions. The following section is a description of the current state of implementation of carbon trading schemes in Europe, the US, Australia and New Zealand.

2.9.1 European Union Emission Trading Scheme

The EU ETS is the largest emissions trading scheme of its kind in the world. This scheme was set up amongst 27 EU countries initially, but has recently been extended to the non-EU European countries of Norway, Liechtenstein and Iceland. This scheme is based on the basic carbon trading principle of a central cap being set by the EU Commission, the allocation of free permits and the creation of a carbon market. The cap is progressively lowered throughout each phase of trading. Phase I of the scheme was initiated on January 1st, 2005 and continued until 2008. Phase II was initiated in 2008 and will run until 2012. The scheme covers over 10,000 entities in the energy and industrial sectors such as steel and iron industries, oil refineries and power plants that the Commission estimates account for 50% the EU's CO_2 and 40% of its total GHG's. Phase III of the scheme will also include the aviation sector from 2012 (European Commission, 2008).

Under current EU ETS regulations each member state is entitled to submit a National Allocation Plan (NAP) to the Commission for approval. These plans detail the amount of emissions permits each country will issue to the relevant industries. These allocations were unchallenged by the Commission during Phase I (2005-2008) of trading; however, the Commission did revise down the allocation of some states for Phase II. The NAP's have drawn criticism in allowing states to devise their own allocations leading some to favour important indigenous industries and have led to instances of over allocation reflected in falling CO_2 prices. For this reason the

Commission has decided to scrap the NAP's for Phase III of the scheme and instead enforce a single EU-wide cap.

The ultimate aim of this scheme is to lower EU emissions by 21% in line with Kyoto targets by 2020 compared to 2005 levels in the ETS sector and by 10% in the non-ETS sector (European Commission, 2009). Consequently, Phase III has set allowances at 2.04 billion tonnes which will be reduced annually by 1.74% until 2020 to reach the reduction aims stated above. The scheme also includes scope for linkages to other global schemes which may be enacted by countries bound by the Kyoto Protocol.

As was previously mentioned, the scheme has been criticised for allowing countries to determine their allocation. This has led to an over allocation of permits, a lack of certainty over Phase III of the scheme and criticisms of the impact of the scheme on the competitiveness of the relevant industries (Grubb and Neuhoff, 2006). While the uncertainty over Phase III have been remedied by announcing targets, the problem of over allocation is difficult to control without being able to accurately predict future emissions. Moreover, some projects may not have tangible environmental benefits equal to the offsets allowed. Finally, lobbying by industry has led to inefficient allocations within each sector which continue to encourage the use of outdated production processes and overly generous subsidies (Corporate Europe Observatory, 2011). It is argued that the scheme has resulted in little or no reductions in emissions due to the number of 'offsets' that industries are allowed to use without purchasing a higher allocation (Corporate Europe Observatory, 2011).

Convery (2009) provided an extensive literature review of carbon trading and also surveyed scholars in the carbon trading field to determine the current thinking on the EU ETS. The review deals with the apparent negligible emissions reductions as identified by Ellerman and Buchner (2007, 2008) during Phase I and the instances of over allocation during the initial phase. The consensus among scholars is that over allocation has occurred in the scheme and that the ETS should transfer from a free allocation scenario to an auction of permits (Ellerman, 2006, Ellerman and Buchner, 2008). A third strand of research highlighted within the literature is competitiveness. Hourcade et al. (2007) concluded the overall effect of the EU ETS would be very minimal on competitiveness in the economy as a whole; however, specific sectors may require subsidies or tax breaks to compete internationally. Klepper et al. (2004)

recommend increasing tax rates on industries in the non-traded sector to level the playing field for industries within the ETS. What is clear from the research and results of the ETS thus far is the need for regular renewal of the scope, goals and regulation as new information becomes available. This will begin in Phase III with the progression towards full auctioning of permits (European Commission, 2009).

2.9.2 Carbon Trading in the United States

Two pieces of legislation have been put before the US Congress in proposing carbon trading since 2009. Both have failed to pass the legislative process. The first piece of legislation which was defeated in Congress was the American Clean Energy and Security Act, 2009 (US Congress, 2009). This wide ranging Act proposed a number of environmental measures to reduce emissions such as subsidies for clean energy technologies, requirements for industries to use renewable energy for 20% of electricity demand and the establishment of a carbon trading scheme (US Congress, 2009). The scheme proposed a progressively lowering upstream cap in which allocations of permits would be allocated freely to major polluters who would then be free to trade with other participants in the scheme. The Act also stated that an auction of permits to the relevant industries would take place in the future. This proposal was very similar to the EU ETS in that it also included provisions for polluters to offset their emissions rather than purchase surplus permits by investing in green initiatives such as planting forestry and investing in green technologies. The reduction target set was a more modest figure than the EU ETS of a 17% reduction on 2005 levels by 2020. The effect on consumers was predicted to be an increase in energy prices which would be offset by Government subsidies for low and middle earners. Concerns over the structure and scope of the scheme as well as the impact on consumer prices led to the Act being rejected in by Congress in 2009.

The 2010 Consolidated Land, Energy, and Aquatic Resources (CLEAR) Act of 2010 proposing a variation of a Cap-and-Dividend scheme has also gone before Congress. This type of scheme is summarised in Table 2-2. Cap-and-Dividend builds on the same basic principles as other carbon trading schemes in that a cap is set and trading of permits takes place. It involves the transfer of wealth from CO_2 emitting industries to consumers compelled to pay for the increased energy prices. This upstream scheme auctions permits to all producers of fossil fuels with a cap being progressively lowered. 75% of the income from auctions is returned to American people, while 25% is invested in clean technologies. Where this scheme differs from other proposed schemes is that no offsets are permitted by government, allaying fears that dubious offsets which yield little or no environmental benefits could be used without purchasing more emission permits. This Act also proposes to reduce CO_2 emissions by 20% by 2020, 30% by 2025, 42% by 2030 and 83% by 2050, relative to 2005 levels. As of October 2011 this Bill has failed to reach the floor of the Congress.

Literature researching the merits of carbon trading in the US has focused on the allocation of permits. Goulder et al. (2010) modelled the effects of the scheme on the profits of relevant industries in the US. This research concluded that a share of 15% of the total allocation of permits being free would prevent profit losses, while anything above this would over compensate and create an incentive to emit more GHG's. Auctioning of permits also lowered Gross Domestic Product (GDP) costs by 33% in the author's model. This paper built on previous research in investigating the effects of an upstream carbon trading system in the US. Bird et al. (2008) emphasised the positive impacts a carbon trading scheme can have on the renewables sector. Establishing the scheme could reap economic benefits as opposed to the competitiveness issues which have been highlighted in the research conducted in the EU. Research has also focused on the potential structure of a scheme (Stavins, 2008). In keeping with recent literature an upstream scheme was recommended and researched. Stavins (2008) found that 35% of the burden of a scheme would be on households with 30% falling on businesses and industry. The effects on GDP would amount to less than 0.5% per annum. The need for international cooperation is again emphasised to realise any environmental or economic benefits from a federal scheme (Jaffe and Stavins, 2008). Reservations amongst legislators that a trading scheme could be ineffective has stalled progress and led some to recommend taxation as a simpler alternative (Keohane, 2009). However, the general inertia to environmental taxation and federal regulations in the US deems progress on any form of carbon trading scheme unlikely in the short term.

2.9.3 Carbon Trading in Australia

Emissions trading schemes of the type proposed in Australia and implemented in New Zealand were first recommended by a report commissioned for the Australian Government in 2007 (Garnaut, 2008). This report emphasised the need for a global CO_2 mitigation policy to avoid a Prisoners Dilemma Problem[1]. This is a scenario in which each country has an incentive to do less about their national emissions while leaving the work to other nations.

With this mind the Garnaut Review (2008) focused on five major policy themes. The first theme explored was the emphasis on integrating any national scheme into an international framework of mitigation such as the EU ETS and any future international climate change agreements. This proposal is also a key tenet of the New Zealand Emissions Trading Scheme (NZ ETS) which is discussed in section 2.9.4. The second policy theme discussed was the necessity to ensure a scheme would not stunt economic growth. A broad based market for CO_2 is recommended with very few sectors being exempt, particularly for short-term political reasons. The third theme explored was the practicality of mitigation targets. Garnaut (2008) warned against the setting of unrealistic international targets that have little chance of been implemented at a national level. However, this concern must not be an incentive to do nothing due to uncertainty. The fourth theme discussed related to the reality that lower income groups and developing countries would be the most disproportionately affected by mitigation policies. Policies which do not compensate the poorest income groups could create a resistance to change. The final theme discussed was the importance of good governance of a scheme. Government must guard against any vested interests which have the potential to lessen the environmental benefits of the policy. The targets recommended by the Garnaut Review were a 25% reduction on 2000 emissions by 2020 and a 90% reduction by 2050 in the context of an international agreement in succession to the Kyoto Protocol (Garnaut, 2008).

Subsequent to the publication of this report a scheme similar to the EU ETS was also proposed by the Australian Government in 2008. The Carbon Pollution Reduction

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[1] Prisoners Dilemma is a theory by which two agents fail to cooperate with each other when it is beneficial to do so leading to a sub-optimal equilibrium. This theory was first developed by Merrill Flood and Melvin Dresher in the 1950's and was formalised as a "Prisoners Dilemma" game by Albert W. Tucker in TUCKER, A. W. 1980. On jargon: The prisoner's dilemma. *UMAP Journal,* 1.

Scheme (CPRS) was put before Parliament in 2008 with the stated aim of being fully functional by 2010. The targets for this scheme were a 5% reduction on 2000 level emissions by 2020, rising to 15% subject to agreements with other major polluting nations (Australian Government, 2008). A key difference between this scheme and the EU ETS was that the market for CO_2 would be constrained within a price range of $20-40AUD (€15 - €30) which would lessen price volatility. This upstream scheme also included less than 1,000 eligible entities trading permits. Offsets were permitted for activities which mitigate CO_2 and subsidies were to be paid to exporting industries to maintain global competitiveness. Subsidies would also be paid to lower income households subject to high energy prices. These offsets included mitigating activities such as reforestation, landfill closure and coalmine decommissioning. Agricultural activities were also exempt from the initial phase of the scheme due to the importance of the sector to the Australian economy. Offsets generated by innovations in agricultural production which could lower emissions would be eligible for CO_2 credits tradable within the CPRS.

Atker and Bennett (2009) researched the public acceptability of the CPRS. In a survey of individuals living in New South Wales it was found that uncertainty about the benefits of a potential scheme and the speed of future increases in global temperatures affect public acceptability of the CPRS. Concerns that other countries will not take similar action also lessened the acceptability of such a scheme. Criticisms of the absence of bilateral linkages in the scheme to the EU ETS and NZ ETS and inbuilt price caps have also been raised (Jotzo and Betz, 2009). Jotzo and Betz (2009) argued against controlling the price of CO_2 as this provides an incentive for emitters to do less than required in reducing emissions and investing in green technologies. Integrating with the aforementioned schemes was also recommended to create more flexibility in the market and reduce emissions more efficiently.

The failure of the Copenhagen Climate Conference in 2009 to reach agreement on substantial international targets and mitigation policies which were crucial to the introduction of the Australian scheme contributed to the CPRS failing to pass into legislation in 2010. The CPRS was subsequently shelved by the Government in anticipation of a future international agreement on climate change. A new Labour Government was elected in Australia in 2010. This new Government has instead committed to introducing a carbon tax which will transition to an ETS-type scheme within five years (Australian Government, 2011). These commitments also include proposals to generate 20% of the nation's energy using renewables by 2020. The establishment of the Clean Energy Finance Corporation which will act as a 'Green Bank' independent of Government will invest in wind and solar projects to achieve this 20% target. Regulations for the motor industry to manufacture more fuel efficient vehicles will also be established before the introduction of CO_2 standards for all new light vehicles (Australian Government, 2011).

In July 2011, a CO_2 price of $23 AUD (€16.7 EUR) was set for the initiation of the carbon trading scheme to come into effect in July 2012 for 500 of the nation's largest polluters. A target of a 5% reduction on 2000 emissions levels was also set; falling far short of the Garnaut recommended 25% reduction. Ensuing energy price rises for households will be compensated with tax breaks and subsidies. Transport fuels are also exempt from the initial tax as an additional equity measure for households. A CO_2 price will only be applied to heavy road transport in 2014 with no plans as yet to tax other forms of road transport. Subsidies and tax breaks will also be extended to 'trade-exposed' industries to protect employment and maintain competitiveness (Australian Government, 2011). These emissions intensive industries include steel manufacturing, coal mining, paper manufacturing and the chemicals industry.

2.9.4 New Zealand Emissions Trading Scheme

New Zealand introduced an ETS type scheme to limit emissions in 2008. The NZ ETS allocates free permits upstream to all sectors of the economy and in the short term has set the price of CO_2 at NZ$25/tonne. One permit in the scheme is the equivalent of one tonne of CO_2 and is called a New Zealand Units (NZU). The aim of this scheme is to meet the country's Kyoto target of a 5.2% reduction by 2012. The major difference between this and the EU ETS is that a wider range of sectors are included in the scheme such as agriculture, forestry and fishing. All GHG's covered by the Kyoto Protocol are regulated in the NZ ETS and are calculated in CO_2 equivalent. The sectors covered are listed in Table 2-3.

Table 2-3: Participants in the New Zealand Emissions Trading Scheme

Sector	Entry Date	Obligations	Allocation of NZU's
Forestry	2008	One NZU for every tonne of CO_2 equivalent	Free Allocation
Energy	2010	One NZU for every two tonnes of CO_2 equivalent	Must be Purchased
Fishing	2010	One NZU for every two tonnes of CO_2 equivalent	Free Allocation
Industry	2010	One NZU for every two tonnes of CO_2 equivalent	Must be Purchased
Liquid fossil fuels	2010	One NZU for every two tonnes of CO_2 equivalent	Must be Purchased
Synthetic gases	2013	One NZU for every two tonnes of CO_2 equivalent	Must be Purchased
Waste	2013	One NZU for every two tonnes of CO_2 equivalent	Must be Purchased
Agriculture	2015	One NZU for every two tonnes of CO_2 equivalent	Free Allocation to be phased out from 2016
Horticulture	2011	One NZU for every tonne of CO_2 equivalent	Free Allocation

The NZ ETS scheme is an upstream system under which large industries in each of the sectors listed above must register to receive NZU's and allocation allowances from the Government. Each sector has specific allowances and regulations within the overall scheme which differ from other sectors. For example the forestry sector is entitled to receive free allowances in some instances for new forestry in an opt-in scheme; however, penalties are incurred if these plantations are cut down without replacement. This is therefore an incentive to preserve existing forests as a means of sequestering CO_2 from other sectors. Another key feature of the scheme is the provision to link into future international trading schemes and the provision to trade permits internationally. A transition period during which a number of sectors listed in Table 2-3 are permitted to emit two tonnes of CO_2 for each NZU at the fixed price of NZ$25 will end in 2013. Entities will then have to surrender one NZU for each tonne of CO_2 equivalent while permits will be allowed to fluctuate according to market forces. This transition period does not apply a specific cap on each sector, but this will be enforced once regular trading begins.

Research into the effectiveness of the NZ ETS has mainly focused on the economic impacts of the scheme on indigenous industries and the effectiveness of the scheme in reducing emissions. The Agriculture sector is estimated to account for up to half of the New Zealand's annual GHG emissions (Lennox et al., 2008) and is therefore the sector of most importance within the scheme. However, due to the economic benefits this sector generates, the scheme will not cover emissions from agricultural processes until 2015 and will also provide an initial free allocation of permits. Lennox et al. (2008) conclude losses in GHG intensive livestock can be offset by changing land use patterns and instigating mitigation policies. The authors also mention 'carbon leakage'[2] as a potential problem within the NZ ETS and this view is shared by others (Barker et al., 2007, Greenhalgh et al., 2007). This problem has the potential to occur while other regions internationally remain unregulated and if industry in New Zealand relocates to remain competitive. The GHG reductions generated within the scheme could potentially transfer to another country.

Greenhalgh et al. (2007) proposed incentives for trade intensive sectors to reduce leakage while maintaining emissions targets which would diminish as trading schemes are established internationally. A caveat to providing incentives is that they should be curtailed in industries where it is not cost effective. Jiang et al. (2009) concluded that the success of the scheme would hinge on the integration of it with international schemes and until such time the environmental benefits would be marginal. Nevertheless the NZ ETS is an important first step in the process of creating a liquid international scheme to meet Kyoto targets.

Criticisms of the scheme have also focused on the free allocation of permits and the provision of subsidies to heavy industries which may provide an incentive to emit GHG's in the absence of a stringent cap (Wright, 2011). Additionally, the abolishment of the two-for-one allocation of NZU's for many sectors by 2013 and the auctioning of all permits was recommended. Extending the two-for-one policy will come at a heavy price to the taxpayer (Wright, 2011). As this thesis is concerned with emissions trading in the transport sector, it is useful to study the system implemented in New Zealand to deal with liquid fossil fuels.

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[2] 'Carbon leakage' is an increase in carbon emissions in one region as a result of the initiation of a strict carbon reduction scheme in another region. Research has indicated emissions will significantly increase in developing countries as a result of carbon reduction schemes in developed countries. For more information see BABIKER, M. H. 2005. Climate change policy, market structure, and carbon leakage. *Journal of International Economics,* 65**,** 421-445, KUIK, O. & GERLAGH, R. 2003. Trade liberalization and carbon leakage. *Energy Journal,* 24**,** 97-120.

2.9.4.1 Regulating the Transportation Sector in the New Zealand ETS

The sector listed as liquid fossil fuels in Table 2-3 mainly constitutes emissions from the transportation sector while also including home heating fuels and the coal mining industries. The approach taken within the scheme is to apply the cap 'as far up the supply chain as possible' (NZ ETS, 2011). This upstream approach has the advantage of providing administrative and regulatory simplicity in dealing with a small number of oil companies and refineries who import or refine oil products. Entities which produce or own more than 50,000 litres of liquid fossil fuels for consumption or refinement must apply to be included on a national register of emissions. Once on the register of emissions, refineries are legally obliged to comply with a number of regulations (NZ Ministry for the Environment, 2009). The scheme also provides for penalties and fines for entities that do not register or comply with regulations. These obligations include; registering as a participant, providing information to authorities, collecting data, calculating emissions and maintaining records, filing annual emissions returns and surrendering or repaying New Zealand Units (NZUs).

Emissions are calculated based on emission factors and a calculation methodology provided by the Ministry for the Environment (NZ, 2009). Unique emission factors may also be used if refineries fulfil certain criteria that are verified by a third party. Emission factors are also utilised in this thesis in estimating CO_2 for commute trips similar to the NZ ETS. This method of calculation using emission factors is outlined in Chapter 3. Annual submissions of emissions information and surrendering of NZU's must be completed by each participating entity within three months of the end of the previous calendar year. As all trading is focused upstream, end users of transport have no obligations to participate. Increased fuel costs have been the major outcome of introducing this scheme and it is hoped that this increase will encourage the use of greener forms of transport (NZ ETS, 2011).

As has been detailed in this detailed review, schemes proposed and implemented to date have been based around an upstream framework. The subsequent chapters will analyse and evaluate a potential downstream PCTS on commuters who undertake travel-to-work trips.

2.10 SUMMARY

This chapter introduced the main concepts and literature relating to carbon trading and related topics. In particular current research and implementation of carbon trading schemes was discussed. The application of census data in previous transportation literature was also highlighted as an important resource in conducting quantitative analysis.

The concepts presented in this literature review will be applied to the analyses in the subsequent chapters. As was discussed in the introduction chapter, a research requirement arises in determining the socio-economic and welfare effects of introducing a PCTS. A number of studies have shown alternative carbon reduction policies to be regressive, particularly carbon taxation. Research into the operation of ETS schemes has found the environmental benefits of these upstream schemes to be minimal at best. Therefore, determining the potential outcomes of a downstream PCTS scheme as an alternative to taxation and upstream trading is an important research requirement. The following chapters 4, 5 and 6 will analyse the research questions identified in the introductory chapters.

3. METHODOLOGY

3.1 INTRODUCTION

This chapter details the methodologies followed to calculate travel-to-work CO_2 emissions, analyse the socio-economic data associated with these trips and determine the welfare changes to individuals in a PCTS. The following section 3.2 of this chapter describes the data sources used in this thesis. The POWCAR dataset and its constituent variables are detailed in this section. A number of additional variables are also created to supplement the existing POWCAR variables and are also detailed in this section. The methodology followed in estimating CO_2 emissions using POWCAR data is presented in Section 3.3. The use of logistic regression modelling is a major part of the research presented in Chapters 4 and 5. Two logistic regression techniques are used in the thesis: binary logistic regression and multinomial logistic regression. The methodology these models are based on is discussed in full in this section 3.4. Section 3.5 details the diagnostic tests used to validate the logistic regression models. The results in Chapter 5 estimate the welfare changes arising from introducing a PCTS. To do so, a consumer surplus analysis is conducted to determine the magnitude of positive or negative changes in welfare. The methodology followed in this analysis is also presented in section 3.6.

3.2 DATA SOURCES

This section will introduce and discuss the main data sources used in this thesis. The suitability and rationale of using these data sources is also discussed.

3.2.1 POWCAR Dataset

As was discussed initially in Chapter 2.3, the primary data used in this research are taken from the Census of Population, 2006. More specifically, a subset of this census is used, namely POWCAR. This dataset tabulates 1,834,472 individual travel-to-work trips of persons over the age of 15 and working for payment or profit. The details of the collection methodology, structure and content can be found in the POWCAR User Guide (CSO, 2006)[3]. This dataset includes 32 separate variables detailing a number of travel specific and socio-economic characteristics. These variables are detailed in Appendix A. A selection of variables are used throughout this thesis and detailed in the relevant chapters. One notable omission from the POWCAR dataset is income information. While regrettable, this is compensated for by the use of supplementary deprivation data sources. (see section 3.2.2).

The rationale for choosing POWCAR as the primary data sources is that it is the largest, most detailed travel survey of its kind in Ireland to date. The National Travel Survey (NTS), 2009 could also have been utilised; however, this survey is a very small sample of 7,221 persons. The CSO have advised the use of POWCAR as the definitive data source on travel to work trips (CSO, 2011). As was mentioned in Chapter 2.4.3, the NTS can be used to validate the scope of the data presented in POWCAR. As the NTS found work trips to account for 27% of all trips surveyed, it can be postulated that POWCAR would account for a share of 25 – 30% of all trips taking into account a margin of error in the NTS survey. This percentage is a significant sample of all trips and therefore a reliable data source to apply to this research. The completion of a unique travel survey for this thesis could also be merited; however, to usurp POWCAR as the primary data source would require a survey of a sizable proportion and scope which was not a feasible option.

3.2.2 Supplementary Data

In addition to the variables tabulated in the POWCAR dataset, a number of additional open source datasets and calculated variables are added to the POWCAR dataset. New variables created to supplement existing variables relate to the calculation of CO_2 emissions, the setting of a cap and the estimation of welfare changes in a PCTS. The

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[3] The POWCAR User Guide is available to download at http://www.cso.ie/census/documents/POWCAR_user_guide_2006.pdfhttp://www.cso.ie/census/documents/POWCAR_user_guide_2006.pdfhttp://www.cso.ie/census/documents/POWCAR_user_guide_2006.pdf

processes involved in of calculating these new variables are described in the sections 3.3 and 3.5.

The existing open source variables added to POWCAR are related to social deprivation and affluence in Ireland (Haase and Pratschke, 2008). This data source (see Chapter 2, section 2.7) is aggregated at a DED level and combined with POWCAR for each record based on the 'Residence ED' variable coding. In addition to deprivation indices, a density index was also calculated and applied to each record in POWCAR based on the number of people per square km in each DED. These deprivation and density indices are utilised in the welfare analysis as a means of comparison across socio-economic groups and to observe any divergences in welfare changes in urban and rural regions.

Welfare variables are also created using existing data in POWCAR and travel cost equations associated with each mode of transport. A price on CO_2 associated with each individual's travel-to-work emissions are also added to existing travel costs to determine any welfare changes in each scenario. This methodology is outlined in section 3.5.

The use of GIS mapping provides an added layer of explanatory power in describing welfare changes. To transpose these results, an open source geographical layer file was obtained from the CSO which identifies each DED using a unique geographical code. This is combined with aggregated welfare results for each DED in the POWCAR dataset using the 'Residence ED' variable.

3.3 ESTIMATING CARBON EMISSIONS USING POWCAR

This section details the methodology used in estimating CO_2 emissions (results are presented in Chapter 4). The POWCAR variable used to determine emissions was the 'Journey Kilometres' variable. Irish emissions factors were chosen to determine an estimate of daily and annual emissions. The emission factors were first presented in Walsh et al. (2008). Based on the review of the literature, these emission factors are the most definitive source in the absence of an Irish emissions inventory as is the case in the UK. In this thesis walking and cycling are assumed to be carbon neutral, while motorised modes of travel are each given a unique emission factors.

Passenger km emissions factors are calculated based on peak time trips and assuming maximum occupancy. This is an additional rationale to apply these factors to POWCAR as the dataset tabulates peak time travel-to-work trips. The emission factor for driving alone was determined based on fuel consumption values (Howley et al., 2003) and engine size data obtained from the Department of the Environment, Heritage and Local Government (DOELG, 2004). Using this information Walsh et al. (2008) found an average emission factor of 0.12 kilograms (kg) of CO_2 per passenger km.

The emission factor for bus transport was calculated using journey length and fuel consumption data from Dublin Bus (Walsh et al., 2008). Emissions for rail transport is calculated based on rail electricity consumption in oil equivalent (O'Leary et al., 2006) and is found to be 0.011kg per passenger km. An emission factor for diesel powered rail travel is not utilised in Walsh et al. (2008). The emission factors used in this thesis to determine are listed in Table 3-1.

Table 3-1: Emission factors used

Means of Travel	CO_2 per passenger km (Kg)
Bus	0.016
Rail	0.011
Motorcycle	0.120
Driving alone	0.120
Lorry/Van	0.184

The following equation is used to calculate the CO_2 emissions generated by travel-to-work trips:

$$CO_2 = \sum (EF_i * VKM * 2) * 215 \qquad (Eq. 3.1)$$

VKM (Vehicle kilometres) is the number of kilometres travelled by an individual on the mode of transport in question and EF_i are the emissions factors presented in Table 3-1 associated with each mode of travel which are inclusive of a peak time occupancy rate. VKM is determined using the 'Journey Kilometres' variable in the POWCAR dataset. This is then doubled to calculate the emissions for a return daily journey and multiplied by 215 (days) to calculate annual emissions. 215 days is the average working year in Ireland. For the purpose of this study, the return trip is assumed to be identical to the outbound trip. While in reality this may not be the case for a number of trips, it is still a reliable assumption based on the size of the dataset. Once emissions are calculated a CO_2 cap can be applied to the dataset based on national emissions levels and a regression analysis conducted to determine the socio-economic characteristics associated with individuals in a PCTS.

3.4 LOGISTIC REGRESSION MODELLING

This section presents the main aspects and concepts of the binary logistic and multinomial logistic regression models used in this thesis. For a more detailed description of the modeling techniques used see Louviere et al. (2000), Washington et al. (2003), Train (2003) or Agresti (2007).

3.4.1 Binary Logistic Regression

Binary logistic regression (BLR) models are used to describe the relationships between a binary dependent variable and a set of independent explanatory variables. This section presents the main features of this model. For a more detailed description see Washington et al. (2003) or Train (2003).

In this thesis the BLR model takes the form of the probability of a person being above a CO_2 cap in a PCTS. If the outcome is true then the resulting case is equal to one (binary variable). If not, it is equal to zero. Equation 3.2 represents the relationship between the dependent binary variable and independent variables. Unlike linear regression, independent variables are not required to be normally distributed or have a constant variance in logistic regression modelling (Train, 2003).

Consider an event Y, which in this case is an individual emitting CO_2 above a predetermined cap. The probability of a person being above this cap is P(Y) in the model and the resulting outcome is equal to one. The dependent variable is the log of the odds ratio of the event Y occurring or the logit of Y. That is:

$$\text{Logit(Y)} = \ln\left(\frac{\hat{Y}}{1-\hat{Y}}\right) = \beta_0 + \beta_i . X_i \qquad (Eq. 3.2)$$

β_0 is the model constant and β_i are the parameter estimates for the set of socio-economic independent variables (X_i,i = 1,…,n). $\hat{Y}$ is the predicted probability of the event which takes binary values of 1 (continue analysis) or 0 (stop the analysis). Transforming Equation 3.2 to solve for the probability of $\hat{Y}$ gives:

$$\left(\frac{\hat{Y}}{1-\hat{Y}}\right) = EXP^{\beta_0 + B_i X_i} = EXP^{\beta_0} EXP^{\beta_i X_i} \qquad (Eq. 3.3)$$

When an independent variable increases by one unit, all other remaining constant, therefore the new probability is of Y is:

$$\left(\frac{\hat{Y}}{1-\hat{Y}}\right) = EXP^{\beta_0}\, EXP^{B_i(X_i+1)} = EXP^{\beta_0} EXP^{\beta_i X_i}\, EXP^{\beta_i}$$

$$= \left(\frac{\hat{Y}}{1-\hat{Y}}\right) EXP^{\beta_i} \qquad (Eq. 3.4)$$

The factor EXP^{β_i} is the odds ratio which indicates the magnitude of the change in the dependent variable for a one unit change in the dependent variable. This ranges from zero to infinity. If less than one the independent decreases the odds of the outcome Y=1, and if greater than one, it increases the odds.

3.4.2 Multinomial Logistic Model

This section presents the main aspects of the multinomial logistic model (MNL). This is a similar model to the BLR model with application to a categorical variable of two or more sub categories. Unlike a BLR model this analysis includes an error term assumed to be independently distributed. For a more detailed analysis of the MNL model see Train (2003), Louviere (2000) or Agresti (2007). As is the case BLR, MNL models do not make any assumptions of normality, linearity or constant variance of independent variables.

In the MNL model Y is the dependent variable with J outcomes $(Y_j, j = 0,1,\dots,J)$ with J being the reference category vis-à-vis all odds ratios for each outcome. The log of the odds ratio of the reference category J (the logit of J) paired with each outcome is:

$$\ln\left(\frac{\hat{Y}_j}{\hat{Y}_J}\right), \qquad j = 1,\dots.,J-1 \qquad (Eq. 3.5)$$

$\hat{Y}$ is the predicted probability of the dependent variable Y and j the predicted outcome categories , $(j = 0,1,\dots,J)$ compared to the reference category J. Thus the logit model including the independent variables is:

$$Logit\left(Y_J\right) = ln\left(\frac{\hat{Y}_j}{\hat{Y}_J}\right) = \beta_0 + \beta_i . X_i + e \qquad (Eq\ 3.6)$$

β_0 is the model constant and β_i are the parameter estimates for the set of independent variables (X_i, i = 1,…,n). Separate equations for J outcomes are determined vis-à-vis the reference category. These equations are fitted simultaneously and have smaller standard errors than if each were fitted using BLR separately for each outcome of Y (Agresti, 2007).

The analysis in Chapter 5 uses a MNL model in determining the relationship between welfare change and a number socio-economic indicator from the POWCAR dataset.

3.5 MEASURING PERFORMANCE OF LOGISTIC REGRESSION MODELS

With each logistic regression model there are a number of goodness-of-fit and test statistics used to interpret the output and performance. This section presents the statistics and tests used in the evaluation of the BLR and MNL models and the diagnostic tests used to validate the models.

3.5.1 Sign of the coefficient

The sign of the beta coefficient calculated for each independent variable indicates the relationship between this variable and the dependent variable. The sign of the coefficient should be intuitive to the research being carried. For example in Chapter 4, journey kilometres would be expected to have a positive coefficient as likelihood of an individual being above a CO_2 cap in a PCTS is increased the longer their journey.

3.5.2 Statistical significance

To test for statistical significance of the variables in each model, a p-value is used. This is the probability of obtaining test statistic at least as extreme as the observed value. If the p-value is less than the critical value of 0.05 (95% confidence interval or a more robust 0.01 (99% confidence interval), one can reject the null hypothesis that the test statistic is not a determinant of the dependent variable in support of the alternative hypothesis of significance.

3.5.3 R-squared values

The R-squared value provides a convenient estimate of the goodness-of-fit of a model when comparing it to other models within the same study. The R-squared value ranges between 0 and 1, with a larger value indicating greater explanatory power of the independent variables in explaining the variation in the dependent variable. A lower value indicates less explanatory power. Using R-squared is less informative when conducting non-linear regression and but is a still a useful indicator of association. However, an alternative logistic regression-specific R-squared value can be used – The Nagelkerke R-squared.

The Nagelkerke R-squared value (Nagelkerke, 1991) was developed for use in logistic regression modeling. This statistic allows for the assumptions of non-linearity in logistic regression modeling. The R-squared is calculated based on the log-likelihood function of the final model versus the baseline model when independent parameters are set to zero. That is:

$$R^2 = 1 - \frac{LL(\hat{\beta})}{LL\,(0)} \qquad (Eq. 3.7)$$

$LL(\hat{\beta})$ is the log-likelihood values of the final model, and $LL\ (0)$ is the log-likelihood of the baseline model with a range between 0 and 1.

3.5.4 Likelihood ratio

This statistic measures the performance of the logistic regression models in explaining the variation in the dependent variable. Also known as the log likelihood (LL), it varies from zero to minus infinity. LL is calculated through iteration, using maximum likelihood estimation. The LL statistic has a chi-squared distribution providing an indicator of the usefulness of including of additional explanatory variables. This statistic also forms the basis of the likelihood ratio test in determining the goodness-of-fit of a model which compares models with additional explanatory variables. As a rule of thumb, the lesser in magnitude the LL is, the better the fit of the model.

3.6 WELARE MODELLING

This section outlines the methodology followed in determining the welfare effects of introducing a PCTS. The results of the welfare model are presented in Chapter 5. To ascertain welfare changes, a consumer surplus analysis is used. Calculating consumer surplus requires a pre-PCTS travel cost (excluding CO_2) and post-PCTS (including CO_2) travel cost. Once costs are determined, changes in consumer surplus can then be predicted for each individual.

3.6.1 Travel Cost Calculations

To determine the pre-PCTS and post-PCTS travel costs for commuters, travel cost equations are used (Steer Davies Gleave, 2009). These equations estimate the cost of travelling by walking, cycling, private vehicle and public transport in Ireland. Research carried out by Steer Davies Gleave Consultants for the NTA has determined mode and departure time parameters for the cost equations and this information has been obtained from the NTA for the purpose of this research. The parameters vary across three separate peak time periods in which a commuter undertakes a trip: 7-

8AM, 8-9AM and 9-10AM. Parameters are related to distance travelled, travel time, public transport fares and tolls occurring in daily trips for three types of commute trips: slow mode trips (walk and cycle), private vehicle trips (car, motorcycle, van) or public transport (bus and train). The parameters used in this chapter are detailed in Table 3-2. These parameters are then inputted into cost equations 3.8 – 3.14 to determine each individual's commute trip cost.

Table 3-2: Travel Parameters used

Parameter Code	Parameter	Value
HWAY1	Distance (7AM-8AM)	1.180
HWAY2	Distance (8AM-9AM)	2.150
HWAY3	Distance (9AM-10AM)	3.425
HWAY4	Travel Time (7AM-8AM)	1.000
HWAY 5	Travel Time (8AM-9AM)	1.000
HWAY6	Travel Time (9AM-10AM)	1.000
HWAY 7	Toll calibration (7AM-8AM)	1.232
HWAY8	Toll calibration (8AM-9AM)	2.409
HWAY9	Toll calibration (9AM-10AM)	0.863
PT1	Public transport fare calibration (7AM-8AM)	3.638
PT2	Public transport fare calibration (8AM-9AM)	2.069
PT3	Public transport fare calibration (9AM-10AM)	3.424
PT4	In Vehicle Time	1.000
PT5	In Vehicle Time	1.000
PT6	In Vehicle Time	1.000

Source: NTA, 2009 (Steer Davies Gleave, 2009)

Private vehicle travel includes highway (HWAY) trips made by private cars, vans and motorcycles. Public Transport trips cover all Dublin Bus services, national bus services, tram lines, commuter rail and intercity rail trips. Having defined the parameters required in Table 3-2 above, the pre-PCTS travel cost equations for slow modes, private vehicles and public transport are:

Slow Modes

$$Cost\ (Slow\ Mode) = \left(\frac{Distance}{Speed}\right) * Trip\ Time * VOT \qquad (Eq.3.8)$$

Private Vehicle Travel

$$Cost(7-8AM) = (Distance * HWAY1) + \ (Trip\ Time * HWAY4) + \left(\frac{Toll\ cost}{HWAY7 * VOT}\right) \quad (\mathrm{Eq.3.9})$$

$$Cost(8-9AM) = (Distance * HWAY2) + (Trip\ Time * HWAY5) + \left(\frac{Toll\ cost}{HWAY8 * VOT}\right) \quad \text{(Eq. 3.10)}$$

$$Cost(9-10AM) = (Distance * HWAY3) + (Trip\ Time * HWAY6) + \left(\frac{Toll\ cost}{HWAY9 * VOT}\right) \quad \text{(Eq. 3.11)}$$

Public Transport

$$Cost(7-8AM) = (In\ Vehicle\ Time * PT4) + \left(\frac{PT\ Fare}{PT1 * VOT}\right) \quad \text{(Eq. 3.12)}$$

$$Cost(8-9AM) = (In\ Vehicle\ Time * PT5) + \left(\frac{PT\ Fare}{PT2 * VOT}\right) \quad \text{(Eq 3.13)}$$

$$Cost(9-10AM) = (In\ Vehicle\ Time * PT6) + \left(\frac{PT\ Fare}{PT3 * VOT}\right) \quad \text{(Eq 3.14)}$$

Distance is calculated in km and trip time is calculated in minutes using POWCAR. PT fare is the cost of a public transport ticket and VOT is the value of time to commuters. The value of time is calculated by the NTA as €9.476 per hour in 2006 prices. Speeds for slow modes are assumed to be 5kph for walking and 15kph for cycling. Toll costs do not apply for commute trips in the rural WBR as no trips would have incurred a toll in this region at the time of the census in 2006. Toll trips in the DMR are averaged at €0.23 per trip (NTA, 2010). These cost equations include for CO_2 in the post-PCTS price of travel (P2). The price of CO_2 per trip is determined using market values.

Post-PCTS travel costs are determined using pre-PCTS cost equations (Equations 3.8 - 3.14) and adding the monetary cost of CO_2. That is:

$$Post\ Costs = Pre\ Costs + \mathrm{PCO_2} \quad \text{(Eq. 3.15)}$$

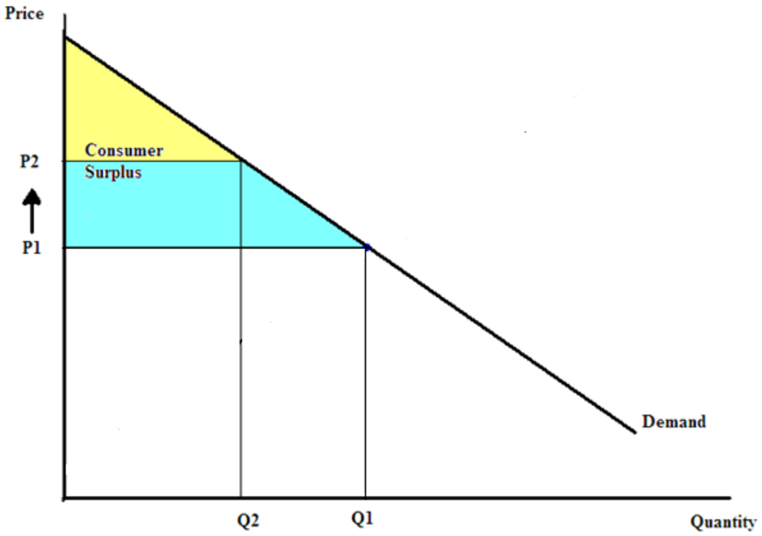
Pre-costs are the travel costs calculated for the various modes and travel times and PCO2 is European Union Allowances (EUA) market CO2 price (Pointcarbon, 2011). This price is varied to investigate any welfare changes in the event of a fluctuating market price. Travel cost results using this methodology are presented in Chapter 5.

3.6.2 Measuring Consumer Surplus Change

In determining any welfare loss to commuters a consumer surplus analysis is used. Consumer surplus measures the difference between what a consumer is willing to pay and what is actually paid for a good. If the price that is paid is below what an individual was willing to pay, the individual attain a consumer surplus. For a more detailed description on consumer surplus see Harberger (1971) Willig (1976) or Slesnick (1998).

Using consumer surplus is a useful tool in measuring the *change* in welfare as opposed to welfare levels before or after a change in market conditions. In this thesis, the absence of income data within the POWCAR dataset does not allow for the research to quantify actual welfare levels before and after the policy is introduced by determining the effect on income. However, using price levels before and after the policy is introduced, the relative change in welfare can be determined using a consumer surplus analysis as a proxy for welfare changes to compare across various socio-economic groups. Figure 3-1 graphically illustrates a change in consumer surplus from a price increase from P1 to P2. Pre-PCTS, consumer surplus is measured as the area above P1 and under the demand curve covered by the blue and yellow area. Post-PCTS, due to a price rise, this area shrinks to the area above P2 (yellow area). This change is the magnitude of welfare loss.

Figure 3-1: Consumer Surplus



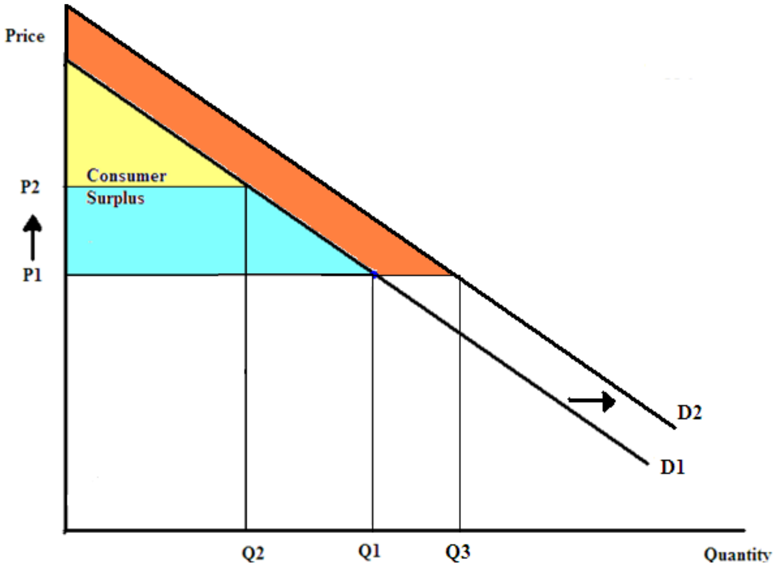
As the varying factor between the pre-PCTS and post-PCTS travel cost is the CO_2 price, individuals who maintain a surplus of CO_2 permits within will experience an increase in consumer and a welfare gain. Individuals with a deficit of CO_2 permits within the market will experience a CS decrease and welfare loss (and produce a negative coefficient). The equation to calculate the change in consumer surplus (ΔCS) is as follows:

$$\Delta CS = \frac{P_1 G_i}{1+\beta_{Pi}}\left\{1-\left(\frac{P_{2i}}{P_1}\right)^{1+\beta_{Pi}}\right\} \qquad (Eq. 3.16)$$

P_1 is the pre-policy price of travel and P_{2i} are the post-policy prices. β_{Pi} is the price elasticity of demand for travel and G_i is the consumption of CO_2. If consumer surplus is found to be a negative, a welfare loss has occurred and vice versa. Zero represents no change in welfare. The size of the numeric figure found is the magnitude of the change in purchasing power for travel of the individual.

Since permits in a PCTS scheme are allocated freely, the opportunity cost of selling surplus permits to the market is also reflected in consumer surplus changes. Individuals using more sustainable forms of transport can benefit to a greater extent than those who use less sustainable forms of transport by selling excess permits. This is illustrated in Figure 3-2, where an increase in travel cost from P1 to P2, shrinks consumer surplus for individuals using less sustainable modes of travel to the yellow area under the demand curve D1. At the same time, demand for travel by more sustainable modes would be expected to increase, thus shifting the demand curve for these modes of travel to D2. Individuals undertaking these trips would benefit with increased consumer surplus represented by the orange area under the demand curve, D2.

Figure 3-2: Consumer surplus change in a PCTS



3.7 SUMMARY

This chapter presented the process used to generate the results that will be presented in Chapters 4, 5 and 6. A discussion on the application of the methodologies will be presented at the beginning of each of these results chapters.

4. EMISSIONS AND SOCIO-ECONOMIC ANALYSIS OF INDIVIDUALS IN A PERSONAL CARBON TRADING SCHEME

4.1 INTRODUCTION

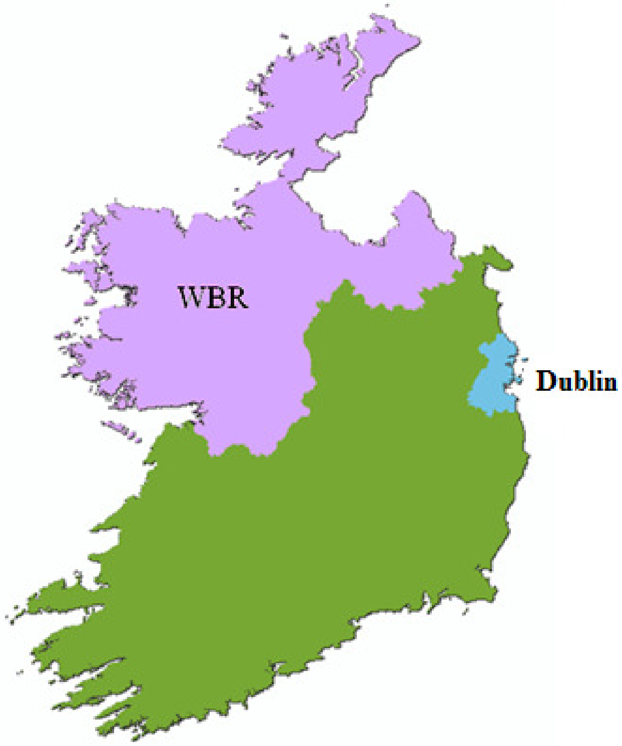
This chapter will investigate the impact of a PCTS on individuals who undertake daily travel-to-work trips. This chapter will initially report the results of the CO_2 emissions estimations for all trips nationally, in Dublin and in the WBR to determine any difference between the urban and rural regions. These estimations are based on the methodology outlined in Chapter 3, section 3.2. Two CO_2 cap levels are then applied to individual trips in each sample to observe the percentage of individuals above and below the cap. Descriptive statistics are also tabulated to determine any important outcomes across each sample. The first cap is based on national average emissions calculated in this chapter and the second cap is lowered from this level by 20% in line with Ireland's 2020 targets (European Commission, 2010). Finally, a BLR model is used to identify the significant socio-economic characteristics of individuals above the CO_2 cap at both levels.

This chapter is organised into seven sections. Section 4.2 introduces the study regions chosen to conduct this research. Section 4.3 reports the findings of the emissions estimation for travel-to-work trips. Section 4.4 presents an explanation of the cap levels chosen in the PCTS and section 4.5 outlines a summary of some important descriptive statistics associated with the cap levels. The results of the BLR model for each study regions are interpreted in section 4.6. Section 4.7 will summarise the results presented in this chapter. The findings in this chapter are mainly based on research presented in McNamara and Caulfield (2011a).

4.2 STUDY REGIONS

The two study regions chosen in this thesis are the WBR and the Dublin. The Dublin region includes all council districts within Dublin County including Dublin City, South Dublin, Fingal, and Dun Laoghaire. According to the Census of Population in 2011 the population of this region was 1,187,176 persons. The WBR includes counties Galway (excluding Galway City), Mayo, Roscommon, Sligo, Leitrim, Donegal, Cavan and Monaghan. The population of this region is 698,971 persons. Galway City is excluded from this analysis as it is a major urban centre and would therefore skew the results when investigating outcomes in this mainly rural region. All travel-to-work trips as tabulated in POWCAR will be analysed in this research. Aside from the rural-urban differential, the geographical size of each region differs significantly. Dublin is a small densely populated region with covering 921 km^2, while the rural WBR is a much larger sprawling region covering 25,700 km^2. The geographical spread of these regions is illustrated in Figure 4-1. These two regions are chosen to observe any urban-rural divide arising from the introduction of a PCTS.

Figure 4-1: Dublin and WBR Regions



4.3 EMISSIONS ESTIMATION

The emission factors discussed in Chapter 3 are used to determine an estimate of average daily and total annual CO_2 emissions from travel-to-work trips. These Irish emission factors are inclusive of an occupancy rate for the relevant modes of public transport and are measured in kg of CO_2 per passenger km.

Table 4-1 presents a modal split of commuter travel for the National, Dublin and WBR datasets. The main mode of transport in Ireland is driving alone. These trips accounts for 58.1% of all commute trips nationally, 49% of trips in Dublin and 62% of trips in the WBR. 9% of commuters use public transport nationally, with a much lower share of 1.6% in the WBR. In Dublin 21.8% of trips are by public transport, much higher than the national average due to the availability of numerous public transport options in the city.

Another interesting result is that nationally more people work from home (3.1%) than in Dublin (1.5%). 4.2% of individuals work from home in the WBR which may be due by the number of farmers and agricultural workers in the region. The largest divergence between the regions is in bus travel. Only 1.5% of commuters travel to work by bus in the WBR compared to 14.4% in Dublin. This finding is due to the extensive Dublin Bus network in the city being the main transport provider in the city (see Chapter 2, section 2.3 for more details).

Table 4-1: Modal split of commuters

	National		**Dublin**		**WBR**	
Mode	**N**	**%**	**N**	**%**	**N**	**%**
Walk	197,517	10.9	70,044	13.2	23,415	8.3
Cycle	35,291	1.9	20,588	3.9	1,901	0.7
Bus	110,932	6.1	76,785	14.4	4,279	1.5
Rail	53,063	2.9	39,510	7.4	319	0.1
Motorcycle	12,673	0.7	6,607	1.2	707	0.3
Drive - Alone	1,052,324	58.1	260,630	49	174,570	61.9
Drive - Passenger	102,438	5.7	19,969	3.8	18,632	6.6
Lorry or van	138,164	7.6	19,232	3.6	34,112	12.1
Other means	6,222	0.3	1,027	0.2	1,455	0.5
Work from home	56,862	3.1	8,213	1.5	11,857	4.2
NA	45,620	2.5	9,362	1.8	10,675	3.8
Total	1,811,106	100	531,967	100	281,922	100.0

Tables 4-2 to 4-4 detail the emissions calculations for the National, Dublin and WBR datasets. In the research presented in this thesis, walking and cycling are assumed to be carbon neutral. As expected the most unsustainable mode of transport is travelling by lorry or van to work with average daily CO_2 emissions of 27kg nationally, 17kg in Dublin and 28kg in the WBR. Nationally car trips account for 3.9kg of CO_2 on average while in Dublin car trips emit 2.7kg on average. This rises to 4.2kg in the WBR. This disparity is due to the longer distances covered by commuters nationally and in the WBR. Average car return journeys are 32km nationally and 35km in WBR compared to 22km in Dublin. The most sustainable mode of transport in all datasets is travelling by bus, which accounts for 0.4kg nationally and 0.3kg in Dublin. Annually, car trips account for 780 million kg/CO_2 compared to 10 million kg/CO_2 from public transport trips. These intuitive results stem from the findings of heavy reliance on driving a car as the primary mode of travel.

Table 4-2: Emission calculations for National dataset

Means of Travel	Number of cases (N)	Mean trip time (mins)	Mean daily return trip (km)	Mean daily emissions (Kg CO_2)	Annual emissions (Kg CO_2)
Walk	197,517	14.90	3.6	-	-
Cycle	35,291	19.42	9.7	-	-
Bus	110,932	41.92	24.4	0.4	7,455,526
Rail	53,063	51.73	39.6	2.5	3,669,264
Motorcycle	12,673	24.38	26.6	3.2	7,742,116
Drive - Alone	1,052,324	27.13	32.7	3.9	780,252,631
Drive - Passenger	102,438	23.13	26.8	2.3	41,755,414
Lorry/Van	138,164	33.01	42.7	27.3	607,615,181

Table 4-3: Emissions calculations for Dublin

Means of Travel	Number of cases (N)	Mean trip time (mins)	Mean daily return trip (km)	Mean daily emissions (Kg CO_2)	Annual emissions (Kg CO_2)
Walk	70,044	19.25	4.30	-	-
Cycle	20,588	22.07	10.9	-	-
Bus	76,785	42.80	19.0	0.3	3,938,731
Rail	39,510	44.69	26.9	1.7	12,521,132
Motorcycle	6,607	24.76	21.7	2.6	3,277,941
Drive - Alone	260,630	30.63	22.5	2.7	128,691,536
Drive - Passenger	19,969	27.49	19.5	1.7	5,664,665
Lorry/Van	19,232	35.44	27.9	17.8	50,781,830

Table 4-4: Emissions calculation for the WBR

Means of Travel	Number of cases (N)	Mean trip time (mins)	Mean daily return trip (km)	Mean daily emissions (Kg CO_2)	Annual emissions (Kg CO_2)
Walk	23,415	10.55	2.96	-	-
Cycle	1,901	15.17	7.92	-	-
Bus	4,279	36.99	40.2	0.6	483,127
Rail	319	81.32	60.7	3.9	232,021
Motorcycle	707	20.79	29.3	3.5	465,638
Drive - Alone	174,570	23.58	35.0	4.2	139,258,234
Drive - Passenger	18,632	20.41	28.3	2.4	8,109,714
Lorry/Van	34,112	30.98	43.9	28.0	155,555,699

4.4 SETTING THE CAP IN A PERSONAL CARBON TRADING SCHEME (PCTS)

The cap levels chosen in this thesis are based on the emissions calculations in section 4.3. The initial cap set is based on average annual emissions calculated. The average CO_2 emitted from a daily commute trip was found to be 2.5kg. This 2.5kg cap is then lowered by 20% (2kg). The purpose of lowering the cap is to ascertain if Ireland is to meet is GHG targets, which would result in approximately a 20% cut in 2005 GHG levels, how this would impact upon travel-to-work trips. The results presented in this section will compare findings at both cap levels.

The effect of imposing a cap on individuals is presented in Table 4.5 This shows the percentage of commuters who would fall above and below a cap in each study region. A cap based on average national emissions would leave 11.2% of commuters above the cap in Dublin, much lower than the national average of 26%. Lowering the cap by 20% would leave 17.1% of commuters above the cap in Dublin compared to 32% nationally. In the WBR the initial cap would result in 33.5% of commuters falling above the cap, while the lowered cap would increase that level to 40.5%. The percentage share of individuals in the WBR above the cap at both levels is therefore significantly higher than the National and Dublin datasets. This disparity can be attributed to the findings in section 4.3 of longer trip distances and a greater reliance on driving as the primary mode of travel.

Table 4-5: Division of individuals above the cap

Cap based on average emissions						
	National (N)	**National %**	**Dublin (N)**	**Dublin %**	**WBR (N)**	**WBR %**
Below Cap	1,144,855	74	3993,77	88.8	79,483	66.5
Above Cap	399,979	26	50,435	11.2	157,806	33.5
Total	1,544,834	100	449,812	100	237,289	100
Cap set 20% below average emissions						
	National (N)	**National %**	**Dublin (N)**	**Dublin %**	**WBR (N)**	**WBR %**
Below Cap	1,044,725	68	370,866	82.9	95,962	59.5
Above Cap	500,109	32	76,536	17.1	140,966	40.5
Total	1,544,834	100	447,402	100	236,928	100

4.5 DESCRIPTIVE STATISTICS

Tables 4-6 to 4-8 present the descriptive statistics associated with a number of variables of interest in each study region and the national dataset. The number of individuals above and below the cap in each socio-economic group is also tabulated.

The majority of commuters who travel less than 10km regardless of the mode of transport used would be under a cap based on average emissions and a cap lowered by 20%. These individuals account for over 50% of trips in the dataset representing a sizable proportion of individuals who would not be affected by the introduction of a cap. 90% of individuals under the cap in Dublin travel less than 10km with 78% and 77% nationally and in the WBR respectively. Individuals who travel over 20km account for 70% of those above the cap nationally and in the WBR. In Dublin, trips over 10km account for the majority of individuals over the cap due to the shorter distances covered in the city.

The largest age group above the cap is 25-34 year old group. However, the majority of this age group in isolation are also under the cap at both levels nationally and in Dublin. In the lowered cap scenario, the majority of individuals in the 25-44 age groups are above the cap in the WBR. These groups account for 54% of all individuals above the cap. This is attributable to the fact that these age groups represent the majority of the population in work in the dataset (62%).

The gender results show more males are above the cap than females across all datasets. This is highest in the WBR where 66% of commuters above the average cap are found to be male. This level falls slightly to 63% in the lowered cap scenario. The household composition variable tabulates the number of children both dependent and independent within a household. The largest group above the cap in all datasets are couples with dependent children ranging from 40% in the Dublin to 50% in the WBR of individual above the cap at both levels. This group also accounts for 30% of those under the cap in Dublin and 44% in the WBR at both levels.

The number of cars/vans variable shows that the largest group above the cap are commuters who own two vehicles. In Dublin, this group accounts for 51% of commuters above the cap. The largest groups below the cap in Dublin are commuters owning one vehicle (37%). Nationally, those owning two vehicles are the largest group below the cap at both levels (40%). In the WBR individuals owning two or more cars account for the majority (90%) of commuters above the cap at each level. The largest group under the cap are those owning 3 cars or less. The means of travel variable shows the vast majority of commuters who drive to work falling above the cap. 72% of those above the cap nationally drive to work. This level rises to 75% with the lowered cap. In Dublin, 80% of those above the cap drive to work.

The majority of individuals who choose public transport fall below the cap across the three regions indicating a switch to public transport from driving a car or van would negate the welfare effects created by a cap. In Dublin, the majority of individuals who drive to work are in fact below the cap, indicating that a significant number of journeys are over shorter distances. This is also the case in the WBR where 69% of those under the cap drive to work. Another large group below the cap are those who walk to work. This groups accounts for 17%, 23% and 16% of those below the cap in the national, Dublin and WBR dataset respectively.

Socio-economic grouping displays even spread of professions falling above the cap. Employers & managers are consistently the largest group above the cap, particularly in Dublin where they account for 24% of commuters above the cap at both levels. In the WBR, manual-skilled and semi-skilled workers account for the largest groups above the cap at each level (38% -40%). Non-manual workers are by some distance the largest group falling below the cap accounting for 20% of commuters across the three datasets.

Table 4-6a: Descriptive statistics associated with variables of interest (National Dataset)

Variable	**National Cap - Average emissions**				**National Cap lowered by 20%**			
	Above cap		**Below cap**		**Above cap**		**Below cap**	
Distance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
0-5 km	8,693	2	517,330	50	12,413	2	513,610	55
6-10 km	22,059	6	289,106	28	22,059	4	289,106	31
11-15 km	12,241	3	146,430	14	59,154	12	99,517	11
16-20 km	75,063	19	65,086	6	117,890	24	22,259	2
21-30 km	112,503	28	14,603	1	118,490	24	8,616	1
31 -40 km	69,418	17	3,199	0	70,101	14	2,516	0
41 + km	100,002	25	3,257	0	100,002	20	3,257	0
Total	399,979	100	1,039,011	100	500,109	100	938,881	100
Age								
15-24	38,598	10	153,499	13	48,641	10	143,456	14
25-34	133,387	33	337,260	29	164,818	33	305,829	29
35-44	115,735	29	276,654	24	143,541	29	248,848	24
45-54	76,514	19	231,668	20	97,093	19	211,089	20
55-64	32,996	8	127,119	11	42,447	8	117,668	11
65+	2,749	1	18,655	2	3,856	1	17,835	2
Total	399,979	100	1,144,855	100	500,396	100	1,044,725	100
Gender								
Male	271,016	68	598,798	52	326,553	65	543,261	52
Female	128,963	32	546,057	48	173,556	35	501,464	48
Total	399,979	100	1,144,855	100	500,109	100	1,044,725	100
Household Composition								
Single	28,965	7	94,558	8	36,159	7	87,364	8
Lone Parent with Children	11,216	3	54,668	5	14,847	3	51,037	5
Lone Parent no Children under 19	13,660	3	47,117	4	17,206	3	43,571	4
Couples with Children	187,925	47	432,926	38	233,282	47	387,569	37
Couple no Children under 19	46,484	12	141,166	12	58,615	12	129,035	12
Couple no Children	78,710	20	185,652	16	97,503	19	166,859	16
Other Households	33,019	8	188,768	16	42,497	8	179,290	17
Total	399,979	100	1,144,855	100	500,109	100	1,044,725	100

Table 4-6b: Descriptive statistics associated with variables of interest continued (National Dataset)

Variable	**National Cap - Average emissions**				**National Cap lowered by 20%**			
	Above cap		**Below cap**		**Above cap**		**Below cap**	
Number of cars/vans	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
One	86,956	22	371,492	32	111,679	22	346,769	33
Two	222,579	56	460,594	40	276,182	55	406,991	39
Three	52,774	13	117,641	10	65,698	13	104,717	10
Four or more	28,475	7	51,732	5	34,966	7	45,241	4
None	4,665	1	125,678	11	5,905	1	124,438	12
Not stated	4,530	1	17,718	2	5,679	1	16,569	2
Total	399,979	100	1,144,855	100	500,109	100	1,044,725	100
Means of Travel								
Walk	0	0	197,622	17	0	0	197,622	19
Cycle	0	0	30,708	3	0	0	30,708	3
Public transport	7227	2	127,782	11	10,301	2	124,708	12
Motorcycle	2511	1	8,757	1	3,621	1	7,647	1
Drive - Alone	287,912	72	636,747	56	376,542	75	548,117	52
Drive - Passenger	11,351	3	73,928	6	14,947	3	70,332	7
Lorry or van	90,978	23	12,414	1	94,698	19	8,694	1
Work from home	0	0	56,897	5	0	0	56,897	5
Total	399,979	100	1,144,855	100	500,109	100	1,044,725	100
Socio-economic group								
Employers & managers	73,998	19	171,537	15	91,472	18	154,063	15
Higher professional	29,341	7	86,271	8	37,474	7	78,138	7
Lower professional	58,700	15	156,664	14	75,521	15	139,843	13
Non-manual worker	70,956	18	313,996	28	95,019	19	295,933	28
Manual skilled	73,637	18	111,820	10	86,994	17	98,463	9
Semi skilled	35,870	9	125,248	11	46,136	9	114,982	11
Unskilled workers	14,041	4	45,096	4	16,898	3	42,239	4
Self employed	26,361	7	37,686	3	29,409	6	34,638	3
Farmers	4,336	1	41,742	4	5,282	1	40,796	4
Agricultural workers	1,958	0	8,065	1	2,440	0	7,583	1
Other	10,781	3	40,730	4	13,464	3	39,047	4
Total	399,979	100	1,138,855	100	500,109	100	1,045,725	100

Table 4-7a: Descriptive statistics associated with variables of interest (Dublin Dataset)

Variable	**Dublin Cap - Average emissions**				**Dublin Cap - Lowered by 20%**			
	Above cap		**Below cap**		**Above cap**		**Below cap**	
Distance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
0-5 km	2,925	2	167,971	59	2,925	2	167,971	64
6-10 km	38,454	28	87,808	31	55,183	34	71,079	27
11-15 km	37,281	27	18,461	7	41,720	26	14,022	5
16-20 km	28,846	21	5,963	2	29,954	19	4,855	2
21-30 km	18,707	13	2,122	1	18,707	12	2,122	1
31 -40 km	7,333	5	583	0	7,333	5	583	0
41 + km	5,526	4	369	0	5,585	3	310	0
Total	139,072	100	283,277	100	161,407	100	260,942	100
Age								
15-24	1,654	1	47,006	15	13,142	8	45,025	16
25-34	46,820	36	106,482	35	53,936	33	99,366	35
35-44	37,457	29	66,220	21	43,122	27	60,555	21
45-54	27,714	21	54,746	18	32,384	20	50,076	17
55-64	14,266	11	30,032	10	16,865	10	27,433	10
65+	1,482	1	4,058	1	1,958	1	3,754	1
Total	129,393	100	308,544	100	161,407	100	286,209	100
Gender								
Male	90,484	65	151,667	49	102,587	64	139,564	49
Female	48,588	35	156,877	51	58,820	36	146,645	51
Total	139,072	100	308,544	100	161,407	100	286,209	100
Household Composition								
Single	12,269	9	29,057	9	14,351	9	26,975	9
Lone Parent with Children	4,168	3	15,760	5	4,913	3	15,015	5
Lone Parent no Children under 19	4,335	3	13,011	4	5,077	3	12,269	4
Couples with Children	55,598	40	91,137	30	63,965	40	82,770	29
Couple no Children under 19	16,693	12	36,716	12	19,746	12	33,663	12
Couple no Children	27,484	20	50,246	16	31,805	20	45,925	16
Other Households	18,525	13	72,617	24	21,550	13	69,592	24
Total	139,072	100	308,544	100	161,407	100	286,209	100

Table 4-7b: Descriptive statistics associated with variables of interest continued (Dublin Dataset)

Variable	**Dublin Cap - Average emissions**				**Dublin Cap - Lowered by 20%**			
	Above cap		**Below cap**		**Above cap**		**Below cap**	
Number of cars/vans	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
One	41,746	30	114,345	37	49,205	30	106,886	37
Two	71,050	51	97,627	32	81,558	51	87,119	30
Three	16,046	12	23,760	8	18,488	11	21,318	7
Four or more	5,680	4	7,168	2	6,453	4	6,395	2
None	2,766	2	60,144	19	3,656	2	59,254	21
Not stated	1,784	1	5,500	2	2,047	1	5,237	2
Total	139,072	100	308,544	100	161,407	100	286,209	100
Means of Travel								
Walk	0	0	70,080	23	0	0	70,080	24
Cycle	0	0	18,190	6	0	0	18,190	6
Public transport	7,935	6	86,097	28	12,811	8	81,221	28
Motorcycle	3,129	2	2,732	1	3,674	2	2,187	1
Drive - Alone	111,508	80	110,539	36	127,692	79	94,355	33
Drive - Passenger	3,629	3	12,275	4	4,359	3	11,545	4
Lorry or van	12,871	9	413	0	12,871	8	413	0
Work from home	0	0	8,218	3	0	0	8,218	3
Total	139072	100	308544	100	161407	100	286209	100
Socio-economic group								
Employers & managers	33,524	24	50,682	16	38,878	24	45,328	16
Higher professional	15,291	11	33,118	11	18,236	11	30,173	11
Lower professional	20,719	15	48,471	16	24,698	15	44,492	16
Non-manual worker	27,945	20	96,538	31	33,603	21	90,880	32
Manual skilled	18,617	13	20,720	7	20,396	13	18,941	7
Semi skilled	8,811	6	25,903	8	9,991	6	24,723	9
Unskilled workers	2,902	2	11,960	4	3,250	2	11,612	4
Self employed	6,475	5	7,737	3	6,918	4	7,294	3
Farmers	211	0	578	0	229	0	560	0
Agricultural workers	127	0	411	0	137	0	401	0
Other	4,450	3	12,426	4	5,071	3	11,805	4
Total	139,072	100	308,544	100	161,407	100	286,209	100

Table 4-8a: Descriptive statistics associated with variables of interest (WBR Dataset)

Variable	**WBR Cap - Average emissions**				**WBR Cap - Lowered by 20%**			
	Above cap		**Below cap**		**Above cap**		**Below cap**	
Distance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
0-5 km	1,915	2	70,629	50.7	2,778	3	69,766	57
6-10 km	5,356	7	36,051	25.9	5,356	6	36,051	29
11-15 km	3,089	4	21,065	15.1	10,325	11	13,829	11
16-20 km	13,992	18	9,663	6.9	21,599	23	2,056	2
21-30 km	23,195	29	1,316	0.9	23,962	25	549	0
31 -40 km	13,139	17	319	0.2	13,145	14	313	0
41 + km	18,797	24	386	0.3	18,797	20	386	0
Total	79,483	100	139,429	100	95,962	100	122,950	100
Age								
15-24	8,356	10	19,587	11	60,518	17	17,731	11
25-34	24,510	28	38,513	22	35,444	10	33,918	21
35-44	22,937	26	40,307	23	60,518	17	35,417	22
45-54	16,323	19	35,818	20	35,444	10	32,106	20
55-64	6,876	8	20,184	11	60,518	17	18,549	12
65+	8837	10	22,984	13	95,962	28	20,976	13
Total	87,839	100	177,393	100	348,404	100	158,697	100
Gender								
Male	52,204	66	82,755	52	60,518	63	74,167	53
Female	27,279	34	75,051	48	35,444	37	66,799	47
Total	79,483	100	157,806	100	95,962	100	140,966	100
Household Composition								
Single	5,339	6.7	12,776	8	6,371	6.6	11,643	8.3
Lone Parent with Children	2,291	2.9	7,177	5	2,975	3.1	6,485	4.6
Lone Parent no Children under 19	3,187	4	6,807	4	3,847	4	6,130	4.3
Couples with Children	39,957	50.3	69,118	44	48,250	50.3	60,751	43.1
Couple no Children under 19	9,783	12.3	19,637	12	11,792	12.3	17,595	12.5
Couple no Children	14,023	17.6	24,428	15	16,746	17.5	21,665	15.4
Other Households	4,903	6.2	17,863	11	5,981	6.2	16,697	11.8
Total	79,483	100	157,806	100	95,962	100	140,966	100

Table 4-8b: Descriptive statistics associated with variables of interest continued (WBR Dataset)

	WBR Cap - Average emissions				**WBR Cap - Lowered by 20%**			
	Above cap		**Below cap**		**Above cap**		**Below cap**	
Number of cars/vans	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
One	831	1	2,140	1	996	1	1,959	1
Two	16,139	20	48,393	31	19,880	21	44,527	32
Three	44,762	56	69,107	44	53,737	56	60,094	43
Four or more	10,815	14	17,724	11	13,016	14	15,508	11
None	6144	8	9,120	6	7,383	8	7,876	6
Not stated	792	1	11,322	7	950	1	11,002	8
Total	79483	100	157806	100	95962	100	140966	100
Means of Travel								
Walk	0	0	23,415	16	0	0	23,415	18
Cycle	0	0	1,901	1	0	0	1,540	1
Public transport	77	0	3,493	2	95	0	3,493	3
Motorcycle	179	0	201	0	226	0	183	0
Drive - Alone	54,182	68	437	0	68,978	72	390	0
Drive - Passenger	2,319	3	100,014	69	3,074	3	85,218	66
Lorry or van	22,726	29	13,357	9	23,589	25	12,602	10
Work from home	77	0	3,131	2	95	0	2,268	2
Total	79560	100	145949	100	96057	100	129109	100
Socio-economic group								
Employers & managers	12,162	15	19,931	13	14,174	15	17,904	13
Higher professional	4,508	6	7,680	5	5,519	6	6,666	5
Lower professional	12,396	16	19,835	13	15,219	16	16,997	12
Non-manual worker	14,006	18	41,814	26	18,330	19	37,444	27
Manual skilled	15,176	19	17,611	11	17,437	18	15,316	11
Semi skilled	8,216	10	20,418	13	10,343	11	18,230	13
Unskilled workers	3,325	4	6,887	4	3,928	4	6,227	4
Self employed	5,716	7	6,424	4	6,217	6	5,912	4
Farmers	1,686	2	10,765	7	2,014	2	10,360	7
Agricultural workers	513	1	1,719	1	604	1	1,622	1
Other	1,779	2	4,722	3	2,177	2	4,288	3
Total	79,483	100	157,806	100	95,962	100	140,966	100

4.6 SOCIO-ECONOMIC ANALYSIS OF COMMUTERS IN A PCTS

This section presents the results of the BLR model used to examine the socio-economic characteristics of individuals falling above the cap in a PCTS. Two models are applied to each study region for both cap levels as a means of comparing findings in both cap scenarios.

4.6.1 Logistic Model Formulation

This model is based on the BLR outlined in Chapter 3, section 3.4. Within each model, the independent variable coefficients are estimated vis-à-vis the reference category in predicting the outcome of the dependent variable. The BLR model takes the form of the probability of a person being above a CO_2 cap in a PCTS. If the outcome is true then the resulting case is equal to one. If not, it is equal to zero. Equation 3.2 outlines the relationship between the dependent binary variable and independent variables.

The socio-economic variables studied in this analysis are: distance travelled to work, age, gender, socio-economic group, number of cars/vans owned and household composition (marital and family status). These independent variables are detailed in Table 4-9. A number of variables from the POWCAR dataset were tested at this stage to ascertain what if any impact they would have on the model. Variables such as travel time, mode of transport, departure time etc were examined. When including these variables the model outputs were not as significant as those presented in Table 4-10. This was mainly due to the correlation between variables in the model which compromised its performance. This result was also found with the MNL models presented in Chapter 5, section 5.3.

Table 4-9: Details of variables examined

Variable	**Definition**
Distance	
0-5 km	= 1 if Distance: 0-5 km
6-10 km	= 1 if Distance: 6-10 km
11-15 km	= 1 if Distance: 11-15 km
16-20 km	= 1 if Distance: 16-20 km
21-30 km	= 1 if Distance: 21-30 km
31 -40 km	= 1 if Distance: 31 -40 km
41 + km	(Reference category = Distance: 41 + km)
Age	
15-24	= 1 if Age: 15-24
25-34	= 1 if Age: 25-34
35-44	= 1 if Age: 35-44
45-54	= 1 if Age: 45-54
55-64	= 1 if Age: 55-64
65+	(Reference category = Age: 65+)
Gender	
Gender: Male	= 1 if Gender: male
Gender: Female	(Reference category = Gender: Female)
Socio-economic group	
Employers and managers	= 1 if Employers and managers
Higher professional	= 1 if Higher professional
Lower professional	= 1 if Lower professional
Non-manual	= 1 if Non-manual
Manual skilled	= 1 if Manual skilled
Semi skilled	= 1 if Semi skilled
Unskilled	= 1 if Unskilled
Self employed	= 1 if Self employed
Farmers	= 1 if Farmers
Agricultural workers	= 1 if Agricultural workers
Other	(Reference category = Other)
Number of cars/vans	
1	=1 if 1
2	=1 if 2
3	=1 if 3
4 or more	=1 if 4 or more
None	(Reference category = None)
Household Composition	
Single	=1 if Single
Lone Parent with Children	=1 if Lone Parent with Children
Lone Parent no Children under 19	=1 if Lone Parent no Children under 19
Couple with Children	=1 if Couple with Children
Couple no Children under 19	=1 if Couple no Children under 19
Couple no Children	=1 if Couple no Children
Other Households	(Reference category = Other Households)

4.6.2 Examining the characteristics of individuals above the cap in a PCTS

This section of the chapter examines the characteristics of people who fall above the cap in a PCTS. Presented in Table 4-10 are the results of the six models estimated. Three models are estimated for each study region in the average emissions cap scenario and three in the lowered cap scenario. The diagnostic tests are found to be adequate for each model. R-squared values for each model range between 0.6 and 0.8, an excellent goodness-of-fit for the independent variables. Log-likelihood scores are lowest in the WBR models suggesting this is the model of best fit.

The age variable demonstrates a clear generational difference. As would be expected due to lower access to motor vehicles, the 15-24 age group has a negative coefficient across the six models suggesting this group would not be above both cap. All other age groups are likely to be above a cap at both levels. In the WBR, beta coefficients are significantly higher for the 25-34 and 35-44 age groups indicating a greater likelihood of these groups being above both cap level than commuters nationally or in Dublin.

The gender variable finds that males are more likely to be above the cap across all six models. However, the coefficients are lower for Dublin compared to the national average indicating less likelihood in Dublin. In the WBR the coefficients are significantly higher than both the national and Dublin models indicating a stronger likelihood of males in this region being above then cap than other regions. As was discussed in section 4.5, this can be partly attributed to the higher proportion of males in the workforce.

The results exhibit a clear pattern across each model for socio-economic group. A national cap based on average emissions finds that only higher and lower professionals and non-manual workers are unlikely to be above the cap at both levels. This finding is replicated in each region particularly in Dublin which has the largest negative coefficients. The groups with the largest positive coefficients in each model are self-employed and manual-skilled workers, indicating that these groups are more likely to be above the cap compared to other socio-economic groups.

The household composition variables are all highly significant across the six models with positive coefficients suggesting families with dependent children are likely to be above a cap. The only exception to this finding is in Dublin, where couples with no dependent children are not likely to be above a cap. Lone parents with dependent families in the WBR also have larger coefficients than individuals in Dublin indicating more of a likelihood of these groups being above the cap in the rural region. Single people are also highly likely to be above the cap at each level. The coefficients found for this category are the larger than other categories across all six model.

The distance travelled variable is highly significant across all groups. Commuters who travel less than 3km per trip are highly unlikely to be above any potential cap. These negative coefficients decrease as distance travelled increases suggesting the chance of being above the cap increases as distance travelled increases. Individuals travelling over 30km to work in each model are found to have positive coefficients indicating a likelihood of being above the cap. However, a caveat to these results is that the findings are marginally statistically insignificant in a number of cases above 30km.

As expected, people owning cars or vans are likely to be above any potential cap across all six models. The positive coefficients associated with each variable increase as the number of cars per household increases, increasing the likelihood of being above a cap compared to those who do not own a car or van.

The results presented in Table 4-10 demonstrate the importance of owning a car and driving long distances to work as the main socio-economic characteristics associated with commuters who fall above the cap across all six models. Having dependent families is also an important factor in constraining an individual's travel choices to using a car travel to work particularly for lone parents in the WBR. This inevitably leads to higher CO_2 emissions reflected in the likelihood of these individuals being above the cap.

Table 4-10: BLR model results

Variable	National		Dublin		WBR	
	Average Cap	**Lowered Cap**	**Average Cap**	**Lowered Cap**	**Average Cap**	**Lowered Cap**
Intercept	-.242**	-.448**	-.445**	-.538*	-0.165*	-.551**
Age						
15-24	-.621**	-.715**	-.700**	-.791**	-0.386**	-.486**
25-34	.114**	.081*	.087	.037	0.355**	.332**
35-44	.221**	.226**	.199**	.199**	0.327**	.372**
45-54	.149*	.134**	.172*	.146*	0.281**	.268**
55-64	.094	.089*	.102	.111	0.193*	.167
65+	Ref	Ref	Ref	Ref	Ref	Ref
Gender						
Male	.821**	.676*	.787**	.635*	1.126**	1.005**
Female	Ref	Ref	Ref	Ref	Ref	Ref
Socio-economic group						
Employers & managers	.149**	.212**	-.143**	-.012	0.55**	.619**
Higher professional	-.606**	-.405**	-.707**	-.454**	-0.559**	-.202**
Lower professional	-.269**	-.088**	-.497**	-.274**	-0.115*	.085
Non-manual	-.402**	-.250**	-.610**	-.430**	-0.305**	-.041
Manual skilled	.888**	.916**	.897**	.852**	0.818**	.896**
Semi skilled	.024	.144**	-.005	.056	-0.028	.111
Unskilled	.453**	.427**	-.051	-.048	0.49**	.542**
Self employed	1.756**	1.662**	1.774**	1.602**	1.695**	1.647**
Farmers	.526**	.488**	1.160**	1.069**	0.528**	.584**
Agricultural workers	.342**	.409**	.589*	.287	0.226*	.240*
Other	Ref	Ref	Ref	Ref	Ref	Ref
Household Composition						
Single	1.032**	1.099**	.936**	1.034**	0.84**	.890**
Lone Parent with Children	.744**	.789**	.646**	.718**	0.542**	.648**
Lone Parent no Child < 19	.372**	.359**	.276**	.230**	0.309**	.265**
Couple with Children	.493**	.496**	.263**	.270**	0.497**	.504**
Couple no Children < 19	.136**	.086**	-.083**	-.155**	0.228**	.181**
Couple no Children	.496**	.513**	.320**	.344**	0.477**	.470**
Other Households	Ref	Ref	Ref	Ref	Ref	Ref
Distance (KM)						
0-3	-7.948**	-7.514**	-7.800**	-7.430**	-8.085**	-7.598**
6-10	-6.587**	-6.545**	-6.803**	-6.761**	-6.462**	-6.394**
11-15	-6.547**	-4.276**	-6.834**	-4.148**	-6.466**	-4.515**
16-20	-3.563**	-1.753**	-3.466**	-2.048**	-3.771**	-1.482**
21-30	-1.329**	-.680**	-1.786**	-1.218**	-0.865**	.090
31-40	-.245**	.014	-.645**	-.028	0.015	.016
41+	Ref	Ref	Ref	Ref	Ref	Ref
Number of Cars						
1	2.280**	2.431**	2.420**	2.501**	2.76**	2.974**
2	3.159**	3.405**	3.290**	3.445**	2.384**	2.624**
3	3.422**	3.666**	3.658**	3.765**	3.043**	3.370**
4 or more	3.665**	3.937**	3.886**	4.000**	3.202**	3.544**
None	Ref	Ref	Ref	Ref	Ref	Ref
Number of Cases	1,438,333		422,153		218,912	
Nagelkerke R-squared	.780	.794	.668	.690	.783	.803
Log Likelihood	580789.2	625347.85	129171.7	168032.5	101123.9	100196.64

** Significant at 1%, *Significant at 5%

4.7 CONCLUSIONS

The results of the research presented in this chapter found that the potential percentage of commuters above the cap at a national level and in the WBR is much higher than the level in Dublin. This is due to a number of factors such as the level of public transport usage, the lower travel distances and the higher percentage of walking and cycling to work in Dublin.

The results of BLR model identified the important socio-economic factors relating to individuals above a prospective cap. A national cap based on average emissions found that only higher and lower professionals in addition to non-manual workers are unlikely to be above a cap. The models also found that males are more likely to be above the cap across all six models. The household composition variable was found to be highly significant; households with dependent children were likely to be above a cap across all six models. The distance travelled variable is also highly significant. Commuters who travel longer distances are more likely to be above the cap then those who travel less than 10km.

These results demonstrate the importance of car ownership, household composition and trip length in determining whether a commuter is above or below a cap. Research in Chapters 5 and 6 will build on this socio-economic analysis in determining the welfare effects and viability of a PCTS.

5. DETERMINING THE WELFARE EFFECTS OF A PERSONAL CARBON TRADING SCHEME

5.1 INTRODUCTION

The research presented in this chapter investigates the welfare effects of a PCTS. A consumer surplus analysis is used to determine the welfare loss to individuals who undertake travel-to-work trips in the Dublin and WBR regions. Three CO_2 price scenarios are analysed: a low, medium and high carbon price. These results are compared at an aggregate level for each DED to existing measures of deprivation derived from the Census 2006 (Haase and Pratschke, 2008) to determine if DED's designated as relatively deprived also incur the largest welfare losses. The results are also compared to density of population in each DED to investigate any link between density levels and welfare changes, particularly in rural regions. Aggregated welfare changes in each DED are transposed geographically using GIS to illustrate any regional differences in welfare across Ireland. Finally, a MNL model is estimated to identify any socio-economic factors, which may influence welfare changes in a PCTS. This results presented in this chapter are mainly based on results published in McNamara and Caulfield (2011b).

This chapter is composed of four sections including the introduction. Section 5.2 outlines the welfare model and the results arising from the analysis. Section 5.4 details the results of the MNL model and Section 5.5 summarises the results presented in this chapter.

5.2 WELFARE ANALYSIS

This section outlines the methods used to estimate welfare changes and present the results arising from the consumer surplus analysis. Cross-tabulations with density and deprivation variables are also presented in this section. The welfare estimation will also be subject to a scenario sensitivity analysis based on a low, medium and high CO_2 price. The prices chosen are listed in Table 5-1 and are determined based on historical European Union Allowances (EUA) market prices. The historical low, high and current prices of allowances in September 2011 are used in this analysis[4]. The cap level chosen for the allocation of permits in the welfare model is based on the average emission cap utilised in Chapter 4.

Table 5-1: CO_2 price in each market scenario

Scenario	**CO_2 Price**
Low	€8.24
Medium (Current)	€16.70
High	€28.73

5.2.1 Travel Cost Calculations

To determine the pre-PCTS and post-PCTS cost of travel for commuters, travel cost equations are used. The equations estimate the cost of travelling by slow modes (walking and cycling), private vehicle (car, motorcycle, van) and by public transport (bus and rail) in Ireland. The cost parameters and equations used to conduct the welfare analysis are detailed in full in Chapter 3, section 3.6.2.

The results for the travel cost calculations are presented in Table 5-2. As each individual is given an equal quota of CO_2 permits in a PCTS, individuals under the quota can theoretically reduce their travel costs by selling their surplus permits. This opportunity cost is encapsulated in the calculation of post-PCTS travel costs and subsequent welfare changes. This free allocation of permits acts as a compensation mechanism to individuals who use more sustainable forms of transport. The higher the price of CO_2 the greater the potential monetary benefits to individuals holding surplus permits.

In Table 5-2 the travel costs for private vehicles are found to be higher in the WBR at €8.33 per trip compared to €7.44 in Dublin. Public transport trips on average cost more in Dublin (€6.92) than in the WBR (€6.38). Once the cap is applied average trip costs decrease for public transport trips across each CO_2 price scenario with the largest saving in the high CO_2 price scenario. This is due to the inbuilt compensation mechanism discussed above in the calculation for pre-PCTS and post-PCTS costs.

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[4] Historical Prices garnered from EUA 'Dec 2011' Market data. Obtained from www.pointcarbon.com

Individuals travelling by slow modes and public transport are likely to retain a surplus allocation of permits and thus benefit from selling this surplus in the market. This is reflected in the reduced costs observed in the medium and high price scenarios in Table 5-2. Private vehicle trip costs remain constant in each scenario in the WBR except for the high CO_2 price scenario where a marginal increase of €0.01 occurs. In Dublin, private vehicle costs fall in the medium and high carbon price scenarios. Overall, prices in each scenario are higher in the WBR than the national average. This is also the case in the majority of scenarios in Dublin with public transport trips being the exception. These trips are found to be more expensive nationally than in either study region.

Table 5-2: Average travel costs

National	**Pre-PCTS**	**Post-PCTS (Low Price)**	**Post-PCTS (Med Price)**	**Post-PCTS (High Price)**
Slow Modes	€3.38	€3.36	€3.34	€3.31
Private Vehicle	€8.30	€8.30	€8.30	€8.29
Public Transport	€7.26	€7.24	€7.22	€7.20
Dublin				
Slow Modes	€3.94	€3.92	€3.90	€3.88
Private Vehicle	€7.44	€7.44	€7.43	€7.42
Public Transport	€6.92	€6.91	€6.89	€6.87
WBR				
Slow Modes	€2.77	€2.73	€2.73	€2.71
Private Vehicle	€8.33	€8.33	€8.33	€8.34
Public Transport	€6.38	€6.36	€6.35	€6.33

5.2.2 Measuring Consumer Surplus Change

Consumer surplus measures the difference between what a consumer is willing to pay and what is actually paid for a good. A full explanation of the methodology used is outlined in Chapter 3, section 6.2. In this case the consumer good is CO_2. Specifically the change in consumer surplus is measured based on pre-PCTS and post-PCTS scenarios of varying CO_2 prices. If consumer surplus is found to be negative, a welfare loss has occurred and vice versa. Zero represents no change in welfare. The figure can be interpreted as the magnitude of the change in an individual's purchasing power for travel and consequently consumer surplus. Travel elasticity parameters are based on the travel equations presented in section 5.3.1 and supplied by the NTA (Steer Davies Gleave, 2009). These travel elasticises are used as the price elasticity of demand in Equation 3.16 to determine consumer surplus change. The elasticity values vary across each mode of transport and travel time and are listed in Table 5-3.

Table 5-3: Travel elasticity values

Mode	**Elasticity Value**
Slow Modes	-0.093
Private Vehicle (7-8AM)	-0.083
Private Vehicle (8-9AM)	-0.070
Private Vehicle (9-10AM)	-0.101
Public Transport (7-8AM)	-0.089
Public Transport (8-9AM)	-0.068
Public Transport (9-10AM)	-0.101

5.2.3 Density of Population

The welfare results are compared across different population density levels to determine whether individuals living in rural regions with limited access to public transport would be adversely affected by the introduction of a PCTS. The population density levels are split into deciles as a means of comparison. These deciles range from the most sparsely populated areas of less than 25 people per square kilometre (Decile 1) to the most densely populated areas of more than 10,000 people per square kilometre (Decile 10). These density deciles are tabulated in Table 5-4. Density deciles are allocated to each individual in the POWCAR dataset based on a unique area code corresponding to over 3,400 DED's in Ireland.

Table 5-4: Density levels

Name	**Population (People per km^2)**
Decile 1	0-25
Decile 2	25-50
Decile 3	50-100
Decile 4	100-250
Decile 5	250-500
Decile 6	500-1,000
Decile 7	1,000-2,500
Decile 8	2,500-5,000
Decile 9	5,000-10,000
Decile 10	10,000+

Table 5-5 presents descriptive statistics associated with the density variables for the national, Dublin and WBR datasets. Nationally the average number of people per square km (km^2) is over 1,700 people. In the rural WBR that figure is much lower with an average of 205 people per km^2. This level falls to as low as one person per km^2 in some rural DED's. The most densely populated DED's in the WBR have a maximum of 2,000 people per km^2. In Dublin, population density is much higher than the national average with an average 4,090 people per km^2. This level increases to nearly 20,000 in some inner city DED's. The most sparsely populated DED's in Dublin have 31 people per km^2.

Figures 5-1 to 5-3 illustrate the distribution of density levels in each study region. The difference in population density is apparent with most individuals in the WBR living in areas of population of less than 250 people per km^2. Table 5-5 also reports the distribution of population density to be more dispersed in Dublin, reflected in the variance scores for each region.

Table 5-5: Descriptive statistics for population density

	National	**Dublin**	**WBR**
Sample size (N)	1,824,744	539,850	281,163
Mean	1,751	4,090	205
Std. Error of Mean	1.835	3.888	0.759
Median	507	3890	40
Mode	4,210	4,210	1,067
Std. Deviation	2,478	2,856	402
Variance	6,142,063	8,162,417	161,811
Range	19,465	19,436	1,956
Minimum	1	31	1
Maximum	19,467	19,467	1,957

Figure 5-1: Density distribution (National)

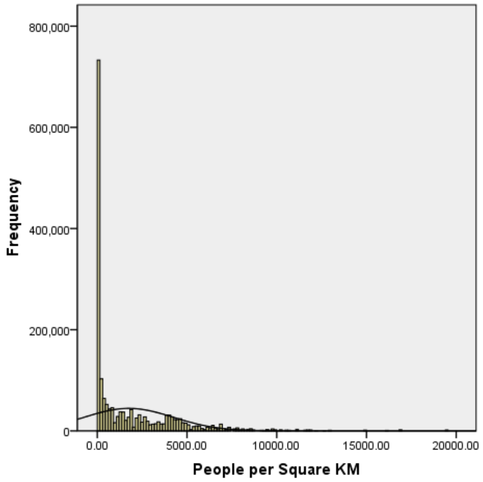


Figure 5-2: Density distribution (Dublin)

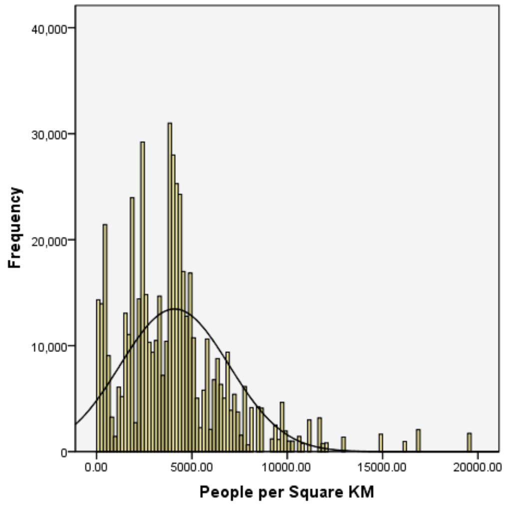
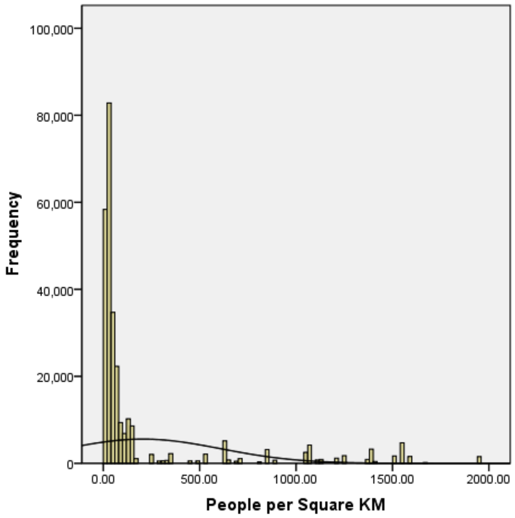


Figure 5-3: Density distribution (WBR)



5.2.4 Measures of Deprivation

In Ireland, a number of studies of deprivation and affluence in terms of spatial distribution have been published since 1998. These studies primarily utilise the census data also used in this study. The most recent results published by Haase & Pratschke (2008) outlined in Chapter 2 provide a detailed snapshot of the spatial distribution of deprivation in Ireland in 2006 and compares the changes in various economic and social indicators since 1991. One of the main indicators of deprivation used in this study is the Relative Measure of Deprivation – A measure of deprivation relative to other regions with a mean of zero and standard deviation of ten.

This indicator calculates a deprivation score for each DED within the range presented in Table 5-6. This range corresponds to a level of affluence or deprivation (This measure is described in Chapter 2, section 2.8). As with density data detailed in Section 5.3.3, the deprivation data compiled by Haase and Pratschke (2008) is combined with POWCAR using the unique area code of each commuter in the dataset. This gives a corresponding level of deprivation or affluence for the area in which the individual resides. A cross-tabulation can then be used to observe any links between consumer surplus changes and existing levels of deprivation in each DED.

Table 5-6: Range of scale used to measure deprivation

Level of Affluence or Deprivation	Range
Extremely disadvantaged	-30 and under
Very disadvantaged	-20 to -29.99
Disadvantaged	-10 to 19.99
Slightly below national average	0 to -9.99
Slightly above national average	0 to 9.99
Affluent	10 to 19.99
Very affluent	20 to 29.99
Extremely affluent	30 and over

The descriptive statistics and the distribution of the Relative Measure of Deprivation are presented in Table 5-7 and Figures 5-4 to 5-6. While the data from the two regions roughly follows a normal distribution, the dispersion in Dublin is much greater than in the WBR with a standard deviation of 17 in Dublin compared to a standard deviation of 9 in the WBR. Nationally the data follows a normal distribution. In terms of the average level of deprivation or affluence the mean score in Dublin is 5.65 compared to -0.97 in the WBR. Nationally the deprivation score is 3.85 - slightly above average. These descriptive statistics demonstrate that on average Dublin is more affluent than the national dataset while the WBR is more deprived than the national average.

Table 5-7: Descriptive statistics for deprivation variable

	National	Dublin	WBR
Sample Size (N)	1,829,643	539,851	283,216
Mean	3.85	5.65	-.97
Std. Error of Mean	0.01	0.02	.017
Median	3.70	7.9	-.20
Mode	7.90	7.9	3.30
Std. Deviation	12.41	17.0	9.3
Variance	154.06	291.5	86.5
Range	84.20	84.2	58.10
Minimum	-41.30	-41.3	-37.90
Maximum	42.90	42.9	20.20

Figure 5-4: Distribution of deprivation scores (National)

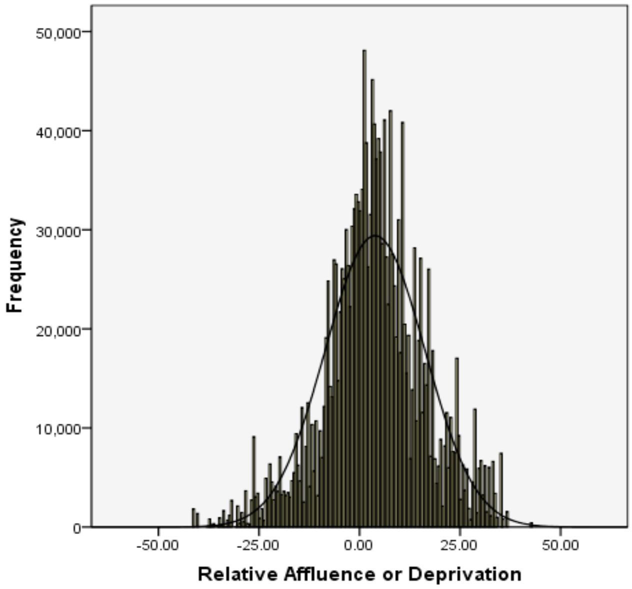


Figure 5-5: Distribution of deprivation scores (Dublin)

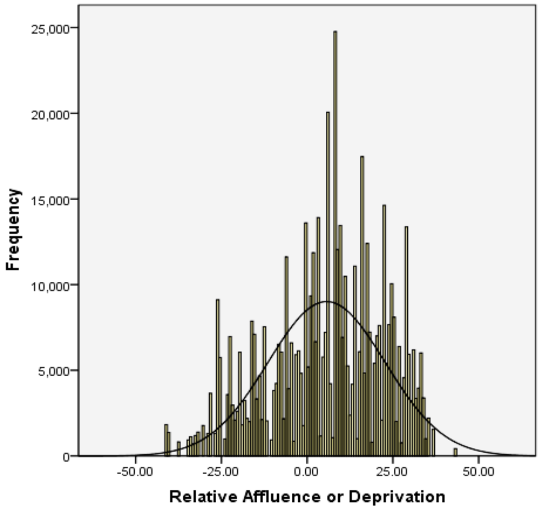
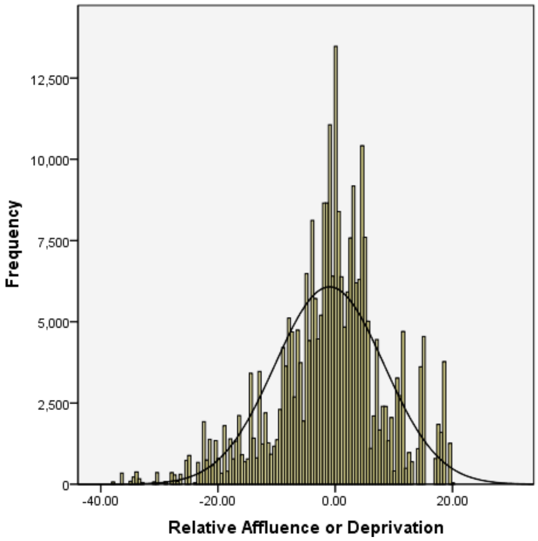


Figure 5-6: Distribution of deprivation scores (WBR)



5.2.5 Descriptive Statistics for the Welfare Model

This section will present the results of the welfare analysis including cross-tabulations of consumer surplus changes with the density and deprivation variables. Tables 5-8 to 5-10 list the descriptive statistics for the national welfare model and both study regions in each CO_2 price scenario.

In the low CO_2 price scenario presented in Table 5-8, welfare effects are found to be minimal. Nationally, average consumer surplus losses are found to be -0.02, rising to

-0.03 in the WBR. Dublin experiences a consumer surplus gain of 0.01 on average. In the medium CO_2 price scenario (Table 5-9), the results diverge more between the regions. Nationally the change in consumer surplus and consequently welfare is marginally negative with a mean value -0.04. In Dublin the introduction of the cap has negligible effects on welfare with a mean consumer surplus change of zero. In the WBR the mean consumer surplus change is -0.05, which is greater than the national average. In the high price scenario (Table 5-10), welfare losses increase to -0.07 nationally and to -0.09 in the WBR. In contrast Dublin falls slightly to zero with high price scenario indicating a negligible overall welfare changes in the region.

Table 5-8: Descriptive statistics for welfare model (Low CO_2 price - €8.24)

	National	**Dublin**	**WBR**
Sample Size (N)	1,217,717	350,437	180,614
Mean	-0.02	0.01	-0.03
Median	0.01	0.01	0.01
Mode	0.01	0.01	0.01
Std. Deviation	0.09	0.03	0.10
Variance	0.01	0.01	0.01
Range	0.98	0.92	0.98
Minimum	-0.95	-0.88	-0.95
Maximum	0.03	0.03	0.03

Table 5-9: Descriptive statistics for welfare model (Med CO_2 price - €16.70)

	National	**Dublin**	**WBR**
Sample Size (N)	1,217,717	350,437	180,614
Mean	-0.04	0.01	-0.05
Median	0.01	0.01	0.01
Mode	0.02	0.02	0.02
Std. Deviation	0.17	0.06	0.20
Variance	0.03	0.01	0.04
Range	1.99	1.86	1.99
Minimum	-1.92	-1.79	-1.92
Maximum	0.07	0.07	0.07

Table 5-10: Descriptive statistics for welfare model (High CO_2 price - €28.73)

	National	**Dublin**	**WBR**
Sample Size (N)	1,217,717	350,437	180,614
Mean	-0.07	0.01	-0.09
Median	0.02	0.02	0.02
Mode	0.04	0.04	0.04
Std. Deviation	0.30	0.11	0.34
Variance	0.09	0.01	0.11
Range	3.42	3.20	3.42
Minimum	-3.30	-3.08	-3.30
Maximum	0.12	0.12	0.12

5.2.6 Welfare and Population Density Results

To determine whether rural commuters are more adversely affected than urban commuters by the PCTS, the results are cross-tabulated against density deciles. As is evident from the variance and standard deviation results presented in the descriptive statistics above, the overall range of welfare changes in each region is quite narrow; hence it is useful to compare both regions at a number of density levels to observe any divergences in the welfare results. The consumer surplus changes tabulated Tables 5-12 to 5-14 are estimated for Dublin, WBR and national datasets. Decile 1 represents the population living in the most sparsely populated areas and Decile 10 represents the population living in the most densely populated areas as defined in Table 5-4. Decile 1 in the Dublin column is blank, as this level of density does not exist in Dublin, while Deciles 8 to 10 are blank in the WBR column due to the fact that higher densities of population do not exist in this region as they do in Dublin.

In the low CO_2 price scenario in Table 5-11, deciles 1-7 all have negative average consumer surplus changes both nationally and in the WBR. However, these welfare losses are relatively small in comparison to the losses incurred in the medium and high CO_2 price scenarios discussed below. The largest loss is incurred nationally in decile 1 where the average loss is -0.04. In Dublin, welfare remains unchanged in most deciles with only a marginal decrease in decile 1. Therefore, low CO_2 prices cause minimal changes in welfare for commuters.

The medium CO_2 price scenario results are presented in Table 5-12. The findings for deciles 1 - 7 nationally are all negative numbers indicating a shrinking of individual consumer surplus on average. Deciles 8, 9 and 10 are found to have positive numbers indicating that on average DED's with over 2,500 persons per km^2 benefit from the introduction of a cap. These results demonstrate that as population density increases, consumer surplus loss decreases. In lower deciles, commuters in the WBR have a greater consumer surplus loss compared to commuters in Dublin who experience a gain on average in all but two of the density deciles. As population density increases rural commuters are found to have a higher consumer surplus loss than urban commuters in Dublin.

The disparity between the regions increases in the high CO_2 price scenario presented in Table 5-13. Losses are found to be three times that of the low CO_2 scenario in lower deciles in both the WBR and national datasets. In Dublin, high CO_2 prices are again found to have a negligible effect on welfare in the region. The largest loss observed is -0.04 in decile 2, which is three times less than the welfare loss incurred nationally.

Table 5-11: Cross-tabulation of welfare and density of population (Low Price – €8.24)

Density of Population Deciles	National CS Change	Dublin CS Change	WBR CS Change
0-25 (1)	-0.04	-	-0.03
25-50 (2)	-0.03	0.00	-0.03
50-100 (3)	-0.03	0.00	-0.02
100-250 (4)	-0.02	0.00	-0.02
250-500 (5)	-0.01	0.00	-0.02
500-1,000 (6)	-0.02	0.00	-0.02
1,000-2,500 (7)	-0.01	0.00	-0.01
2,500-5,000 (8)	0.00	0.00	-
5,000-10,000 (9)	0.00	0.00	-
10,000 + (10)	0.00	0.00	-

Table 5-12: Cross-tabulation of welfare and density of population (Med Price - €16.70)

Density of Population Deciles	National CS Change	Dublin CS Change	WBR CS Change
0-25 (1)	-0.08	-	-0.07
25-50 (2)	-0.07	0.00	-0.05
50-100 (3)	-0.06	0.00	-0.05
100-250 (4)	-0.04	-0.01	-0.04
250-500 (5)	-0.03	0.01	-0.04
500-1,000 (6)	-0.04	0.01	-0.04
1,000-2,500 (7)	-0.02	0.01	-0.02
2,500-5,000 (8)	0.01	0.00	-
5,000-10,000 (9)	0.00	0.01	-
10,000 + (10)	0.01	0.01	-

Table 5-13: Cross-tabulation of welfare and density of population (High Price – 28.73)

Density of Population Deciles	National CS Change	Dublin CS Change	WBR CS Change
0-25 (1)	-0.14	-	-0.12
25-50 (2)	-0.12	-0.04	-0.09
50-100 (3)	-0.11	0.00	-0.08
100-250 (4)	-0.08	0.00	-0.07
250-500 (5)	-0.06	-0.01	-0.06
500-1,000 (6)	-0.07	0.01	-0.06
1,000-2,500 (7)	-0.04	0.01	-0.04
2,500-5,000 (8)	-0.01	0.00	-
5,000-10,000 (9)	0.00	0.01	-
10,000 + (10)	0.01	0.02	-

5.2.7 Welfare and Deprivation Results

As discussed in Section 5.2.4, some of the most deprived districts in Ireland are rural areas, which have been found to experience greater consumer surplus losses than DED’s in Dublin. One would expect therefore, a higher welfare loss in the most deprived areas. To test this hypothesis, the deprivation variable was also divided into its constituent groups defined in Table 5-6. Percentile 1 represents the most deprived areas and percentile 8 represents the most affluent areas within the range. The results of this analysis are presented in Tables 5-14 to 5-16 for the low, medium and high CO_2 price scenarios. Percentile 8 in the WBR region is blank as there are no DED’s in this region that attain the aggregate affluence levels to be included in this percentile. While the range of deprivation scores observed varies for the two regions, the scale of deprivation used to determine each percentile (Table 5-7) is kept uniform for both regions as a means of comparison.

The results reveal that the most deprived areas represented by the lower percentiles will suffer a greater loss in consumer surplus compared to those commuters living in more affluent areas. As affluence increases, welfare losses generally decrease, particularly in the WBR. The only exception to this finding is in disadvantaged percentiles in Dublin, which have a consumer surplus gain. The mitigating factor in this case may be due to the fact that the most deprived areas in Dublin are generally inner city DED’s which would be well served by more sustainable public transport modes. Also, a higher percentage of commuters would walk and cycle to work in Dublin City.

In the low CO_2 price scenario, the largest losses are found in DED's that have deprivation levels in and around the national average. DED's which were found to be slightly above and below the national average experience slight losses in the WBR and national datasets. However, in Dublin no change in welfare is found to occur at any level of affluence or deprivation. This was also the case in the residential density cross-tabulations. Welfare losses occur in all percentiles in the WBR and remain consistent across each group with no apparent trend of smaller losses in more affluent DED's observed in the medium and high price scenarios.

In the medium CO_2 price scenario in Table 5-15 all eight percentiles in Dublin experience a marginal consumer surplus gain. No change occurs in percentiles 4 and 5. All percentiles in the rural WBR experience a consumer surplus loss larger than the national average. These losses in the WBR are also twice the size of the losses incurred in the low CO_2 price scenario.

The results for the high CO_2 price scenario reveal a large divergence between the regions consistent with findings in the density cross-tabulations. In Dublin, increasing the price of CO_2 to its highest level has negligible effects on commuter welfare. In all percentiles welfare remains unchanged or gains are experienced in the case of the high price scenario. The WBR in contrast experiences double the losses found for the same region in the medium price scenario. All percentiles in the WBR experience losses with the largest losses found in disadvantage DED's.

Table 5-14: Cross-tabulation of welfare and deprivation (Low Price - €8.24)

Deprivation Level Percentiles	National CS Change	Dublin CS Change	WBR CS Change
Extremely disadvantaged (1)	0.00	0.00	-0.04
Very disadvantaged (2)	0.00	0.00	-0.02
Disadvantaged (3)	-0.01	0.00	-0.02
Slightly below national average (4)	-0.02	0.00	-0.03
Slightly above national average (5)	-0.02	0.00	-0.03
Affluent (6)	-0.01	0.00	-0.02
Very affluent (7)	0.00	0.00	-0.04
Extremely affluent (8)	0.00	0.00	

Table 5-15: Cross-tabulation of welfare and deprivation (Med Price - €16.70)

Deprivation Level Percentiles	National CS Change	Dublin CS Change	WBR CS Change
Extremely disadvantaged (1)	0.00	0.01	-0.07
Very disadvantaged (2)	0.00	0.01	-0.05
Disadvantaged (3)	-0.03	0.01	-0.05
Slightly below national average (4)	-0.06	0.00	-0.06
Slightly above national average (5)	-0.05	0.00	-0.06
Affluent (6)	-0.02	0.01	-0.03
Very affluent (7)	0.00	0.01	-0.02
Extremely affluent (8)	0.00	0.01	-

Table 5-16: Cross-tabulation of welfare and deprivation (High Price - €28.73)

Deprivation Level Percentiles	National CS Change	Dublin CS Change	WBR CS Change
Extremely disadvantaged (1)	0.00	0.01	-0.13
Very disadvantaged (2)	-0.01	0.01	-0.09
Disadvantaged (3)	-0.05	0.01	-0.08
Slightly below national average (4)	-0.10	0.00	-0.03
Slightly above national average (5)	-0.08	0.00	-0.02
Affluent (6)	-0.03	0.00	-0.01
Very affluent (7)	0.00	0.01	-0.01
Extremely affluent (8)	0.00	0.01	-

The results in both cross-tabulations reveal a clear gap between the welfare losses experienced by urban commuters and rural commuters as a result of introducing a PCTS. Varying the price of carbon alters the Dublin results minimally. Welfare in this region on average remains unchanged in many percentiles and some experience a positive consumer surplus change in the medium and high price scenarios. In the WBR, welfare losses are found in all three price scenarios, with a particular divergence from Dublin in the high price scenario as negative consumer surplus changes increase substantially.

5.2.8 Spatial Distribution of Welfare Changes

As the POWCAR dataset also provides unique geographical codes for each individual, the results can be transposed geographically using GIS software. This provides an additional layer of results as a means of comparing welfare changes across the study regions. Aggregated consumer surplus changes are calculated for over 3,400 DEDs in each CO_2 price scenario and presented in this section. DED's colour coded as dark blue experience aggregate welfare gains from the introduction of a PCTS, while DED'S colour coded light blue and green experience small welfare losses. DED'S colour coded yellow, orange and red experience the largest welfare losses.

In the low CO_2 price scenario illustrated in Figure 5-7, losses are minimal across the country. The largest losses of any occur in the WBR, Midlands and Dublin commuter belt regions (Wicklow, Kildare and Meath). Focusing on the study regions more closely reveals contrasting welfare changes between Dublin and WBR. Figure 5-8 shows the majority of DED's in the WBR experience an aggregate loss, albeit a minimal loss represented by DED's colour coded light blue. A small minority of isolated rural DED's experience larger losses coloured coded orange and yellow. The Dublin region in contrast experiences an aggregate welfare gain in Figure 5-9. The vast majority of DED's in the region experience a gain aside from a number of DED's in the north of the region which experience a marginal loss.

Figure 5-7: National consumer surplus change (Low CO_2 price - €8.24)

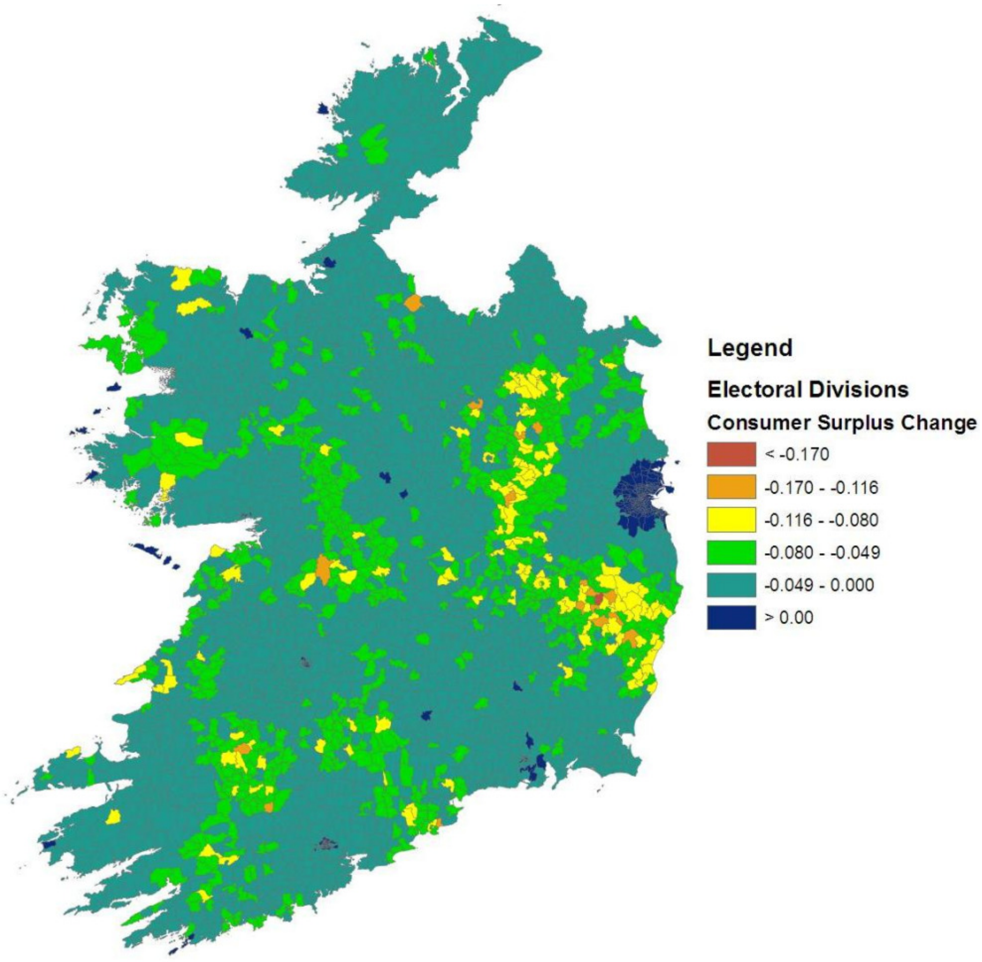


Figure 5-8: WBR consumer surplus change (Low CO_2 price - €8.24)

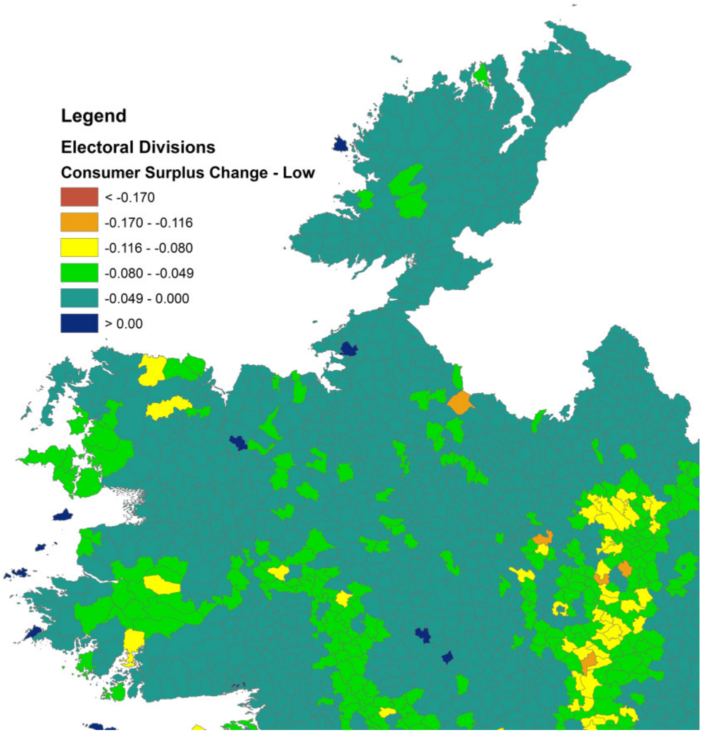
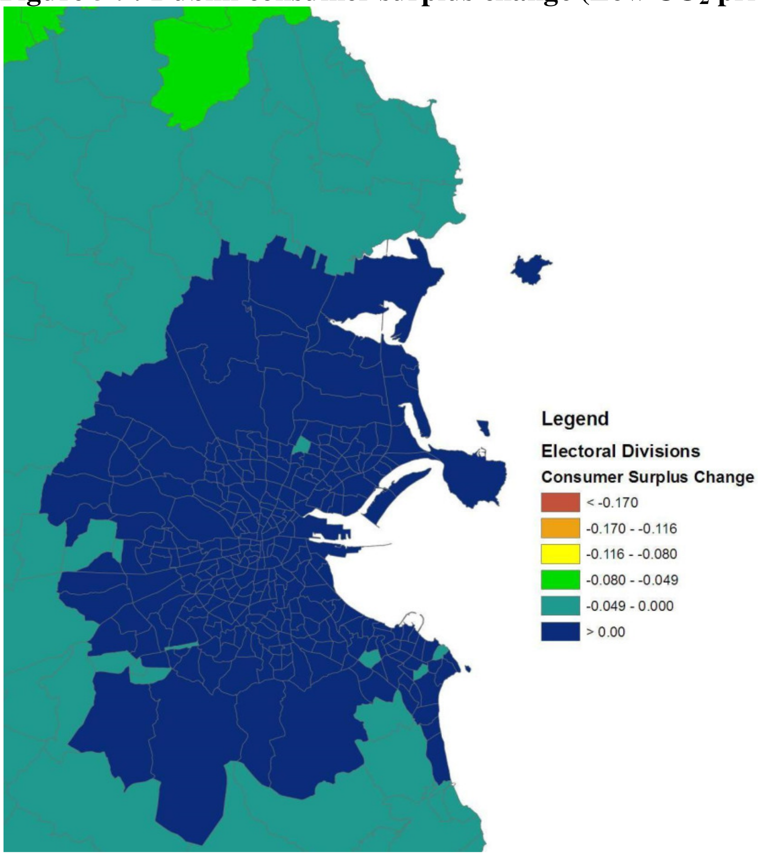


Figure 5-9: Dublin consumer surplus change (Low CO_2 price - €8.24)



In the medium price scenario, considerable differences in welfare changes are evident nationally and in the WBR compared to the low price scenario. Figure 5-10 illustrates the regions experiencing the largest losses are rural regions in the WBR, Munster and the Dublin commuter belt. Figure 5-11 shows larger welfare losses occurring in DED's greater distances from urban centres in the WBR. Welfare changes in Dublin (Figure 5-12) remain as they were observed in Figure 5-9, with the vast majority of DEDs in the region experiencing an aggregate welfare gain excluding a number of DEDs in the north of the county which experience marginal losses.

Figure 5-10: National consumer surplus change (Medium CO_2 price - €16.70)

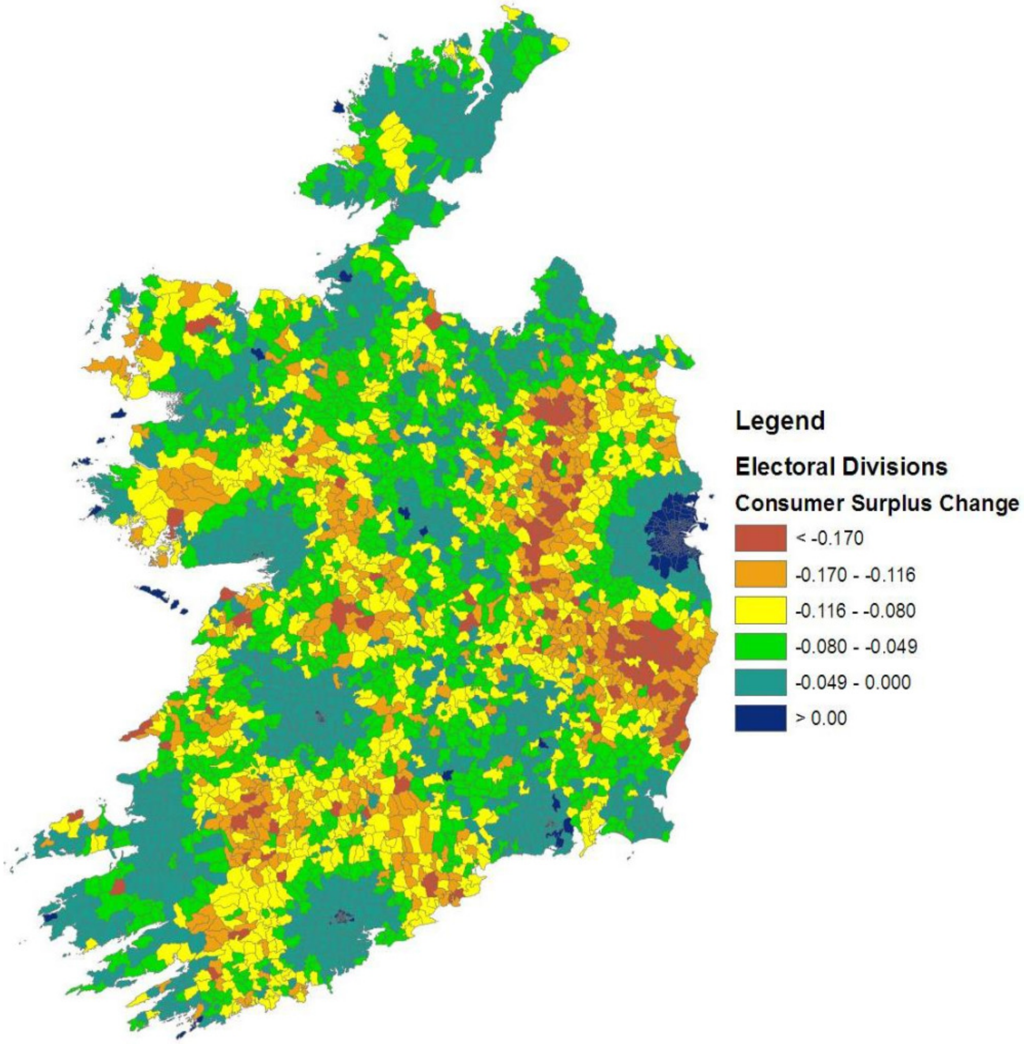


Figure 5-11: WBR consumer surplus change (Medium CO_2 price- €16.70)

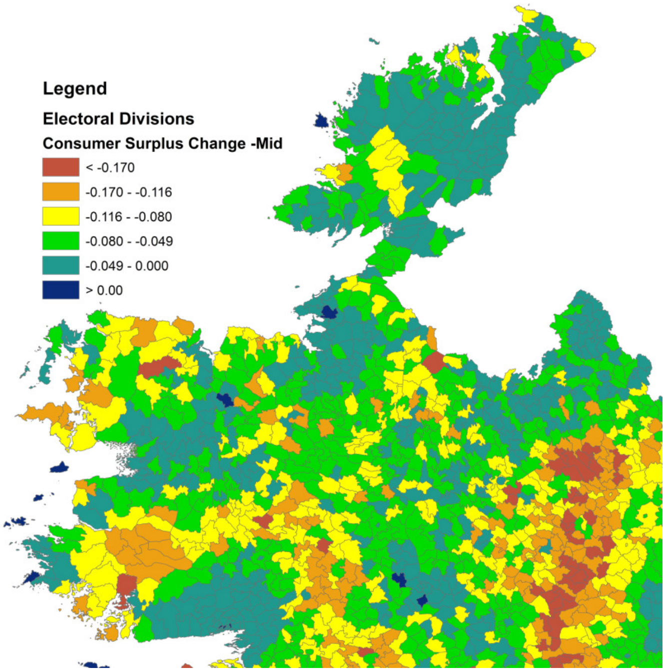
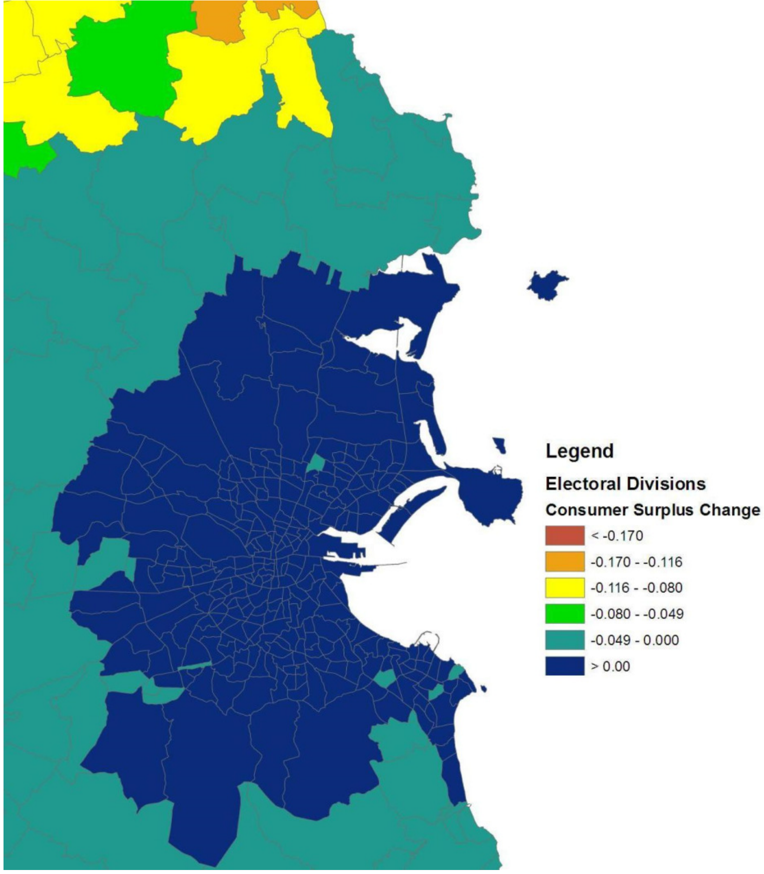


Figure 5-12: Dublin consumer surplus change (Medium CO_2 price - €16.70)



Figures 5-13 to 5-15 illustrate a clear outcome of larger welfare losses in DED's farther from major urban centres in a high CO_2 price scenario. DED's encompassing the major urban centres of Dublin, Cork, Limerick, Galway and Waterford are found to have welfare gains with the advent of a PCTS. A pattern of concentric rings around these urban centres is also visible in each figure as welfare gains convert into losses the greater the distance from urban centres. Regions in the WBR, Midlands and Munster experience the highest aggregated consumer surplus losses. Figure 5-15 again shows no change in welfare in Dublin compared to the low and medium price scenarios save for the aforementioned DEDs in the north of the county which experience marginal welfare losses.

Figure 5-13: National consumer surplus change (High CO_2 price - €28.73)

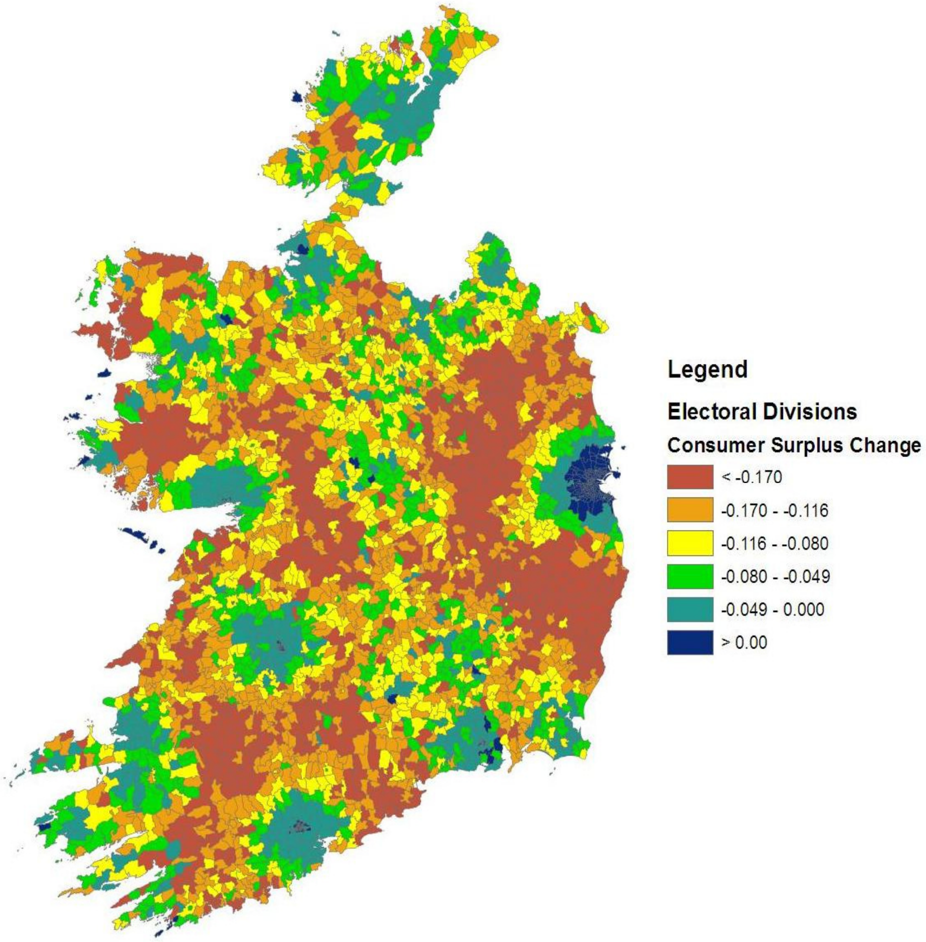


Figure 5-14: WBR consumer surplus change (High CO_2 price - €28.73)

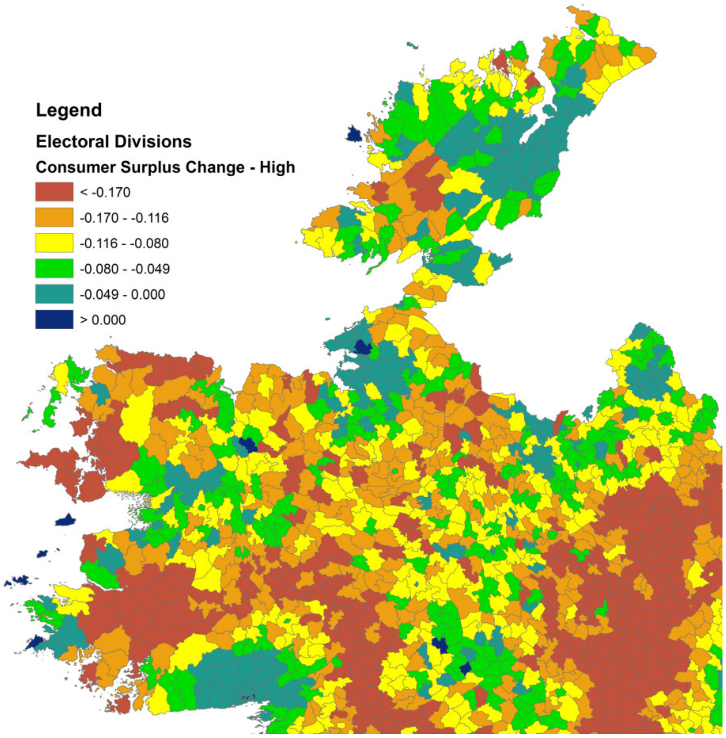
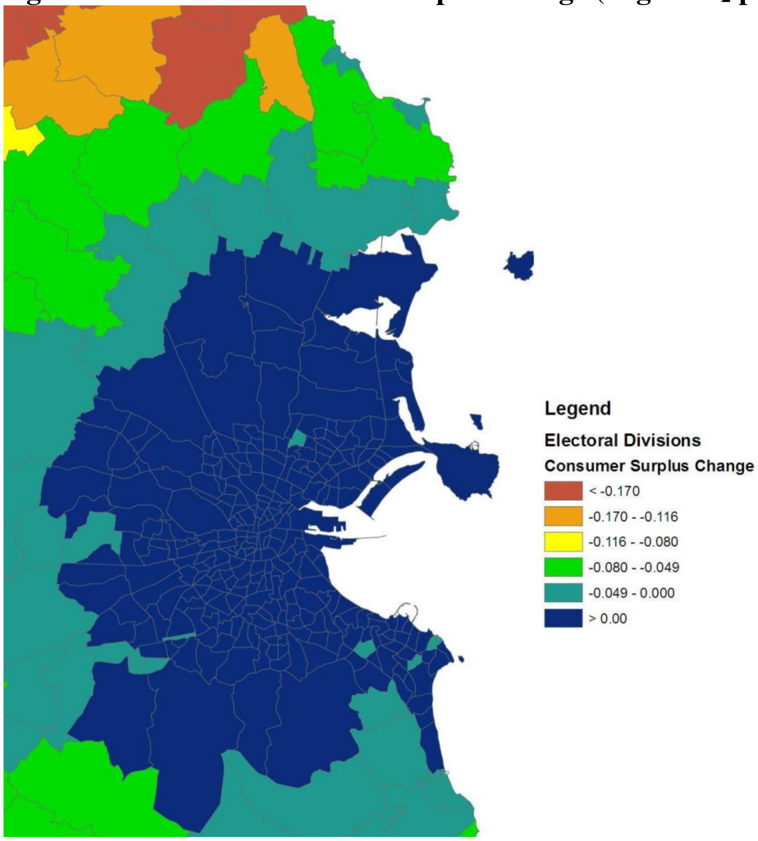


Figure 5-15: Dublin consumer surplus change (High CO_2 price - €28.73)



This GIS analysis confirms the urban-rural divide in the welfare results. Dublin is found to experience a welfare gain on aggregate in a PCTS under all CO_2 price scenarios, while large swaths of the WBR experience aggregate losses in each scenario. In the WBR, a small number of DED's in and around the urban centres of Galway, Sligo and Letterkenny experience an increase in welfare as a result of the introducing a PCTS. However, the vast majority of DED's in the region experience welfare loss, particularly DED's in the rural Galway and Mayo regions.

5.3 SOCIO-ECONOMIC ANALYIS OF WELFARE RESULTS

This section of the chapter estimates an MNL model for the welfare changes presented in the previous section. The methodology of this analysis is described in detail in Chapter 3, section 3.4. This analysis will model for four welfare outcomes. Using a BLR constrains the number of outcomes to a binary choice variable of two outcomes, thus using a MNL model in this case allows a greater number of outcomes for the dependent variable. Moreover, equations for each outcome are fitted simultaneously and have smaller standard errors than if fitted using BLR separately for each outcome.

Welfare changes for the dependent variable are categorised as 'positive' or 'negative' in the model under four categories detailed in Table 5-17. These welfare changes, measured by changes in consumer surplus, are then regressed on a number of socio-economic variables to determine the factors that contribute to individuals having a negative or positive change in consumer surplus and consequently welfare.

Table 5-17: Details of consumer surplus variable

Welfare Change	**Range**
Large Negative Change (LNC)	-0.50 and under
Marginal Negative Change (MNC)	Between 0 and -0.50
Marginal Positive Change (MPC)	Between 0 and 0.02
Positive Change (PC)	0.02 and over

5.3.1 Multinomial Logistic Regression Model Formulation

Six models are estimated in this section; a national, a Dublin and a WBR model, each with a low, medium and high CO_2 price scenario. Six variables are chosen as independent variables in the model. The age, gender, socio-economic group, household composition variables are the same variables that were used in the BLR analysis of Chapter 4. Density and deprivation levels used in the reporting of the welfare change in this chapter are now added to the MNL with the aforementioned socio-economic variables.

The constituent groups of these variables are detailed in Table 5-18. The dependent variable categories are ‘large negative change’, ‘marginal negative change’ and ‘marginal positive change’. The reference category is the ‘positive change’. The outcomes for the dependent variable are predicted vis-à-vis the reference category ‘positive change’ as defined in Table 5-17.

Table 5-18: Details of variables examined

Variable	**Definition**
Age	
15-24	= 1 if Age: 15-24
25-34	= 1 if Age: 25-34
35-44	= 1 if Age: 35-44
45-54	= 1 if Age: 45-54
55-64	= 1 if Age: 55-64
65+	(Reference category = 65+)
Gender	
Gender: Male	= 1 if Gender: male
Gender: Female	(Reference category = Gender: Female)
Socio-economic group	
Employers and managers	=1 if Employers and managers
Higher professional	= 1 if Higher professional
Lower professional	= 1 if Lower professional
Non-manual	= 1 if Non-manual
Manual skilled	= 1 if Manual skilled
Semi skilled	= 1 if Semi skilled
Unskilled	= 1 if Unskilled
Self employed	= 1 if Self employed
Farmers	= 1 if Farmers
Agricultural workers	= 1 if Agricultural work
Other	(Reference category = Other)
Household Composition	
Single	=1 if Single
Lone Parent with Children	=1 if Lone Parent with Children
Lone Parent no Children under 19	=1 if Lone Parent no Children under 19
Couple with Children	=1 if Couple with Children
Couple no Children under 19	=1 if Couple no Children under 19
Couple no Children	=1 if Couple no Children
Other Households	(Reference category = Other Households)
Level of Deprivation in DED	
Extremely affluent	=1 if Extremely affluent
Very affluent	=1 if Very affluent
Affluent	=1 if Affluent
Slightly above national average	=1 if Slightly above national average
Slightly below national average	=1 if Slightly below national average
Disadvantaged	=1 if Disadvantaged
Very disadvantaged	=1 if Very disadvantaged
Extremely disadvantaged	(Reference category = Extremely Disadvantaged)
DED Density per km^2	
0-50 persons	=1 if 0-50 persons
50-250 persons	=1 if 50-250 persons
250-1,000 persons	=1 if 250-1000 persons
1,000-5,000persons	=1 if 1,000-5,000 persons
5,000+ persons	(Reference category = 5000+ persons)

5.3.2 MNL Regression Results in a Low CO_2 Price Scenario - €8.24.

The following results presented in Tables 5-19 to 5-21 are estimated for the national, Dublin and WBR datasets based on a low CO_2 price scenario of €8.24. The reference category in all cases is a 'positive change' in consumer surplus and all outcomes are predicted vis-à-vis this category. The performance of each model shows the national model to be the best fitted model. R-squared value for the national model of 0.16 is the largest of the three models. The Dublin and WBR datasets yield R-squared values of 0.043 and 0.086 respectively. The WBR model yields the lowest log-likelihood despite the lower R-squared value observed. R-squared values are considerably lower than the BLR models in Chapter 4 due to the inclusion of an error term in MNL models.

The age category has a significant effect on the outcomes of having a large negative change (LNC) and a marginal negative change (MNC) in comparison to having a positive change both nationally, in the WBR and to a lesser extent in Dublin. Nationally the groups most likely to have a LNC are younger age groups particularly the 25-44 age group. This is also the case in the WBR. The Dublin model returns lower beta coefficient for all groups and all are insignificant outside of the aforementioned 25-44 group. This age group is also likely to experience a MNC and marginal positive change (MPC) nationally and in Dublin. All age groups with a positive welfare change in the WBR are insignificant in the model. Previous sections have shown very few individuals experience a welfare gain in this region in any scenario. The number of cases therefore is not sufficient to merit statistical significance. In terms of gender, the probability of having a LNC as opposed to positive welfare change is increased by being male in all three datasets, particularly in the WBR. This is also the case for individuals having a MNC in Dublin and the WBR. Individuals with a MPC are more likely to be females in all three models.

The results for the socio-economic variable are less conclusive. Many categories within this variable are likely to have both positive and negative consumer surplus changes. Employers and managers and higher and lower professionals are the only groups likely to have a LNC and a MNC across all three models. This may be due to higher income levels within these groups and the use of less sustainable modes of transport. Semi skilled and unskilled groups are unlikely to have a negative change in the national and WBR models, but are in Dublin. However, these groups are also unlikely to have a positive change yielding an inconclusive result. Farmers and agricultural worker are unlikely to have a negative change in consumer surplus across each model except in Dublin where they are likely to have a MNC.

For the household composition variable, couples with dependent children and are more likely to have a negative consumer surplus change than single or lone parents in all three models. Couples with no children also have a large beta coefficient in the negative change categories indicating more of likelihood of this outcome than having a positive change.

Many of the p-values associated with the deprivation variable are insignificant in the low CO_2 price scenario in the national and WBR models; therefore the associated coefficients are not determinants of consumer surplus changes in these models. However, individuals slightly above and below the national deprivation average are likely to have negative consumer surplus changes in all three models. In the WBR, individuals living in affluent and disadvantaged DED’s are unlikely to have a negative change in consumer surplus. In Dublin, individuals living in DED’s close to the national deprivation average are most likely to have a negative consumer surplus change.

The density variable yields more conclusive results. Large beta coefficients across all three models are found for individuals living in sparsely populated DED’s indicating a likelihood of individuals in these areas having a negative consumer surplus change. These individuals are also unlikely to have a positive change in Dublin and the WBR. Individuals living in DED’s with a density of population of more than 1,000 persons per km^2 are less likely to have a negative consumer surplus change. Due to the high statistical significance and relatively large coefficients it can be postulated that density of population explains much of the variation in consumer surplus changes found in this analysis. This result shows that population density has a greater impact upon consumer surplus changes than deprivation.

Table 5-19: MNL model results (National Dataset: Low CO_2 price - €8.24)

Variable	**Large negative change**	**Marginal negative change**	**Marginal positive change**
Intercept	-4.223**	.060	4.979**
Age			
15-24	1.089**	1.128**	.567**
25-34	1.615**	1.428**	.483**
35-44	1.541**	1.407**	.578**
45-54	.978**	1.014**	.436**
55-64	.373	.529**	.202**
65+	Ref	Ref	Ref
Gender			
Male	.195**	-.549**	-.911**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	1.501**	1.331**	.940**
Higher professional	1.220**	1.010**	.501**
Lower professional	1.014**	1.031**	.477**
Non-manual	.237*	.361**	.320**
Manual skilled	.473**	.594**	.309**
Semi skilled	-.784**	-.378**	-.311**
Unskilled	-.506**	-.320**	-.197*
Self employed	1.362**	1.157**	.841**
Farmers	-1.664**	-1.088**	-.217
Agricultural workers	-1.963**	-1.369**	-.744**
Other	Ref	Ref	Ref
Household Composition			
Single	.788**	.567**	.078
Lone Parent with Children	.714**	.685**	.445**
Lone Parent no Children under 19	.457**	.527**	.144
Couple with Children	1.058**	.976**	.484**
Couple no Children under 19	1.013**	.946**	.524**
Couple no Children	1.169**	.984**	.312**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	.124	-.356	-.186
Very affluent	-.249	-.044	-.004
Affluent	.108	.284	-.262
Slightly above national average	.649*	.430*	-.414*
Slightly below national average	.831**	.289	-.577**
Disadvantaged	.459	.206	-.473*
Very disadvantaged	.060	.085	-.191
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	3.858**	3.378**	1.363**
50-250 persons	2.871**	2.477**	.753**
250-1,000 persons	2.278**	1.655**	.263**
1,000-5,000persons	1.393**	1.061**	.286**
5,000+ persons	Ref	Ref	Ref
Number of Cases	1,212,306		
Nagelkerke R-squared	.160		
Log Likelihood	118183.763		

** Significant at 1%, *Significant at 5%

Table 5-20: MNL model results (Dublin Dataset: Low CO_2 price - €8.24)

Variable	Large negative change	Marginal negative change	Marginal positive change
Intercept	-4.769**	-3.453**	.818**
Age			
15-24	-.081	.060	.252**
25-34	.297*	.370**	.169**
35-44	.330*	.394**	.146**
45-54	.164	.249**	.088*
55-64	-.082	.135	.045
65+	Ref	Ref	Ref
Gender			
Male	.598*	.372**	-.096**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.450**	.525**	.132**
Higher professional	.389**	.343**	.114**
Lower professional	.004	.348**	.081**
Non-manual	-.364**	.002	.124**
Manual skilled	.572**	.648**	.133**
Semi skilled	-.079	.013	.084**
Unskilled	.037	-.065	.120**
Self employed	.709**	.660**	-.028
Farmers	1.145**	-.214	-.758**
Agricultural workers	.099	-.577	-.592**
Other	Ref	Ref	Ref
Household Composition			
Single	.198**	.299**	.006
Lone Parent with Children	.150	.255**	-.047*
Lone Parent no Children under 19	.291**	.437**	.189**
Couple with Children	.218**	.501**	.020
Couple no Children under 19	.322**	.481**	.147**
Couple no Children	.332**	.509**	.073**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	.618**	.239**	.351**
Very affluent	.550**	.422**	.354**
Affluent	.585**	.462**	.416**
Slightly above national average	.850**	.963**	.429**
Slightly below national average	.861**	.806**	.263**
Disadvantaged	.519**	.387**	.375**
Very disadvantaged	.663**	.612**	.275**
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	1.772**	2.352**	-.249*
50-250 persons	.546**	1.408**	.073*
250-1,000 persons	.986**	1.482**	.066**
1,000-5,000persons	.509**	.773**	.161**
5,000+ persons	Ref	Ref	Ref
Number of Cases	350,437		
Nagelkerke R-squared	.043		
Log Likelihood	77933.814		

** Significant at 1%, *Significant at 5%

Table 5-21: MNL model results (WBR Dataset: Low CO_2 price - €8.24)

Variable	**Large negative change**	**Marginal negative change**	**Marginal positive change**
Intercept	-3.158**	-2.679	1.200
Age			
15-24	.972**	.787**	.037
25-34	1.432**	1.085**	.059
35-44	1.250**	.957**	.101
45-54	.925**	.835**	.164
55-64	.522**	.560**	.165
65+	Ref	Ref	Ref
Gender			
Male	.420**	.035	-.100
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.432**	.222**	-.060
Higher professional	.948**	.665**	.065
Lower professional	.938**	.705**	.021
Non-manual	-.040	-.029	-.190**
Manual skilled	.194**	.250**	-.034
Semi skilled	-.307**	.050	-.133**
Unskilled	-.314**	-.155*	-.203**
Self employed	-.010	-.115	-.389**
Farmers	-.950**	-.766**	-.468**
Agricultural workers	-.668**	-.550**	-.258**
Other	Ref	Ref	Ref
Household Composition			
Single	.610**	.569**	.199**
Lone Parent with Children	.485**	.422**	.330**
Lone Parent no Children under 19	.677**	.604**	.293**
Couple with Children	.758**	.660**	.406**
Couple no Children under 19	.792**	.608**	.360**
Couple no Children	.941**	.776**	.303**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	N/a	N/a	N/a
Very affluent	-1.771	-1.868	.172
Affluent	-.675**	-.254*	-.017
Slightly above national average	-.254*	.486**	-.047
Slightly below national average	-.210	.325*	-.117
Disadvantaged	-.460**	.129	-.140
Very disadvantaged	-.432**	.032	-.067
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	1.139**	1.382**	.058*
50-250 persons	.603**	.864**	.016
250-1,000 persons	.609**	.750**	.148**
1,000-5,000persons	Ref	Ref	Ref
Number of Cases	178,448		
Nagelkerke R-squared	.086		
Log Likelihood	66670.007		

** Significant at 1%, *Significant at 5%

5.3.3 MNL Regression Results in a Medium CO_2 Price Scenario - €16.70

This section presents the MNL model results for the medium CO_2 price scenario of €16.70. Tables 5-22 to 5-24 detail the findings of the MNL for the national, Dublin and WBR datasets. Model performance is improved on the low CO_2 price model. R-squared values increase to 0.131 for the national dataset, but remain static at 0.043 and 0.086 for the Dublin and WBR models respectively. The WBR model maintains the smallest log likelihood value.

For the age variable, as was the case in the low CO_2 price scenario, age groups ranging from 25-44 are most likely to have a negative consumer surplus change. However, this is not the case in Dublin where all but one of the outcomes for the LNC was found to be insignificant. The gender variable follows the same trend as was observed in the low CO_2 price scenario with males being more likely to have a negative consumer surplus change than females. Females are also more likely to have a positive consumer surplus change than males across all three models.

Socio-economic groupings again yield inconclusive results beta coefficients smaller than those observed in the low CO_2 price scenario. Nationally and in the WBR, farmers and agricultural workers are the most likely groups to avoid having a negative consumer surplus change. The likelihood of employers, managers and professionals having a LNC also falls in comparison to the low price scenario in all three models. No group is likely to have a positive consumer surplus change nationally or in the WBR. Manual skilled workers are the only group likely to have a positive consumer surplus change in Dublin. However, this result is statistically insignificant and therefore inconclusive.

The household composition variable returns more conclusive results than in the low CO_2 scenario. Nationally and in the WBR, all groups in this variable are likely to be to have a negative change (LNC and MNC). However, individuals living in Dublin have a much smaller likelihood of having a LNC. Couples with dependent children in Dublin are also marginally unlikely to have a positive welfare change. Nationally and in the WBR, individuals with dependent children are the likeliest group to have a positive welfare change. However the associated coefficients are smaller than those observed in the Dublin dataset. Single individuals are likely to have a positive change. In Dublin, single individuals with a positive consumer surplus change and are more likely to have positive welfare change than a MPC. The results indicate that individuals with dependent families are more likely to experience welfare losses.

The deprivation variable returns more significant results than in the low CO_2 price scenario. Nationally and in the WBR, individuals in more affluent DED’s are more likely to have positive consumer surplus changes. In the National and WBR models, individuals living in more affluent DED’s are less likely to have a negative change. In Dublin the opposite is the case – individuals in more affluent areas are less likely to have a positive change than disadvantaged DED’s. This confirms the results found in the cross-tabulation in section 5.3.5, in which deprived and affluent DED’s in Dublin are found to experience welfare gains in all scenarios. Again the density variable is highly significant across all three models confirming the importance of population density in explaining welfare losses.

Table 5-22: MNL model results (National Dataset: Medium CO_2 price - €16.70)

Variable	Large negative change	Marginal negative change	Marginal positive change
Intercept	-6.585**	-3.633**	1.009**
Age			
15-24	.813**	.662**	.158**
25-34	1.350**	.975**	.086**
35-44	1.121**	.844**	.053*
45-54	.671**	.610**	.055*
55-64	.317**	.354**	.041
65+	Ref	Ref	Ref
Gender			
Male	.837**	.267**	-.082*
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.446**	.344**	-.062**
Higher professional	.674**	.470**	-.034*
Lower professional	.562**	.528**	-.031*
Non-manual	-.178**	-.005	-.081**
Manual skilled	.132**	.286**	-.016
Semi skilled	-.465**	-.067**	-.032*
Unskilled	-.362**	-.155**	-.062**
Self employed	.303**	.185**	-.175**
Farmers	-1.801**	-1.201**	-.548**
Agricultural workers	-1.293**	-.732**	-.193**
Other	Ref	Ref	Ref
Household Composition			
Single	.705**	.493**	.024*
Lone Parent with Children	.390**	.309**	.098**
Lone Parent no Children under 19	.515**	.485**	.144**
Couple with Children	.679**	.571**	.115**
Couple no Children under 19	.629**	.520**	.140**
Couple no Children	.956**	.728**	.096**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	-.030	-.051	.131**
Very affluent	-.671**	.014	.001
Affluent	.177	.698**	.146**
Slightly above national average	.959**	.958**	.144**
Slightly below national average	1.184**	.893**	.055*
Disadvantaged	.895**	.773**	.135**
Very disadvantaged	.205	.413**	.157**
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	2.205**	1.851**	-.201**
50-250 persons	1.890**	1.625**	-.119**
250-1,000 persons	1.875**	1.398**	.039**
1,000-5,000persons	.971**	.799**	.035**
5,000+ persons	Ref	Ref	Ref
Number of Cases	1,212,306		
Nagelkerke R-squared	.131		
Log Likelihood	192232.780		

** Significant at 1%, *Significant at 5%

Table 5-23: MNL model results (Dublin Dataset: Medium CO_2 price - €16.70)

Variable	**Large negative change**	**Marginal negative change**	**Marginal positive change**
Intercept	-5.509**	-3.308*	.807**
Age			
15-24	-.273	.125	.348**
25-34	-.066	.408**	.209**
35-44	-.005	.405**	.151**
45-54	-.148	.262**	.094*
55-64	-.467*	.132	.042
65+	Ref	Ref	Ref
Gender			
Male	.806**	.391**	-.097**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.060	.413**	-.017
Higher professional	.210	.256**	-.008
Lower professional	-.592**	.251**	-.029
Non-manual	-.882**	-.052	.076**
Manual skilled	-.045	.571**	.014
Semi skilled	-.915**	.045	.092**
Unskilled	-.243	-.014	.152**
Self employed	.501**	.648**	-.069
Farmers	.926*	.145	-.715**
Agricultural workers	.058	-.362	-.463**
Other	Ref	Ref	Ref
Household Composition			
Single	.125	.234**	-.063**
Lone Parent with Children	.162	.206**	-.096**
Lone Parent no Children under 19	.072	.350**	.102**
Couple with Children	-.007	.394**	-.087**
Couple no Children under 19	.147	.360**	.020
Couple no Children	.176	.413**	-.025
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	.894**	.189*	.270**
Very affluent	.586	.255**	.145**
Affluent	.712*	.369**	.313**
Slightly above national average	.938**	.841**	.318**
Slightly below national average	.968**	.739**	.189**
Disadvantaged	.818*	.329**	.321**
Very disadvantaged	.787*	.573**	.237**
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	.774	2.367**	-.194
50-250 persons	.316	1.262**	-.019
250-1,000 persons	.449**	1.335**	-.073**
1,000-5,000persons	.398**	.657**	.060**
5,000+ persons	Ref	Ref	Ref
Number of Cases	350,437		
Nagelkerke R-squared	.043		
Log Likelihood	75526.744		

** Significant at 1%, *Significant at 5%

Table 5-24: MNL model results (WBR Dataset: Medium CO_2 price - €16.70)

Variable	Large negative change	Marginal negative change	Marginal positive change
Intercept	-4.083**	-2.335**	1.208*
Age			
15-24	.903**	.882**	.092
25-34	1.417**	1.145**	.037
35-44	1.176**	.983**	.048
45-54	.823**	.827**	.125*
55-64	.448*	.512**	.114
65+	Ref	Ref	Ref
Gender			
Male	.744**	.112	-.071**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.449**	.211**	-.126
Higher professional	.912**	.605**	-.076
Lower professional	.791**	.676**	-.096
Non-manual	-.150	-.043	-.232
Manual skilled	.073	.200**	-.099
Semi skilled	-.573**	-.017	-.170
Unskilled	-.454**	-.164**	-.205
Self employed	.148	-.108	-.401
Farmers	-1.091**	-.717**	-.413
Agricultural workers	-.734**	-.532**	-.231**
Other	Ref	Ref	Ref
Household Composition			
Single	.594**	.509**	.121**
Lone Parent with Children	.334**	.344**	.218**
Lone Parent no Children under 19	.598**	.530**	.187**
Couple with Children	.711**	.546**	.260**
Couple no Children under 19	.797**	.546**	.256**
Couple no Children	.983**	.692**	.181**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	N/a	N/a	N/a
Very affluent	-.769	-2.083*	.428
Affluent	-.926*	-.413**	-.110
Slightly above national average	-.358*	.403**	.057
Slightly below national average	-.308	.282**	-.024
Disadvantaged	-.594**	.130	.013
Very disadvantaged	-.401*	.021	.068
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	.789**	1.098**	-.255**
50-250 persons	.508**	.637**	-.187**
250-1,000 persons	.537**	.712**	.135**
1,000-5,000persons	Ref	Ref	Ref
5,000+ persons	N/a	N/a	N/a
Number of Cases	178,448		
Nagelkerke R-squared	.086		
Log Likelihood	63881.912		

** Significant at 1%, *Significant at 5%

5.3.4 MNL Regression Results in a High CO_2 Price Scenario - €28.73

This section presents the MNL model results for the high CO_2 price scenario of €28.73. The MNL model results for this scenario are presented for the national, Dublin and WBR datasets in Tables 5-25 to 5-27 respectively. Model performance improves from previous models with R-squared values of 0.115, 0.089 and 0.155 for the national, Dublin and WBR models. The WBR model maintains the lowest log-likelihood value.

The age category again indicates younger age groups to be more likely to have a negative change in all three models. This is the case for 25-44 year old groups in Dublin and the national models. In the WBR, 15-24 year olds are more likely to have a negative change than older age groups. Older individuals are also more likely to have a positive change in consumer surplus across all three models. The 55-64 and 65+ age groups are more likely to have a positive change than other outcomes particularly in the national dataset. This is due to the lower percentage share of these age groups who fall above the cap as identified in Chapter 4, section 4.5.

The likelihood of males having a negative consumer surplus change is also observed in this scenario. In all three models males are more likely to have both a LNC and a MNC than females. Females are also more likely to have a MPC than males.

Socio-economic group results do not vary greatly from the other two scenarios. Nationally and in the WBR, farmers and agricultural workers are the most likely groups to not have a negative consumer surplus change. This is not the case in Dublin where farmers are the most likely group to have a LNC. The likelihood of employers, managers and professionals having a LNC also falls in comparison to the low and medium price scenarios in all three models. As was observed in the previous scenarios, non-manual, semi-skilled and unskilled workers are unlikely to have a LNC across all three models with these grouping more likely to have a positive consumer surplus change.

In all three models, household composition is found to be a significant factor in determining welfare changes. The only exception to this is in Dublin where this variable is found to be insignificant in explaining a LNC. All groups are likely to have a MNC across all three models. In terms of having a positive consumer surplus change, all groups are unlikely to have this outcome particularly couples with dependent children.

The deprivation variable finds individuals in more affluent DED’s to be less likely than those in deprived DED’s to have a negative consumer surplus change. This is particularly the case in the WBR, which is found to have large negative beta coefficients in the affluent and above average categories. However, similar to the findings in the low and medium price scenarios, individuals in more affluent DED’s are more likely to have a negative consumer surplus change than those in disadvantaged DED’s in Dublin.

While the coefficients associated with the density variable are not as large as the low and medium CO_2 price scenarios, relatively larger beta coefficients in comparison to other independent variables are found for the density variable. Across all three models individuals living in DED’s with less than 50 persons per km^2 are more likely to have a negative consumer surplus change. Individuals with a positive welfare change are also more likely to live in densely populated DED’s than those in sparsely populated DED’s. Density is the most significant determinant of welfare changes in the high CO_2 price scenario.

Table 5-25: MNL model results (National Dataset: High CO_2 price - €28.73)

Variable	**Large negative change**	**Marginal negative change**	**Marginal positive change**
Intercept	-6.146**	-3.981**	.721**
Age			
15-24	.856**	.706**	.387**
25-34	1.252**	.885**	.015
35-44	1.021**	.751**	-.084**
45-54	.610**	.538**	-.066**
55-64	.274**	.310**	-.045*
65+	Ref	Ref	Ref
Gender			
Male	.720*	.236**	-.153**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.345**	.219**	-.387**
Higher professional	.543**	.313**	-.385**
Lower professional	.499**	.385**	-.353**
Non-manual	-.117**	-.015	-.165**
Manual skilled	.072*	.186**	-.271**
Semi skilled	-.380**	-.065**	-.082**
Unskilled	-.223**	-.066**	.082**
Self employed	.274**	.165**	-.347**
Farmers	-1.322**	-.862**	-.120**
Agricultural workers	-.987**	-.629**	-.082**
Other	Ref	Ref	Ref
Household Composition			
Single	.543**	.353**	-.225**
Lone Parent with Children	.203**	.140**	-.192**
Lone Parent no Children under 19	.348**	.286**	-.162**
Couple with Children	.460**	.351**	-.274**
Couple no Children under 19	.401**	.294**	-.234**
Couple no Children	.736**	.524**	-.248**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	-.547**	-.290**	-.427**
Very affluent	-.979**	-.158**	-.564**
Affluent	-.003	.509**	-.268**
Slightly above national average	.773**	.790**	-.129**
Slightly below national average	1.003**	.788**	-.098**
Disadvantaged	.718**	.642**	-.047
Very disadvantaged	.074	.299**	-.031
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	1.927**	1.639**	-.838**
50-250 persons	1.708**	1.513**	-.421**
250-1,000 persons	1.666**	1.252**	-.173**
1,000-5,000persons	.839**	.700**	-.125**
5,000+ persons	Ref	Ref	Ref
Number of Cases	1,212,306		
Nagelkerke R-squared	.155		
Log Likelihood	208630.400		

** Significant at 1%, *Significant at 5%

Table 5-26: MNL model results (Dublin Dataset: High CO_2 price - €28.73)

Variable	**Large negative change**	**Marginal negative change**	**Marginal positive change**
Intercept	-5.602**	-3.582**	.480**
Age			
15-24	.001	.139*	.644**
25-34	.096	.337**	.250**
35-44	.040	.321**	.085*
45-54	-.003	.214**	.075*
55-64	-.324	.100	-.011
65+	Ref	Ref	Ref
Gender			
Male	.694**	.375**	-.210**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.157	.268**	-.379**
Higher professional	.226	.120**	-.319**
Lower professional	-.299*	.154**	-.276**
Non-manual	-.605**	-.100*	.017
Manual skilled	.214	.426**	-.274**
Semi skilled	-.238	-.008	.093**
Unskilled	.053	.019	.321**
Self employed	.737**	.530**	-.345**
Farmers	1.724**	.309	-.410**
Agricultural workers	.323	-.191	-.315*
Other	Ref	Ref	Ref
Household Composition			
Single	.033	.168**	-.251**
Lone Parent with Children	.013	.144**	-.318**
Lone Parent no Children under 19	-.007	.205**	-.142**
Couple with Children	-.059	.295**	-.407**
Couple no Children under 19	.012	.231**	-.259**
Couple no Children	.082	.312**	-.278**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	.559*	-.122	-.170**
Very affluent	.343	-.054	-.447**
Affluent	.460	.032	-.162**
Slightly above national average	.619*	.498**	-.199**
Slightly below national average	.772**	.514**	-.139**
Disadvantaged	.556*	.064	.004
Very disadvantaged	.766**	.364**	-.012
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	.953*	2.343**	-.478**
50-250 persons	.231	1.152**	-.354**
250-1,000 persons	.484**	1.195**	-.537**
1,000-5,000persons	.211**	.509**	-.260**
5,000+ persons	Ref	Ref	Ref
Number of Cases	350,437		
Nagelkerke R-squared	.089		
Log Likelihood	82685.532		

** Significant at 1%, *Significant at 5%

Table 5-27: MNL model results (WBR Dataset: High CO_2 price - €28.73)

Variable	**Large negative change**	**Marginal negative change**	**Marginal positive change**
Intercept	-3.745**	-2.728**	1.169**
Age			
15-24	1.091**	.919**	.297**
25-34	1.395**	1.048**	-.080
35-44	1.149**	.853**	-.151**
45-54	.772**	.675**	-.100
55-64	.401**	.410**	-.028
65+	Ref	Ref	Ref
Gender			
Male	.602**	.109**	-.075**
Female	Ref	Ref	Ref
Socio-economic group			
Employers and managers	.392**	.126**	-.348**
Higher professional	.787**	.438**	-.433**
Lower professional	.746**	.496**	-.496**
Non-manual	-.074	-.052	-.398**
Manual skilled	.048	.097*	-.385**
Semi skilled	-.412**	-.018	-.314**
Unskilled	-.232**	-.112*	-.198**
Self employed	.231**	-.034	-.464**
Farmers	-.772**	-.577**	-.355**
Agricultural workers	-.424**	-.446**	-.107
Other	Ref	Ref	Ref
Household Composition			
Single	.337**	.345**	-.180**
Lone Parent with Children	.190**	.097*	-.140**
Lone Parent no Children under 19	.329**	.318**	-.162**
Couple with Children	.335**	.275**	-.177**
Couple no Children under 19	.444**	.267**	-.166**
Couple no Children	.632**	.475**	-.181**
Other Households	Ref	Ref	Ref
Level of Deprivation in DED			
Extremely affluent	N/a	N/a	N/a
Very affluent	-1.850	-2.397*	-.706
Affluent	-1.028**	-.385**	-.380**
Slightly above national average	-.439**	.474**	-.040
Slightly below national average	-.340**	.361**	-.113
Disadvantaged	-.619**	.220*	-.042
Very disadvantaged	-.458**	.060	.022
Extremely disadvantaged	Ref	Ref	Ref
DED Density per km^2			
0-50 persons	.545**	.776**	-1.118**
50-250 persons	.311**	.435**	-.681**
250-1,000 persons	.359**	.546**	-.120**
1,000-5,000persons	Ref	Ref	Ref
5,000+ persons	N/a	N/a	N/a
Number of Cases	178,448		
Nagelkerke R-squared	.115		
Log Likelihood	69545.917		

** Significant at 1%, *Significant at 5%

The MNL models confirm that density of population is an important factor in explaining the determinants of welfare changes. To a lesser extent levels of deprivation are also a determinant in welfare changes for the medium and high price scenarios. In the low CO_2 price scenario, deprivation was found to be less significant a determinant than other variables. The gender variable consistently found males to be more likely to have larger welfare losses than female in all three scenarios, while individuals with dependent children were found to be likely to experience larger welfare losses. Individuals aged between 25 and 44 were also consistently the most likely individuals to have a negative welfare change. This result is expected in a dataset detailing commute trip as the bulk of the workforce is drawn from this age group. Socio-economic grouping was mostly inconclusive in each scenario, with only non-manual and unskilled workers the most likely individuals to have a positive welfare change in all scenarios. Employers and managers, higher professionals and lower professionals were also consistently likely to have negative changes in welfare in each scenario. Beta coefficients for individuals likely to have negative changes were also consistently higher in the WBR compared to Dublin, indicating a greater likelihood of losses in the rural region.

5.4 SUMMARY

This chapter evaluated the welfare effects of introducing a PCTS on the end users of transport in Ireland. Issues relating to the complexities and administrative challenges of introducing such a scheme are researched further in the subsequent Chapter 6.

A consumer surplus analysis was used to determine welfare changes based on daily travel costs and the pre-PCTS and post-PCTS price of CO_2. This consumer surplus change was then compared across population density deciles in each region to determine whether the loss to commuters was greater in sparsely populated areas. The results of this analysis show that commuters in rural regions would be worse off than commuters in urban areas as a result of introducing a PCTS. Moreover, the most deprived areas as measured on a scale of deprivation were found to bear a greater welfare loss as a result of introducing the scheme in the WBR.

A MNL model then analysed some important socio-economic variables to ascertain the determinants of welfare changes. This analysis confirmed the importance of living in a sparsely populated region as a determinant of an individual having a negative welfare change. Having dependent children and being in the 25 to 44 year old age group were also found to be highly significant in explaining negative welfare changes.

6. DESIGN AND IMPLEMENTATION OF A PERSONAL CARBON TRADING SCHEME

6.1 INTRODUCTION

The previous chapters have discussed the research relating to carbon trading and have also determined the potential welfare effects of a downstream PCTS. This chapter will outline the current research on the implementation of a PCTS, the structure of a potential scheme and the costs involved in introducing such a scheme in Ireland. A scenario analysis was also conducted to determine the effects of a modal switch to alternative modes transport on permit allocations across all Irish regions.

This chapter will proceed with a discussion of the potential steps involved in implementing and regulating a PCTS in section 6.2. Section 6.3 discusses the transactions and potential CO_2 permit allocations in an initial trading phase. Section 6.4 presents a scenario analysis of permit allocation changes in the event of a modal switch from private vehicles to cycling, walking or public transport. This scenario analysis uses a similar methodology to that used in Farrell et al. (2010). Section 6.5 summarises the findings presented in this chapter.

6.2 POTENTIAL FRAMEWORK OF A PERSONAL CARBON TRADING SCHEME

This section assesses the options for the introduction of a PCTS scheme and determines the potential market outcomes of introducing this scheme.

6.2.1 International Research

As the potential PCTS scheme examined in this research is downstream based it is useful to examine the structure of downstream schemes advocated in previous literature. Comhar (2008a) recommended a phased introduction of a trading scheme as the most appropriate course of action to acclimatise the population to 'counting their carbon' and also to iron out any systematic and regulatory problems. A further report commissioned by Comhar (2008b) recommended the introduction of a scheme within the transportation sector initially with the extension to other sectors in due course. While this report advocates a hybrid cap-and-share approach over a purely downstream scheme mainly due to administrative simplicity, a number of international studies mainly in the UK and Denmark have advocated a downstream scheme. Fawcett is one of the more prolific authors in the area of personal carbon trading (Fawcett, 2005, Fawcett, 2010, Fawcett et al., 2007, Fawcett et al., 2010). The research to date by the author has focused on the viability of introducing such a scheme and the public perception of rationing carbon in the UK. The details of these studies will be discussed in more detail in this chapter. Roberts and Thumim (2006) published a guide to personal carbon allocation (PCA) schemes which identifies the need for research into public acceptability, feasibility and the welfare effects of such schemes. PCA schemes are downstream schemes similar to the PCTS scheme researched in this thesis. Fawcett (2005) described the results of a survey of individual transport emissions as a precursor to piloting a PCA scheme. This found a sizeable variation between the smallest and largest emitters emphasising the need for a fully operational market within any scheme and the potential difficulties of the highest emitters in reducing their emission to the national average.

This research was followed by UK Government funded studies into the potential workings of a PCA scheme. Research conducted by The Department for the Environment (DEFRA) concluded that no 'insurmountable technical obstacles' exist in setting up such a scheme (DEFRA, 2008). The main caveats of PCA identified in the research were public acceptability of such a scheme (deemed surmountable by Fawcett, 2008), the large monetary costs of establishing a scheme and the technology available to monitor emissions. Fawcett et al. (2007) described a potential phased introduction of a PCA scheme through a trial period of up to two years in which individuals across varying socio-economic groups would participate in a trial scheme with CO_2 allowances as means of monitoring the effectiveness of the scheme. This approach would also acclimatise individuals to the workings of the scheme. Again the only caveat to this approach identified was the initial start up costs; however, the benefits of a ‘dry run’ of the scheme before full implementation would be beneficial in the long run in researching the effectiveness of this type of downstream scheme (Fawcett et al., 2007). Fawcett et al. (2007) recommended online personal administration of the scheme and the use of existing monitoring technologies to calculate emissions. These technologies include electric meters, vehicle odometers and travel smart cards. Recent research in the UK has also recommended serious consideration for using downstream schemes as part of overall climate change strategy concluding such a scheme be as socially acceptable as carbon taxation (Fawcett, 2010, Brand and Preston, 2010).

The implementation of a potential PCTS in Ireland can be recommended. This would entail the following steps and structures:

1. An independent body setting annual cap levels in line in Ireland’s international commitments.
2. An initial trial period to educate and acclimatise individuals to the workings of a scheme.
3. A free allocation of permits equally to individuals based on Personal Public Service (PPS) numbers.
4. A corresponding carbon account similar to a bank account of carbon usage.
5. Creation of a market for carbon in which individual can buy and sell as required.

The following subsections will expand on each of steps identified above.

6.2.2 Independent Regulation

An independent body already established such as the EPA or a new dedicated body would be responsible for the establishment, regulation and enforcement of a PCTS. This body would require expertise in accurately measuring CO_2 emissions as the EPA is currently responsible for in Ireland, and would also need to liaise with law enforcement agencies to administer the CO_2 cap. According to economic theory, the institution of any new market will yield ‘free riding’ in which some individuals cheat the system and do to pay for their CO_2 output. This problem will exist unless systems are perfectly designed to deter this behaviour and rules are not strictly enforced. With this in mind, a trial period and phased implementation of a scheme to remedy any flaws in the system would be necessary. This approach has been advocated in international research as a means of familiarising the population with the concept of CO_2 as a currency (Fawcett et al. 2007).

6.2.3 Phased Introduction

The need to introduce any new scheme on a phased basis is a necessity to acclimatise individuals to the system (Comhar, 2008a; Fawcett et al. 2007). This scheme would begin with a trial period of a minimum of one year during which a sample of the population would participate in a market surrendering permits to value of their emissions. No monetary transactions would occur during this ‘dry run’ period. Once this trial period has reached a conclusion the institution of the scheme would initially cover personal transportation trips. Fawcett et al (2007) recommend a conservative approach of covering only private vehicle trips initially because to the difficulty of calculating public transport emissions due to variable occupancy rates which would alter personal emissions. This approach however could be perceived as inequitable by individuals constrained to using private vehicles. However, it would incentivise individuals to use public transport during the initial phase of trading with public transport trips being covered after a period of time of up to five years (Harwatt, 2008). Within the research presented in this thesis, public transport trips are subject to the PCTS due to the inequity issues identified by Harwatt (2008). Providing an incentive to use public transport by not including it in the PCTS would be inequitable for individuals unable to switch to this mode. This is because individuals who do use public transport do not use any of their carbon allocation in doing so. The introduction of the scheme to other sectors such as air travel, home energy markets and agriculture would also take place over a 5 to 7 year period (Comhar, 2008b).

6.2.4 Free Allocation of Permits

In order to ensure equity in the system permits must be allocated freely and equally to all individuals. Previous research has advocated an auction of permits to agents (Cramton and Kerr, 2002), however this assertion is premised on the assumption of permits being distributed upstream to large polluting entities. Downstream allocation necessitates a free allocation of permits to each individual (Harwatt, 2008). Research suggests providing a half allocation to individuals under the age of 17 (Starkey and Anderson, 2005, Fawcett et al., 2007, Harwatt, 2008) as these individuals account for a smaller percentage of emissions. The analysis in this thesis does not include for children and assumes a full allocation of permits to each individual. This is due to the fact that only persons of working age are included in the POWCAR dataset. In practise however a half allocation would be the most equitable measure, but further research would need to be conducted on this in Ireland. A yearly cap level would be set by the independent regulatory body which would be progressively lowered in line with Ireland's emission targets and the corresponding number of permits released to the market. Harwatt (2008) recommended the release of permits on a phased basis every quarter annum to avoid individuals 'stockpiling' permits which can distort the market price. This body could also hold a percentage of permits which would be sold to individuals in deficit at the end of each trading period at the market price and would fund the administration of the scheme. The scheme could also be funded through transaction charges within the market administered by financial intermediaries who would then pass on a percentage of this transaction fee to the regulatory body to cover costs.

6.2.5 Carbon Accounts

Existing current account and smart card technologies can be used to provide easy access to information and transaction for individuals. Each individual would therefore be allocated a carbon account of which they can access in real-time. The success of the scheme would hinge on this real-time information being available to access online or via the designated agents in order for individuals to determine their surplus or deficit of CO_2. Quarterly statements of account would also be provided by the central regulatory body as allocations of permits are released. These carbon accounts could also be administered in conjunction with current accounts or an individual's utility bills (Fleming, 1997). If administered by financial institutions, transaction fees would cover the administration of the scheme, or if administrated by the regulatory body in isolation, up to 50% of permits would be required to be sold centrally to cover administration and enforcement of the scheme.

6.2.6 Carbon Market

The recent introduction of carbon trading schemes in New Zealand and Australia has initially set a fixed price for CO_2 (see Chapter 2, section 2.9). Setting a fixed price during the first phase of trading would provide certainty for individuals acclimatising to using carbon as a currency. This fixed price would then transition to a quasi free market scenario in which the price would float between a price floor and ceiling as is the case in Australia and New Zealand. The next phase of trading could involve trading of permits within a progressively increasing range. A price floor in particular would guard against an oversupply of permit and the risk that the market price could fall below the equilibrium price on international markets; thus providing an incentive to emit more CO_2. Eventually, the market would be free to determine the equilibrium price once the correct allocation and rationing of permits is determined. This scheme would link in to international trading schemes, particularly the EU ETS. The following sections will analyse the transactions required in an initial phase of fixed price trading based on price of carbon of €16.70[5]. This price is taken from current European carbon market prices linked to the EU ETS in September 2011.

6.3 TRANSACTIONS WITHIN A PERSONAL CARBON TRADING SCHEME

Within a working scheme it is useful determine the number of transactions which could potentially take place and the potential surplus or deficit of permits which may occur based on the overall cap level. Section 6.3.1 will determine the number of transactions required within an initial fixed price market (€16.70) based on quarterly trading activity while varying CO_2 permit denominations. A breakdown of permit distribution will also be estimated amongst socio-economic groups in section 6.3.2. Once again it should be noted that these transactions are restricted to trips to work and

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[5] EUA 'Dec 2011' market price on the 16th June 2011. Prices obtained from www.pointcarbon.com

if the scheme were introduced it would also include non-work trips which would increase the number of transactions.

6.3.1 Quantity of CO_2 Permits in a PCTS

Table 6-1 and 6-2 present transaction statistics for two different cap scenarios: a cap set at average emissions and a cap lowered 20% under the average. These cap levels are identical to the scenarios outlined in Chapter 4. If it is assumed that transactions occur every quarter with a range of permits levels (varying by kgs per permit), the number of transactions required by individuals with a surplus and deficit of CO_2 can be estimated. In addition, transactions costs can also be determined based on the number of transactions calculated. As detailed in section 6.2, research has recommended a quarterly allocation of permits to guard against an oversupply if one annual round of allocations took place. Four rounds of allocations per annum provide flexibility for the regulatory authority to react to any market changes in which large surpluses or deficits may arise. It must be noted that transaction are assumed to remain constant in each quarter. In reality seasonality effects may change the volume of transaction.

In each cap scenario, permits are divided into four separate denominations: 5kg, 10kg, 20kg and 25kg permits. Providing set levels of permits aids administrative simplicity for individuals and the regulatory authority in the market. To determine the number of surplus or deficit permits per quarter, the following equation is used:

$$Surplus \;/\; Deficit = \frac{QCO_2 - \mu \, CO_2}{PD} \qquad \text{(Eq. 6.1)}$$

Where QCO_2 is total quarterly CO_2 emissions and μCO_2 is mean quarterly CO_2 emissions. This is divided by the PD, the relevant permit denomination, to determine the number of transactions required. An identical process is repeated for the lower cap with a 20% reduction on the mean value. Individuals with a ‘negative excess’ (below zero) have a deficit while those with a ‘positive excess’ (above zero) possess a surplus. Using this equation, an estimate of the number of transactions per quarter and the deficit/surplus ratio can be obtained.

Table 6-1 presents the average number of transactions individuals would require to clear a surplus or make up a deficit at each permit denomination. The larger the denomination of CO_2 permits, the lower the number of transactions required. This in turn would reduce transaction costs which are assumed to be in the region of 7 – 11% (Comhar, 2008a). The sum total of transactions illustrated in Figure 6-1 shows that individuals with a deficit and those with a surplus are evenly matched across each permit denomination in the average cap scenario.

Table 6-1: Number of quarterly transactions required based on average emissions cap

	5kg permit deficit	5kg permit surplus	10kg permit deficit	10kg permit surplus	20kg permit deficit	20kg permit surplus	25kg permit deficit	25kg permit surplus
No. Trans	399,820	1,148,898	399,820	1,148,898	399,820	1,148,898	399,820	1,148,898
Mean	98	34	49	17	25	9	20	7
Std. Dev	168	13	84	7	42	3	34	3
Variance	28,257	177	7,064	44	1,766	11	1,130	7
Max	1,315	48	657	24	329	12	263	10
Total Permits (000)	39,215	39,450	19,607	19,725	9,803	9,862	7,843	7,890

Figure 6-1: Total quarterly transactions required based on average emissions cap

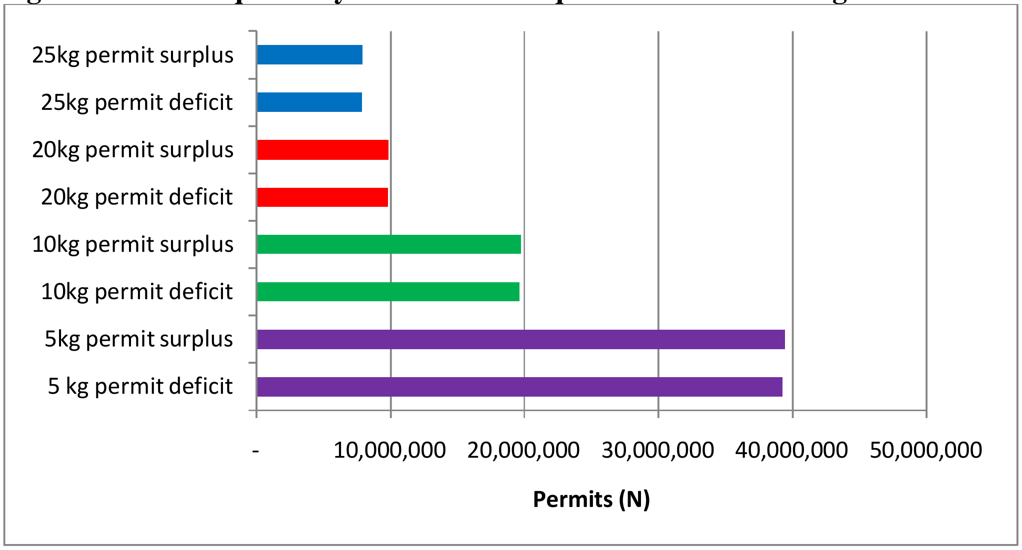
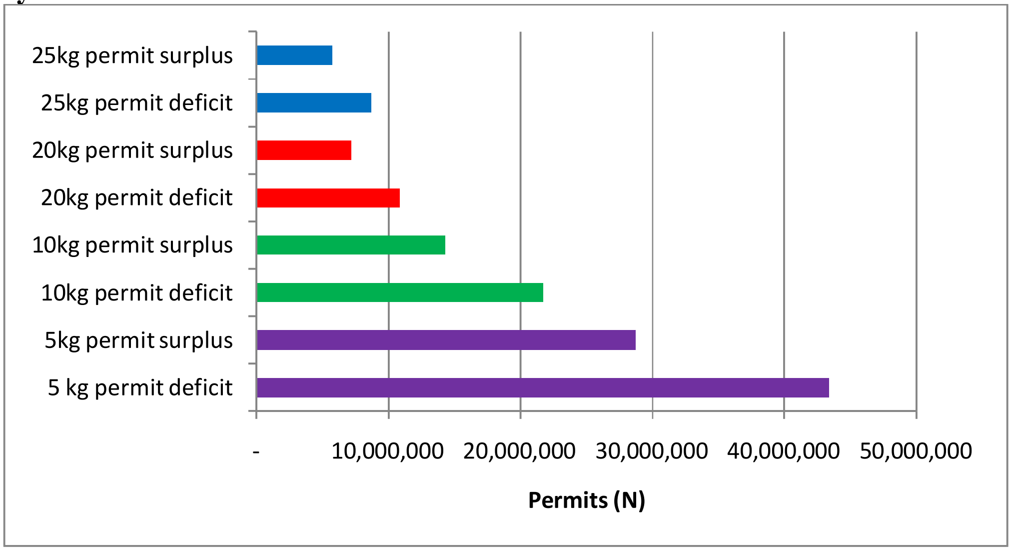


Table 6-2 presents the number of transactions required in the event of the cap being lowered buy 20%. While the average number of permits required in each category is lower than the average cap, the total number of permits required to service a deficit has increased considerably. The disparity between the total number of surplus and required permits has also widened as the cap lowers. This disparity is illustrated in Figure 6-2. Lower denominations of permits requiring more transactions lead to a greater disparity between the total number of surplus permits and required permits.

Table 6-2: Number of quarterly transactions required based on cap lowered by 20%

	5kg permit deficit	5kg permit surplus	10kg permit deficit	10kg permit surplus	20kg permit deficit	20kg permit surplus	25kg permit deficit	25kg permit surplus
No. Trans	499,913	1,048,805	499,913	1,048,805	499,913	1,048,805	499,913	1,048,805
Mean	87	27	43	14	22	7	17	5
Std. Dev	156	11	78	5	39	3	31	2
Var	24,352	112	6,088	28	1,522	7	974	4
Max	1,324	38	662	19	331	9	265	8
Total Permits (000)	43,387	28,688	21,693	14,344	10,846	7,172	8,677	5,737

Figure 6-2: Total quarterly transactions required based on average cap lowered by 20%



One of the largest costs associated with the introduction of a PCTS is the administration cost. This section estimates the likely cost of administration of a PCTS in Ireland for travel-to-work trips. Assuming that transaction costs incurred would be between 7% -11% as predicted by Comhar (2008a), approximate costs for the low, medium and highest scenarios can be estimated for the total number of transactions. This is tabulated in Table 6-3. Quarterly and annual transaction costs are determined for the average emissions cap and the cap lowered by 20%. As the number of transactions required in total increases when the cap is lowered, transactions cost slightly increase in this scenario. This is a static estimate however and one could assume that individuals would lower their CO_2 emissions in the event of a lowered cap, negating much of the increase in transactions and costs. The equation used to determine transaction costs is as follows:

$$TC = (CO_2.P).\mathrm{T_i} \qquad \text{(Eq. 6.2)}$$

Where TC is transaction costs, CO_2 is the level of carbon emitted in kg, P is the price of CO_2, in this case the fixed price of €16.70/tonne (EUA price as of September, 2011) and T_i are percentage costs levied with each transaction. Transaction costs are calculated for a low, medium and high cost scenario in Table 6-3.

Table 6-3: Transactions Costs

% of transaction cost	Average Cap Quarterly Transaction Cost (€)	Average Cap Annual Transaction Cost (€)	Lowered 20% Cap Quarterly Transaction Cost (€)	Lowered 20% Cap Annual Transaction Cost (€)
7%	230,590	922,360	253,599	1,014,396
9%	296,473	1,185,892	326,056	1,304,224
11%	362,356	1,449,424	398,513	1,594,052

The transaction costs are based on the optimum 25kg permit allocation which yields the lowest number of transactions. The highest quarterly transaction cost is in the average cap scenario which is found to be with an 11% transaction cost and lowered cap corresponding to €1.5 million per annum.

6.3.2 Socio-economic Division of Permits in a PCTS

In previous chapters the socio-economic characteristics of individuals above the cap were examined. Again in this chapter it is informative to breakdown the transactions further to determine the mean and total number of transactions occurring in each group. In this case the 25kg permit is analysed in isolation as it would be superfluous to repeat the process on each permit level as before yielding the same absolute results. Quarterly CO_2 averages are also tabulated in this case to determine a mean surplus (S) or deficit (D) across each socio-economic group. These results are then compared across the two cap scenarios: a cap based on average national emissions and the cap level lowered by 20%. These cap levels are the identical to those utilised in the socio-economic studies in previous chapters.

Table 6-4 divides the permits into constituent deficit (D) and surplus (S) allocations for both cap scenarios in each socio-economic group. The groups with the largest surplus are non-manual workers and farmers who on average have a surplus allocation of CO_2 of 100kg and 137 kg respectively per quarter. Observing population size, the largest group of individuals are non-manual worker who have a mean surplus of CO_2. The next largest group, lower professionals also have a mean surplus, albeit a considerably lower mean than non-manual workers at 46 kg per quarter. In terms of permits required, the group with the lowest mean deficit of permits required are semi-skilled workers (17 permits), while own account workers, owing to their large mean deficit of CO_2, require the largest number of permits on average (39 permits). In contrast, individuals with a surplus vary little between groups with the average surplus ranging from 6 to 9 permits per person each quarter. The groups with the largest mean deficit of CO_2 are manual skilled workers and own account workers who on average exceed the cap by 202 kg and 290 kg respectively.

Table 6-4: Breakdown of permit totals by socio-economic group (Average emissions cap)

Socio-economic Group	**Quarterly Excess CO_2**		**Quarterly Deficit (25 Kg Permit)**				**Quarterly Surplus (25 Kg Permit)**			
	N	**Mean***	**Mean**	**Std Dev**	**Total permits (000)**	**Max**	**Mean**	**Std Dev**	**Total permits (000)**	**Max**
Employers and Manager	27,9158	47.5 **(D)**	21	35	1,581	263	6	3	1,114	10
Higher Professional	123,806	48.6 **(S)**	12	19	350	255	7	3	574	10
Lower Professional	235,307	46.2 **(S)**	11	16	617	252	6	3	1,015	10
Non-Manual	447,790	100.4 **(S)**	10	16	699	260	7	3	2,272	10
Manual skilled	222,240	202 **(D)**	30	44	2,202	260	6	3	699	10
Semi-skilled	188,644	40.7 **(S)**	17	32	610	260	7	3	873	10
Unskilled	73,316	21.3 **(D)**	28	44	387	257	7	3	335	10
Own account workers	93,480	290.7 **(D)**	39	47	1,017	257	7	3	271	10
Farmers	69,688	137.7 **(S)**	26	39	113	254	9	2	367	9
Agricultural workers	12,508	17.8 **(S)**	27	44	53	238	7	3	60	10
All others gainfully occupied	87,711	43.5 **(S)**	20	34	214	257	7	3	304	10

* D = Deficit, S = Surplus

Lowering the cap by 20% in Table 6-5 brings the majority of groups into deficit on average. Three groups remain in surplus on average in this scenario. These are groups are; higher professionals, non-manual workers and farmers. The group with the largest mean surplus of CO_2 is again farmers (90 kg). Own account workers and manual skilled groups have the largest mean deficit with 339kg and 250kg respectively per quarter. The group with the largest mean deficit of permits are own account workers with an average deficit of 36 permits per quarter. The mean level of surplus permits for remains within a small range of 5 to 7 permits per quarter across each group and this variation has reduced in response to the cap being lowered. The standard deviation is calculated at 2 across every group except one demonstrating the low level of variance.

Table 6-5: Breakdown of permit totals by socio-economic group (Cap lowered by 20%)

Socio-economic Group	**Quarterly Excess CO_2**		**Quarterly Deficit (25 Kg Permit)**				**Quarterly Surplus (25 Kg Permit)**			
	N	**Mean***	**Mean**	**Std Dev**	**Total permit(000)**	**Max**	**Mean**	**Std Dev**	**Total permits (000)**	**Max**
Employers and Manager	279,158	95.7 **(D)**	19	33	1,734	265	5	2	794	7
Higher Professional	123,806	.36 **(S)**	11	17	411	257	5	2	413	7
Lower Professional	235,307	2.1 **(D)**	10	15	741	254	5	2	723	7
Non-Manual	447,790	52.2 **(S)**	9	15	851	262	6	2	1,669	7
Manual skilled	222,240	250 **(D)**	27	42	2,352	262	5	2	490	7
Semi-skilled	188,644	7.5 **(D)**	15	29	685	262	5	2	637	7
Unskilled	73,316	69.5 **(D)**	25	41	415	259	6	2	249	7
Own account workers	93,480	338 **(D)**	36	46	1,069	259	6	2	20	7
Farmers	69,688	89.5 **(S)**	23	37	121	257	7	1	287	7
Agricultural workers	12,508	30.4 **(D)**	23	41	57	240	6	2	44	7
All others gainfully occupied	87,711	4.8**(D)**	18	32	236	259	6	2	226	7

* D = Deficit, S = Surplus

The data is also divided by gender, age and regional location to determine any other discernable geographical or demographic differences across the population. Table 6-6 presents the quarterly breakdown of permits by gender for both cap scenarios. In this dataset males outnumber females 1.3 to 1. With the cap based on average emissions, males on average have a deficit of CO_2 of 77kg while females have a surplus of 101kg per quarter. Males with a deficit on average require 25 permits per quarter in comparison to 8 permits per female. The mean number of permits in surplus for both groups is 7 per quarter. Lowering the cap by 20% reduces female mean surplus but the group retains a quarterly surplus of 52kg of CO_2. Male's mean deficit increases to 125kg of CO_2. Despite the rise in the CO_2 deficit, males on average require fewer permits to service this shortfall with 22 permits required on average. Females also have marginally more surplus permits than males with a lowered cap with the average female having 7 surplus permits to 6 permits for males.

Table 6-6: Breakdown of permits by gender

Average Cap	**Quarterly Excess CO_2**		**Quarterly Deficit (25 Kg Permit)**				**Quarterly Surplus (25 Kg Permit)**			
	N	**Mean***	**Mean**	**Std Dev**	**Total Permits (000)**	**Max**	**Mean**	**Std Dev**	**Total permits (000)**	**Max**
Male	1,049,745	76.95 **(D)**	25	39	6,784	263	7	3	4,097	10
Female	783,903	101.11 **(S)**	8	10	1,059	238	7	3	3,792	10
Lowered Cap	**Quarterly Excess CO_2**		**Quarterly Deficit (25 Kg Permit)**				**Quarterly Surplus (25 Kg Permit)**			
	N	**Mean***	**Mean**	**Std Dev**	**Total Permits**	**Max**	**Mean**	**Std Dev**	**Total Permits**	**Max**
Male	1,049,745	125.17 **(D)**	22	37	7,341	265	5	2	2,971	7
Female	783,903	52.90 **(S)**	8	9	1,336	240	6	2	2,766	7

* D = Deficit, S = Surplus

Analysing the results in each age group (Table 6-7) shows the majority of group to have a surplus. The exceptions to this finding are the 25-24 and 35-44 age groups, who also account for over 50% of the dataset. The group with the largest deficit is the 35-44 year olds with a 34kg of CO_2 deficit per quarter. As would be expected for a dataset detailing commute trips, the 75+ group has the largest surplus. Within the groups of working age the 15-24 and 35-44 have the largest surplus. Mean surplus and deficit permit level vary little amongst groups in the range of 17- 21 deficit permits and 7-8 surplus permits.

Table 6-7: Breakdown of permits by age group (Average emissions cap)

Age Group	Quarterly Excess CO_2		Quarterly Deficit (25 Kg Permit)				Quarterly Surplus (25 Kg Permit)			
	N	Mean*	Mean	Std Dev	Total permits (000)	Max	Mean	Std Dev	Total permits (000)	Max
15-24	232,682	52.8 **(S)**	19	33	725	255	7	3	1,133	10
25-34	549,664	13.1 **(D)**	19	33	2,560	260	7	3	2,313	10
35-44	456,982	34.5 **(D)**	21	35	2,373	260	7	3	1,831	10
45-54	362,930	6.5 **(S)**	19	33	1,487	257	7	3	1,568	10
55-64	199,435	39.7 **(S)**	19	33	641	263	7	3	897	10
65-74	26,743	99.7 **(S)**	20	33	50	238	8	2	125	10
75+	5,211	159.5 **(S)**	17	29	3	210	8	2	22	9

* D = Deficit, S = Surplus

The reduced cap brings the 45-54 and 55-64 groups into deficit leaving the majority of groups of working age in deficit. Table 6-8 shows that the 35-44 age group retain the largest mean deficit of 82kg per quarter with permit levels for all groups remaining within a narrow band.

Table 6-8: Breakdown of permits by age group (Cap lowered by 20%)

Age Group	Quarterly Excess CO_2		Quarterly Deficit (25 Kg Permit)				Quarterly Surplus (25 Kg Permit)			
	N	Mean*	Mean	Std Dev	Total permits	Max	Mean	Std Dev	Total permits	Max
15-24	232,682	4.60 **(S)**	17	31	806,064	257	6	2	841,561	7
25-34	549,664	61.31 **(D)**	17	31	2,837,249	262	5	2	1,680,006	7
35-44	456,982	82.68 **(D)**	18	32	2,614,533	262	5	2	1,314,661	7
45-54	362,930	41.69 **(D)**	17	31	1,647,934	259	5	2	1,132,902	7
55-64	199,435	8.46 **(D)**	17	30	711,130	265	6	2	656,761	7
65-74	26,743	51.44 **(S)**	17	30	56,220	240	6	2	94,441	7
75+	5,211	111.26 **(S)**	14	26	4,350	212	7	2	17,355	7

* D = Deficit, S = Surplus

Studying the results divided into geographical regions (Table 6-9) reveals Dublin as the only region with a mean surplus of permits. The midland region has the largest deficit with 108kg of CO_2. The Border and Western regions which were used as one study area in previous chapters also have large mean deficits of 64kg and 56kg respectively. This is in stark contrast to the Dublin region which has a large mean surplus of 124kg per quarter. Individuals in the midlands also require the largest number of permits per quarter (26 permits) on average with Dublin requiring the lowest (12 permits). Surplus permit averages are all but identical across each region.

Table 6-9: Breakdown of permits by region (Average Emission Cap)

Region	Quarterly Excess CO_2		Quarterly Deficit (25 Kg Permit)				Quarterly Surplus (25 Kg Permit)			
	N	Mean*	Mean	Std Dev	Total permits	Max	Mean	Std Dev	Total permits	Max
Border	190,087	63.87 **(D)**	24	39	1,160,053	260	7	3	753,376	10
Dublin	539,851	124.17 **(S)**	12	21	598,102	257	7	3	2,832,201	10
Mid-East	219,160	96.04 **(D)**	18	31	1,431,794	260	6	3	705,335	10
Midland	107,092	108.50 **(D)**	26	41	787,601	257	7	3	398,695	10
Mid-West	151,991	15.86 **(D)**	18	31	707,819	257	7	3	625,215	10
South-East	191,460	36.32 **(D)**	23	37	1,037,508	263	7	3	800,669	10
South-West	261,755	1.99 **(D)**	18	31	1,113,125	255	7	3	1,095,382	10
West	172,251	56.42 **(D)**	22	36	1,007,192	257	7	3	67,9288	10

* D = Deficit, S = Surplus

Under the lowered cap scenario (Table 6-10) Dublin commuters maintain a large surplus of 75kg while Midland deficits increase to an average of 156kg. The Western and Border regions also have increased deficits of 104kg and 112kg respectively. These geographical divisions exhibit the benefits to commuters living within the urbanised Dublin region under both cap scenarios.

Table 6-10: Breakdown of permits by region (Cap lowered by 20%)

Region	Quarterly Excess CO_2		Quarterly Deficit (25 Kg Permit)				Quarterly Surplus (25 Kg Permit)			
	N	Mean*	Mean	Std Dev	Total permits	Max	Mean	Std Dev	Total permits	Max
Border	190,087	112.09 **(D)**	22	37	1,260,842	262	5	2	547,195	7
Dublin	539,851	75.95 **(S)**	9	18	709,992	259	6	2	2,076,610	7
Mid-East	219,160	144.25 **(D)**	17	29	1,593,456	262	5	2	502,302	7
Midland	107,092	156.71 **(D)**	23	39	850,651	259	5	2	288,923	7
Mid-West	151,991	64.08 **(D)**	17	29	788,706	259	6	2	455,023	7
South-East	191,460	84.54 **(D)**	20	35	1,133,042	265	5	2	581,824	7
South-West	261,755	50.21 **(D)**	16	29	1,239,536	257	5	2	792,654	7
West	172,251	104.64 **(D)**	20	34	1,101,255	259	5	2	493,152	7

* D = Deficit, S = Surplus

6.4 MODAL SWICTH SCENARIO ANALYSIS

This section will estimate the potential impact of a modal switch from private vehicles to other modes on CO_2 permit allocations. Three modal switch scenarios are analysed in this section; a 20% switch away from private vehicles, a 15% switch and 10% switch. Within each scenario a switch from private vehicles to public transport, cycling and walking are also analysed. As was discussed in Chapter 2, the stated target of the Irish Government is a reduction from 65% to a 45% modal share for private vehicles and an increase in modal share of public transport, walking and cycling to 55% of total trips (Dept. of Transport, 2009). The 20% scenario therefore is based on this target as the 'optimal' scenario, while the 15% and 10% are potential 'sub optimal' scenarios. A caveat to this analysis is that these modal shifts are not assumed to be a reaction to the PCTS but as a result of other policies. In order to determine the estimated modal shift arising from a PCTS would potentially require further market research in the form of a stated preference study. This was deemed to be outside the scope of the research presented in this thesis.

Table 6-11 outlines the range of trips targeted for a modal switch from private vehicle and the number of quarterly km travelled in each range. Trips below 2km are targeted for a switch to walking, while trips ranging between 2km and 5km are targeted for a switch to cycling. Trips between 5km and 40km are targeted for public transport modes of bus and rail. Trips within these three ranges account for 94% of total private trips tabulated in the POWCAR dataset. Private vehicle trips travelled within the targeted walking range account for 2% of total trips, while private vehicle trips within the targeted cycling range account for 6%. The remaining 92% of private vehicle trips are targeted for a switch to public transport.

Table 6-11: Details of modal switch from private vehicles

Trip range	Total Quarterly Private Vehicle KM	%	Number of Persons	Switch to:
0 – 2 km	20,343,838	2	120,266	Walking
2 – 4 km	80,361,195	6	184,121	Cycling
5- 40 km	1,149,242,403	92	635,804	Public Transport
Total	1,249,947,436	100	940,191	

Breaking down these trips further by region in Table 6-12 shows the bulk of kilometers travelled which can be targeted to switch mode are in the Dublin region. The Dublin region accounts for 21% of all km travelled. The Mid-East and South-West have the second highest share of trip km at 16% each. Within each range, Dublin accounts for 20% of trip km less than 2km, 31% of trip km between 2km and 5km and 20% of trip km between 5km and 40km. Thus within each scenario, trip km reductions in Dublin would account for 20-30% of total modal shift changes in each range.

Table 6-12: Breakdown of quarterly private vehicle KM by region

Region	Walk (0 – 2km)	%	Cycle (2-4km)	%	Public Transport (5km – 40km)	%	Total km	Total %
Border	2,738,885	13	8,779,955	11	118,213,988	10	129,732,828	10
Dublin	4,046,515	20	24,883,348	31	234,650,785	20	263,580,648	21
Mid-East	1,963,488	10	6,183,185	8	192,839,198	17	200,985,870	16
Midland	1,428,245	7	4,231,845	5	68,609,080	6	74,269,170	6
Mid-West	1,952,523	10	7,361,493	9	111,548,235	10	120,862,250	10
South-East	2,861,973	14	8,879,393	11	121,781,590	11	133,522,955	11
South-West	3,167,595	16	12,164,593	15	182,056,733	16	197,388,920	16
West	2,184,615	11	7,877,385	10	119,542,795	10	129,604,795	10
Total	20,343,838	100	80,361,195	100	1,149,242,403	100	1,249,947,436	100

Table 6-13 details the potential private VKM reductions from a modal switch in each of the three scenarios. The potential VKM reductions are also sub-divided by each target mode. As 92% of targeted private vehicle km fall within the 5 to 40km range, public transport trips have the potential to increase by up to 115 million km/quarter in the optimal 20% switch scenario. Walking has the potential to increase by up to 4 million km/quarter and cycling by up to 16 million km/quarter.

Table 6-13: Potential private VKM reduction

Range	Required Quarterly Reduction (KM)		
	10% switch	**15% switch**	**20% switch**
Walk (0-2km)	2,034,383	3,051,576	4,068,768
Cycle (2-4km)	8,036,119	12,054,179	16,072,239
Public Transport (5-40km)	114,924,240	172,386,361	229,848,481
Total	124,994,742	187,492,116	249,989,488

Table 6-14 details the potential CO_2 savings from a modal switch away from private vehicles to walking, cycling and public transport. Total quarterly savings of 26 million kg/quarter of CO_2 are estimated in a 20% modal switch scenario. A switch yields a saving 13 million kg/quarter, while the 15% scenario saves 20 million kg/quarter.

Table 6-14: Potential CO_2 saving from modal switch

Range	**CO_2 Savings (kg)**		
	10% switch	**15% switch**	**20% switch**
Walk (0-2km)	244,126	366,189	488,252
Cycle (2-4km)	964,334	1,446,501	1,928,669
Public Transport (5-40km)	12,138,873	18,208,309	24,277,746
Total	13,347,333	20,021,000	26,694,667

Based on the initial fixed CO_2 price of €16.70, the monetary savings of a modal switch can also be estimated in Table 6-15. Total savings of over €400,000 are estimated in the optimal 20% modal switch scenario, with savings of over €300,000 in the 15% switch scenario and €202,000 in the 10% switch scenario.

Table 6-15: Potential monetary from a modal switch

Range	**Monetary Savings (€)***		
	10% switch	**15% switch**	**20% switch**
Walk (0-2km)	€4,077	€6,115	€8,154
Cycle (2-4km)	€16,104	€24,157	€32,209
Public Transport (5-40km)	€202,719	€304,079	€405,438
Total	€222,900	€334,351	€445,801

* Based on a CO_2 price of €16.70

A modal switch in each scenario would also change the allocation of permits within the market based on the CO_2 savings calculated in Table 6-15. The Dublin region would be expected to account for the largest share of this modal switch as 20% of the total targeted private vehicle kilometres are in this region. Thus the estimated switch is weighted between this and other regions according to the percentage weightings presented in Table 6-12. Tables 6-16 to 6-18 lists the estimated excess surplus CO_2 permits that would be generated in each of the three modal switch scenarios. These permits are denominated at 25kg/CO_2 per permit. In each scenario, the Dublin region receives the largest share of additional surplus permits in the event of a modal switch. The Midlands, Mid-West and Western regions receive the lowest share of additional permits. Total additional surplus permits are estimated at over a million in the optimal 20% switch scenario and at 533,000 and 800,000 in the 10% and 15% scenarios respectively.

Table 6-16: Quarterly extra surplus permits (10% modal switch)

	25kg Permit			
Region	**Walk**	**Cycle**	**Public Transport**	**Total**
Border	1,315	4,214	49,945	55,474
Dublin	1,942	11,944	99,140	113,026
Mid-East	942	2,968	81,475	85,385
Midland	686	2,031	28,987	31,704
Mid-West	937	3,534	47,129	51,600
South-East	1,374	4,262	51,453	57,089
South-West	1,520	5,839	76,919	84,278
West	1,049	3,781	50,507	55,337
Total	9,765	38,573	485,555	533,893

Table 6-17: Quarterly extra surplus permits (15% modal switch)

	25kg Permit			
Region	**Walk**	**Cycle**	**Public Transport**	**Total**
Border	1,972	6,322	74,918	83,212
Dublin	2,913	17,916	148,710	169,539
Mid-East	1,414	4,452	122,212	128,077
Midland	1,028	3,047	43,481	47,556
Mid-West	1,406	5,300	70,694	77,400
South-East	2,061	6,393	77,179	85,633
South-West	2,281	8,759	115,378	126,418
West	1,573	5,672	75,760	83,005
Total	14,648	57,860	728,332	800,840

Table 6-18: Quarterly extra surplus permits (20% modal switch)

	25kg Permit			
Region	**Walk**	**Cycle**	**Public Transport**	**Total**
Border	2,629	8,429	99,891	110,949
Dublin	3,885	23,888	198,280	226,053
Mid-East	1,885	5,936	162,949	170,770
Midland	1,371	4,063	57,975	63,408
Mid-West	1,874	7,067	94,258	103,200
South-East	2,747	8,524	102,905	114,177
South-West	3,041	11,678	153,838	168,557
West	2,097	7,562	101,014	110,673
Total	19,530	77,147	971,110	1,067,787

This analysis of three modal switch scenarios demonstrates that 20% of the additional surplus permits which could be generated from the switch would benefit the Dublin region. 92% of private vehicle kilometres targeted to switch to more sustainable modes of transport are within the range of public transport. This is assuming public transport would have the capacity and coverage to enable this switch. This may not be the case in rural regions where public transport links are limited. As a result, the excess surplus of permits generated in these scenarios may increase in share in Dublin and other urban centres in the public transport range. Therefore, walking and cycling scenario results are more reliable estimates in that they do not rely on the assumption of a public transport service being available to replace private vehicle trips.

6.5 SUMMARY

This chapter recommended a potential structure of implementation of a PCTS scheme to cover commute trips. A progressive extension of the scheme to cover other sectors was also suggested in line with recommendations from previous research and the experience from the phased introduction of schemes in Australia and New Zealand. The initial transaction costs within the scheme and the division of permit surplus and deficits into socio-economic and regional groups were also investigated. A clear urban-rural divide is apparent when segmenting these results by region with Dublin being the only region to retain a mean surplus of CO_2 permits per person. However, breaking down individuals by socio-economic group finds farmers to retain a large surplus within these rural areas also. The findings indicate the group most susceptible to having a large surplus are individuals within rural areas required to travel longer distances to work.

A scenario analysis was also conducted to determine what affect a modal shift from private vehicles to walking, cycling and public transport would have on the distribution of permits in a PCTS and potential CO_2 savings. This analysis found the region with the largest number ‘target trips’ within a potential modal shift range was Dublin. The potential benefits of a 10%, 15%, 20% were also quantified in terms of permit allocation, with the Dublin region gaining the largest excess surplus of permits in each scenario. The Western, Mid-Western and Midlands gained the lowest share of excess surplus permits in each scenario.

Due to the disparity between regions, any implementation of a PCTS would require compensation for individuals in disadvantaged areas constrained to using private vehicle as their primary form of transport. This may take the form of direct compensation through lower permit prices or an increased allocation of permits. An indirect compensation through income tax breaks and subsidies could also remedy any disparities between urban and rural regions. These policy implications will be discussed in more detail in Chapter 7 .

7. CONCLUSIONS

7.1 INTRODUCTION

The main objective of this thesis was to determine the effects of introducing a PCTS on various socio-economic groups. In particular, two study regions were compared to observe any divergences in welfare outcomes between urban and rural regions. The regions chosen were Dublin and the WBR. This research was carried out by initially estimating CO_2 emission for travel-to-work trips tabulated in the Census of Population, 2006. The next step involved determining the characteristics of individuals above the CO_2 cap in a PCTS. A welfare analysis determined the relative share of the burden between the two distinct regions in a PCTS. The final analysis recommended a potential framework for the implementation of a PCTS and the initial outcomes arising from the introduction of a scheme. This chapter will summarise these findings, discuss the impacts and limitations of the research and suggest further areas of research.

7.2 SOCIO-ECONOMIC ANALYSIS OF A PERSONAL CARBON TRADING SCHEME

The initial research objective identified in the introduction chapter sought to *determine the socio-economic characteristics of individuals within a PCTS*. The analysis in Chapter 4 dealt with this research question in addition to estimating CO_2 emission for travel-to-work trips.

The results of the emissions estimations showed that the mode of transport with the highest amount of emissions was the driving a car. This intuitive result stemmed from the finding that nearly 60% of travel-to-work trips being by this mode nationally. Driving to work also accounted for the longest average daily return trips of all modes with a national average of 30km, a WBR average of 35km and a Dublin average of 22km. This also contributed to the large share of CO_2 attributed to this mode. Having found average national trip emissions to be 2.5kg, the first emissions cap was set at this level. An additional cap set at 20% below this level was also set in line with Ireland's emissions reduction targets.

The socio-economic analysis of this cap yielded a number of interesting findings. The first finding was that only 15% of commuters in Dublin would be over the cap at either level. Nationally, and in the WBR this was found to be between 35% and 40%. Descriptive statistics indicated that individuals who drive to work alone would be the largest group above the cap, while those who use public transport would mainly fall under the cap. Many of the trips observed were over short distances under 10km, particularly in Dublin. Consequently, these individuals fell under the cap, regardless of mode of travel. The results showed that individuals aged between 25 and 44 make up the largest cohort of individuals in employment in Ireland, and as such it was not unexpected to find that this age group had the largest probability of being above the cap (at either level).

A BLR model was utilised to determine statistical significance between a number of socio-economic variables and the propensity to be above the cap. In addition to confirming the findings in the descriptive statistics, the analysis also demonstrated the importance of owning a car and driving longer distances to work as the main characteristics of individuals who fell above the cap. Household composition was also an important factor as individuals with dependent children were likely to be above the cap. These individuals would likely be constrained to using private vehicles in travelling to work due to trip chaining considerations. This inevitably leads to higher CO_2 emissions reflected in the likelihood of these individual being above the cap. The findings were more pronounced in the rural WBR than the urban Dublin region due to the parameter coefficients for the independent variables in the WBR model being consistently larger than the national or Dublin models.

7.3 WELFARE EFFECTS OF A PERSONAL CARBON TRADING SCHEME

The second research question posed in the introduction chapter was to determine the *welfare changes arising from introducing a PCTS*. The analysis in Chapter 5 analysed the welfare effect of introducing a scheme.

The findings for this analysis were consistent with the initial findings of Chapter 4 in that those in the WBR region experienced a larger welfare loss than the Dublin region. This analysis studied welfare changes in three market scenarios of a low medium and high CO_2 price. A consumer surplus analysis was used as a proxy for welfare changes. Consumer surplus changes were based on a comparison between travel costs before and after the introduction of a PCTS. An addition of a CO_2 price into individual trips caused a negative welfare change for individuals using carbon-intensive modes of transport and a positive welfare change for individuals using more sustainable modes of transport, particularly those who walk and cycle to work. The inbuilt equity of the scheme whereby an individual with a surplus could theoretically benefit from selling excess permits was reflected in the results. Walking, cycling and public transport trips were found to generally reduce in cost with the introduction of a scheme. The higher the CO_2 price, the greater the benefit derived by individuals with excess permits was the key finding of this section. The opposite was true for individuals using private vehicles to travel to work, particularly in the WBR. Travel costs increased in the medium and high CO_2 price scenarios for these individuals in the WBR, but remained static for individuals in Dublin. This can be attributed to the shorter travel distances in Dublin than the WBR.

Welfare results were also cross-tabulated with density and deprivation levels. Again, negative welfare changes were larger in less densely populated regions in the WBR than regions in Dublin. Moreover, the majority of DED's in Dublin experienced a welfare gain in each CO_2 price scenario. The second cross-tabulation was based on existing deprivation statistics in Ireland as determined by Haase and Pratschke (2008). The results reveal that the most deprived areas will suffer a greater welfare loss compared to more affluent areas, if such a scheme were to be introduced. As affluence increase welfare loss generally decrease, particularly in the WBR. The only exception to these finding is in Dublin. The most deprived areas in Dublin were instead found to experience a marginal welfare gain. The mitigating factor in this case may be due to the fact that the most deprived areas in Dublin are generally inner city areas well served by more sustainable public transport modes and also the high prevalence of walking and cycling in the city.

Mapping the welfare changes using GIS across each DED also confirmed the largest losses occur in rural regions greater distances from major urban centres. The largest losses were found in the WBR, Munster and Midland regions.

A further socio-economic analysis using a MNL model compared the socio-economic characteristics of individuals having a positive or negative welfare change. This analysis confirmed that density of population was the major determinant of welfare changes as individuals living in more sparsely populated areas were more likely to experience a negative welfare change. Parameter coefficients associated with the density variable were significantly larger than other independent variables included in the model. Deprivation levels were not as statistically significant as density levels in Dublin or the national results but were of marginal significance in determining negative welfare changes in the WBR. As was the case with the BLR model results, individuals in the 25 to 44 year old age groups were likely to have a negative welfare change. Males were also more likely to have a larger negative welfare change than females possibly due to the higher percentage of males in the workforce in the dataset.

7.4 IMPLEMENTATION AND OUTCOMES OF A CARBON TRADING SCHEME

The final research question outlined in the introduction chapter and addressed in Chapter 6 of this thesis was *the potential implementation and structure of a PCTS*.

Based on previous research into the implementation of carbon trading schemes, a potential framework was outlined for the introduction of a PCTS. This framework was expanded on in five areas: i) an independent body setting annual cap levels in line in Ireland’s international commitments, ii) an initial trial period to educate and acclimatise individuals to the workings of a scheme, iii) free allocation of permits equally to individuals, iv) creation of carbon accounts to track usage and v) creation of a market to trade permit.

The most important recommendations in implementing a scheme were found to be the regulation and scope of the scheme. The regulatory body must retain complete independence from political influence to maintain integrity in the system. It must also have expertise in emissions estimation and reporting to efficiently apply the cap in a PCTS. The EPA was suggested as a potential regulatory authority. Another important recommendation was a phased introduction of a PCTS to acclimatise individuals to the concept of carbon trading. This would occur over a 5 to 7 year period. The allocation of free and equal permits to all individuals would also ensure upmost equity within the system.

Based on an initial fixed price of CO_2 the potential number of transactions and the division of surplus and deficit permits was investigated. The results were also analysed across various socio-economic groups. The urban-rural divergence found in Chapters 5 and 6 was apparent when segmenting these results by region. Dublin was the only region to retain an average surplus of permits per person in the initial phase of trading. However, in rural regions farmers are also likely to retain a surplus. The results found the groups most susceptible to having a large surplus were individuals within rural areas required to travel longer distances to work.

Finally a scenario analysis predicted the savings of CO_2 emissions and permit allocations in each region in a low, medium and high modal switch scenario. This analysis found the region with largest number of trips with potential to switch to walking, cycling or public transport from private vehicles was Dublin. These potential modal switch scenarios benefit the Dublin region with increased surplus permits while the Western, Mid-Western and Midlands gain the lowest share of excess surplus permits.

7.5 IMPACT OF RESEARCH

The research presented in this thesis contributes the field of research in determining the welfare outcomes of introducing a downstream PCTS. The analysis of the socio-economic characteristics of individuals above a potential cap in a PCTS is one of the main contributions to knowledge in this thesis. This type of analysis had not been previously completed using logistic regression techniques. Segmenting the analysis across socio-economic groups and regions further strengthens the contribution to knowledge in using this modeling technique. The use of a MNL model in determining the characteristics of individuals with negative and positive welfare changes is also a contribution to the knowledge in observing the socio-economic effects of a PCTS.

While studies have been conducted to determine the welfare effects of carbon trading, this thesis focused on identifying any divergences in welfare changes between urban and rural regions. The divergences observed in the results discussed in Chapter 5 highlight the importance of comparing the effects of the policy in both regions and validate the research objective to study this aspect of a PCTS outcome.

The results presented in this thesis also have a number of practical policy implications. The findings of inequity for individuals in rural regions would necessitate a heterogeneous structure of a PCTS scheme to remedy theses potential outcome. This could involve an increase of CO_2 permit allocations for individuals constrained to using private vehicles as their primary form of transport in rural regions. A price ceiling on CO_2 within the market for these vulnerable socio-economic groups could also provide a mechanism to ensure more equitable welfare outcomes. An indirect mechanism of compensation implemented in the Australian ETS would be a reduction in the tax burden of vulnerable groups identified in this research. This could take the form of a cut in income tax or any vehicle related taxation. A final measure to alleviate the burden on these groups would be to incentivise and/or subsidise the purchase or environmentally friendly electric or hybrid vehicles in rural regions where public transport alternatives are not a viable alternative. This thesis identified the equity problems and ambiguous environmental dividend associated with existing carbon reduction measures such as carbon taxation and upstream trading. Therefore, there is a necessity for further investigation of a downstream type scheme as an alternative policy.

7.6 CRITICAL ASSESSMENT

While the research presented in this thesis has added to the field of research into downstream carbon trading, there are a number of limitations summarised below.

The use of work only trips as tabulated in the POWCAR does not account for other important trips such a leisure and shopping trips. This may skew the modeling results in determining welfare particularly in socio-economic groups with a higher work participation rate. While the CSO surveys these trip types in the National Travel Survey, the sample used is very small and not recommended as a guide for trips at an aggregated level. What this survey does indicate is that work trips in POWCAR most account for nearly 30% of all trips. Therefore, the 1.8 million trips recorded in POWCAR is the most comprehensive survey of travel behaviour in Ireland to date.

The lack of income data in the dataset is also a limitation of this research. Within the welfare model, the effect of a price change of CO_2 on individual welfare is determined. However, the income effects of a price change are also important indicators in determining welfare. An affluent individual experiencing a similar price effect to a less affluent individual would in theory experience less of a welfare loss than the poorer individual. However, the use of deprivation and affluence statistics in comparing the welfare results compensates somewhat for the absence of income data.

CO_2 price change and modal switch scenario analyses are conducted in this research in isolation. The development of a more fluid model including both variables to determine the environmental and market outcomes of a PCTS would be more desirable. Allowing for the equilibrium CO_2 price to be determined by simulation could provide a more rigorous result in determining the allocation of surplus and deficit permits in the economy. However, this thesis has recommended an initial fixed CO_2 price based previous research and experience of international trading schemes. Consequently the analysis in this thesis which used a fixed CO_2 is a reliable prediction the initial phase of a PCTS.

7.7 AREAS FOR FURTHER RESEARCH

A possible area for further research would be in the implementation of a PCTS. While this thesis provided a framework for the implementation of a scheme, the complexity of initiating a PCTS scheme would justify an entire research project to determine the exact roadmap to implementation. While the literature reviewed has identified no insurmountable technical or theoretical barriers to implementing such a scheme, the initial costs and structure of a PCTS would also require detailed analysis.

In terms of the carbon market, an analysis of a fluid model of prices changes within a market as a precursor to the scheme would help inform the regulatory authority in setting the optimum cap level. Previous experience has shown the EU ETS to have set too high a cap in the initial phase of trading resulting low carbon prices. An analysis to predict price movements would guard against this outcome.

While public acceptability of a PCTS has been found to be quite high under certain circumstances in international studies, this is an area of required research in Ireland. The success of a PCTS would hinge on the acceptance of the scheme in a manner similar to the success of the plastic bag levy in Ireland to reap the full environmental benefits of the scheme. This is a potential future area of research.

Key to the public acceptability of a scheme would be the learning curve required for participants in the scheme. A research requirement in this area arises in efficiently designing a framework to educate and acclimatise individuals in monitoring their carbon usage.

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APPENDIX A: POWCAR VARIABLES

Variable	**Description**
Residence Planning Region	Regional Authority of residence
Residence county	Administrative county of residence
Residence ED	Electoral Division of residence
Residence ED (OSI)	Electoral Divisions of residence using Ordnance Survey of Ireland coding
Residence Town	Town where residents are enumerated
Residence Enumeration Area	Residence Enumeration Area in major urban centres of Dublin, Cork, Galway, Limerick and Waterford
Resident Persons	Number of persons resident in household
Resident Workers	Number of resident workers in household
Household Composition	Marital and family status of household
Accommodation Type	Type of house lived in
Year Built	Year house was built
Nature of Occupancy	Owner or renting in household
Sewerage	Type of sewerage system in house
Gender	Male or Female
Age Group	Age group of individual
Marital Status	Current marital status
Usual Residence One Year Ago	Where person lived one year ago
Highest Level of Education	Highest level of education completed to date
Socio-Economic Group	Type of work a person is employed in
Industrial Group	Type of Industry a person works in
Means of Travel	Means of travel to work, school or college
Time of Departure	Time of departure to work
Journey Kilometres	Journey to work length in kilometres
Journey Minutes	Journey to work length in minutes
Place of Work County	County in which a workplace is located
Place of Work ED	Electoral District in which a workplace is located
Place of Work ED (OSI)	Electoral District in which a workplace is located using Ordnance Survey of Ireland coding
Place of Work Town	Town in which a workplace is located
Place of Work Enumeration Area	Urban Enumeration Area in which a workplace is located in Dublin, Cork, Galway, Limerick and Waterford
Fuzz Eastings	Easting location on National grid rounded to 250M X 250M grid squares
Fuzz Northings	Northing location on National grid rounded to 250M X 250M grid squares

APPENDIX B: PUBLISHED RESEARCH

Conference Papers:

McNamara, D and B Caulfield. 2009. Identifying the socio-economic characteristics of CO2 emitters in an Irish Metropolitan Region. *The 12th International Conference on Travel Behaviour Research.* Jaipur, India: IABTR

McNamara, D. & Caulfield, B. 2010. Identifying the socio-economic characteristics of CO2 emitters in the Greater Dublin Area. *The 42nd Annual UTSG Conference,* Plymouth, England

McNamara, D. & Caulfield, B. 2010. Examining the potential impacts of introducing a cap-and-share scheme in Ireland. *Irish Transport Research Network conference,* Dublin

McNamara, D. & Caulfield, B. 2011. Examining the potential impacts of introducing a cap-and-share scheme in Ireland. *The 90th Meeting of The Transportation Research Board,* Washington D.C

McNamara, D. & Caulfield, B. 2011. 'Determining the welfare effects of introducing a cap-and-share scheme on rural commuters' The 2nd Annual Irish Transport Research Network Conference, Cork

Caulfield, B. & McNamara, D. 2011. 'Measuring the transport patterns of those living in deprived areas in Dublin, Ireland. *The 91st Meeting of The Transportation Research Board,* Washington D.C.

Journal Papers:

Farrell, S., McNamara, D. & Caulfield, B. 2010. Estimating the Potential Success of Sustainable Transport Measures for a Small Town. *Transportation Research Record: Journal of the Transportation Research Board,* 2163**,** p97-102

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