Measuring the potential implications of introducing a cap and share scheme in Ireland to reduce green house gas emissions

David McNamara and Brian Caulfield*
*Department of Civil, Structural and Environmental Engineering
Trinity College Dublin
Dublin 2
Ireland
Tel: +353 1 8962534
Fax: +353 1 6773072
Email: brian.caulfield@tcd.ie

Abstract

This paper examines some of the potential impacts of introducing a cap and share scheme in Ireland, whereby a cap or limit is placed on national CO_2 emissions and individuals are allocated an annual CO_2 allowance. The research presented in this paper focuses on travel-to-works trips specifically. CO_2 emissions for these annual work trips are calculated and a cap is determined based on these results. Cap levels are set based on average emissions and a 20% reduction in average emissions as per Ireland's reduction targets. A national and Dublin only cap are examined and the results are presented as a means of comparison. Binary logistic models are used to determine the socio-economic characteristics of individuals who fall above and below the cap. The results demonstrate the importance of car ownership, journey distance, mode choice, and household composition in determining whether a commuter is above or below a cap. Many commuters who fall above the cap are likely drive to work over long distances, have dependent children in their household and own more than one car.

1. Introduction

Cap and share schemes set a limit on the quantity of green house gases (GHG), which can be emitted in an economy annually. This cap is enforced by issuing permits to GHG emitters in the economy. If an entity exceeds their allowance they can purchase permits from entities that have a surplus. This creates a market for GHG's that is operated and regulated by government. The different configurations of such schemes are discussed in more detail in the subsequent sections. Under Kyoto guidelines, Ireland's GHG emissions must not exceed 1990 levels by more than 12% by 2012. In 2008, Environmental Protection Agency (EPA) published a report that annual emissions were reducing but not at a fast enough rate to meet Kyoto targets in 2012 (EPA, 2008). The Irish government has outlined a number of policy objectives to promote sustainability to meet Kyoto targets (Department of Transport, 2009), particularly in public transportation. These objectives include alleviating urban sprawl by limiting single house developments whilst promoting sustainable high density developments, investing significantly in public transportation and promoting work at home policies such as e-working.

The Irish government has also commissioned a number of reports into the viability of a cap and share scheme. Research has focused on the national implementation of an emissions cap across all sectors of the economy. This paper will investigate the impact of a cap on individuals who undertake daily travel-to-work trips under a personal cap and share scheme. This paper is organised into five sections including this introduction. It will proceed with an explanation of cap and share and a review of the relevant literature, an explanation of the methodologies used, results of the analysis and conclusions to be drawn from the research.

2. Cap and share

Internationally literature relating to cap and share has reached a consensus that such a scheme can effectively reduce GHG emissions and is less regressive than a carbon tax (SDC, 2008; Starkey and Anderson, 2005; Harwatt, 2008). Debate therefore has focused on the technical implementation of a potential scheme. Fleming (1997) was one of the first authors to advocate the use of "tradable quotas" in reducing carbon emissions. Such a scheme distributed free allowances to end-users and created an auction process for businesses and public sector bodies to purchase quotas. This approach is an example of a downstream cap. Subsequent studies have advocated an upstream cap (Fleming, 1997; Tietenberg, 2001; Millard-Ball, 2008). An upstream cap allocates permits to importers of energy i.e. oil refineries, fuel importers etc. 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 MAC was created to study market-based mechanisms to reduce GHG emissions in the US state. The 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 Air Resources Board, 2007).

Advocates of a downstream cap argue that durable reductions in GHG emissions can only be achieved through the behavioural changes associated with a downstream cap on consumers (Fleming, 1997; Fawcett, 2005; Niemeier, 2008). The potential impact of an upstream cap is increased fuel prices, which would be in effect a tax on consumers, creating inequitable market outcomes (Fleming, 1997). Niemeier (2008) proposed a household GHG cap and trade (HHCT) system 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 expanded on Fleming's model in allocating free allowances to consumers while granting regulation of the scheme to energy utility companies. This system is found to be more equitable than carbon taxes and an upstream cap. Millard-Ball (2008) identified five options, which would incorporate the transportation sector into a cap and share scheme. An upstream and downstream cap was discussed in addition to a vehicle manufacturer based scheme. This manufacturer scheme was rejected however as tailpipe standards appear to achieve the same results. An offset scheme is also examined which would not explicitly cap transport emissions but allow developers, municipalities transit agencies etc. to put forward transportation projects that offset emissions from the stationary sector. Millard-Ball (2008) found that the favoured scheme was a 'municipal mobility manager' scheme, which would hold local governments responsible for emissions cap target, providing penalties for exceeding the cap and incentives for reducing emissions. This provides the benefits of an offset scheme without the administrative costs.

As this paper is concerned with the end users of road transport, the impacts of a potential downstream cap on transport emissions will be studied. End users are studied in this case because the dataset involved tabulates end user activity and therefore lends itself to studying the effects of a downstream cap. A potential downstream cap would allocate permits to individuals to emit CO_2 equally to transport uses. Research in the transportation sector is limited, with many authors suggesting a cap on household energy use only. This is ignoring the importance of the transport sector's contribution to GHG emissions. The Sustainable Development Council (2008) recommended an initial cap on the transport sector applied downstream. This cap was compared to other carbon reduction measures and the potential effects of a cap were discussed. 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. A research requirement arises in studying the effects of the inequalities created by cap and share. The Sustainable Development Council report did not outline the important socio-economic characteristics of individuals who would be affected by the cap, instead concentrating on comparing income groups across the economy. This paper will investigate the relevant socio-economic groups. Recent research has dealt somewhat with socio-economic and equity issues. Wadud (2010) found that the majority of allocation strategies were progressive. A caveat of this conclusion was that the effects on poor rural commuters were most likely regressive without allocations being adjusted accordingly. Raux and Marlot (2005) stressed the importance of an equal allocation of CO_2 permits to mitigate equity issues together with a tailored allocation of permits based on socio-economic characteristics. Recent literature has suggested further research is needed in the area of cap and share and associated energy poverty and equity issues (Brand and Preston, 2010). This paper does not deal with the technical implementation of a national cap rather it studies the socio-economic impacts effects of a cap on the daily trip to work.

3. Methodology

The dataset used in this paper is a subset of the Irish Census of Population, 2006 relating to people's daily trips to work, school and college. This dataset is named the place of work census of anonymised records (POWCAR). It contains information on trips of 1,834,472 individuals in Ireland. It is the most extensive national travel dataset available at present in the country. This dataset also contains information on the distance travelled, socio-economic grouping, occupation, household structure, and modes of transport. As this paper is concerned with a potential cap on personal travel emissions, a method for calculating individual's annual emissions must be determined initially. Once this is calculated a cap can be set on emissions. Regression analysis can then be used to study the socio-economic characteristics of individuals who lie above this level.

3.1 Emissions Estimation

This section of the paper presents the methods by which the relevant CO_2 emissions were estimated. Emission factors calculated in Walsh et al. (2008) are used in this particular paper. These Irish emission factors are inclusive of average peak hour occupancy rates for the relevant modes of public transport and are measured in kilograms of CO_2 per passenger kilometre. Emission factors for motorized transport are calculated based on fuel consumption for a range of engine sizes. Emission factors for electric powered public transport are calculated based on energy usage converted to carbon and distance travelled per year. These factors are presented in Table 1.

Table 1 Occupancy rates and emissions factors

Mode	Occupancy	kg CO2/Pass km
Train	945	0.011
Tram	235	0.064
Intercity bus	57	0.015
Dublin bus	90	0.016
Private car	1.4	0.12

- *Factors taken for Walsh et al. (2008)*

The following equation was used to calculate the CO_2 emissions generated by travel-to-work trips,

Equation 1

$$CO_2 = EF * 2 * VKM * 215$$

where VKM is the total number of kilometres travelled by the mode of transport in question and EF is the emission factor per passenger kilometres travelled by that mode. This was then doubled to calculate the emissions for a return journey and multiplied by 215 to calculate annual emissions. This figure of 215 days is the average working year in Ireland. Average emissions can be calculated and a potential cap on personal emissions set.

3.2 Setting the Cap

The cap levels chosen in this case is based on the emissions calculations only as a starting point to determine the potential socio-economic characteristics of individuals above and below the cap. An average emissions level was chosen as the measure of the cap, which is inline with previous studies, as it enables and analyses socio-economic characteristics of those above and below the cap. As the data used in this paper is taken from the 2006 Census, the cap is set at 2006 emissions levels. The potential allocation of permits to individuals would be distributed at zero cost and equally to all users of transport as has been recommended in previous literature. The initial cap in the model for both the Dublin and the national datasets is set at the average annual emissions calculated. The cap is then lowered by 20% in both datasets. The purpose of lowering the cap is to ascertain if Ireland is to meet its GHG targets, which would result in approximately a 20% cut in 2006 GHG levels, how this would impact upon society, and what sectors would be most impacted. Two caps are examined in this paper: a national cap and a Dublin only cap. This results in eight subsections of the population being examined - those above and below the average cap and those above and below average cap less 20% both nationally and in the Dublin only model. Table 2 presents the percentage of commuters who would fall above and below a cap. A cap based on average emissions calculated would leave 31% of commuters above the cap in Dublin, which is higher than the national average of 26%. Lowering the cap further by 20% would leave 36% of commuters above the cap in Dublin compared to 32% nationally.

Table 2 Percentage of commuters over the cap

Cap based on average emissions				
	Dublin	**Dublin %**	**National**	**National %**
Above Cap	139,072	31	399,979	26
Below Cap	308,544	69	1,144,855	74
Total	369,318	100	1,544,834	100
Cap 20% below average emissions				
	Dublin	**Dublin %**	**National**	**National %**
Above Cap	161,407	36	500,109	32
Below Cap	286,209	64	1,044,725	68
Total	369,318	100	1,290,315	100

Figures 1 and 2 graph the number of mechanised trips taken both in Dublin and nationally respectively. The numbers of trips are split between those trips that fall below the cap and those over the cap. The results presented in these figures show that approximately 15million or 16% of all drive alone trips were above the cap in Dublin per annum. Nationally it was found the over 64million drive alone trips per annum (30%) were above the cap. It was found that nationally 89% (20million) of all lorry or van trips we found to be above the cap. Of the public transport modes examined rail trips were the only trips found to be in some cases over the cap limit. The results show that 11% of rail trips nationally were over the cap limit whereas just 5% of these trips in Dublin were above the cap limit.

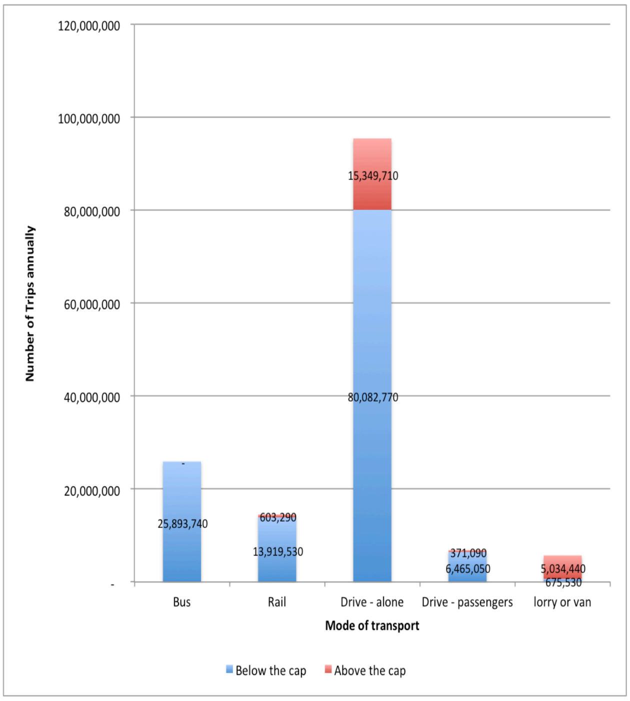

Figure 1 Annual Dublin Trips

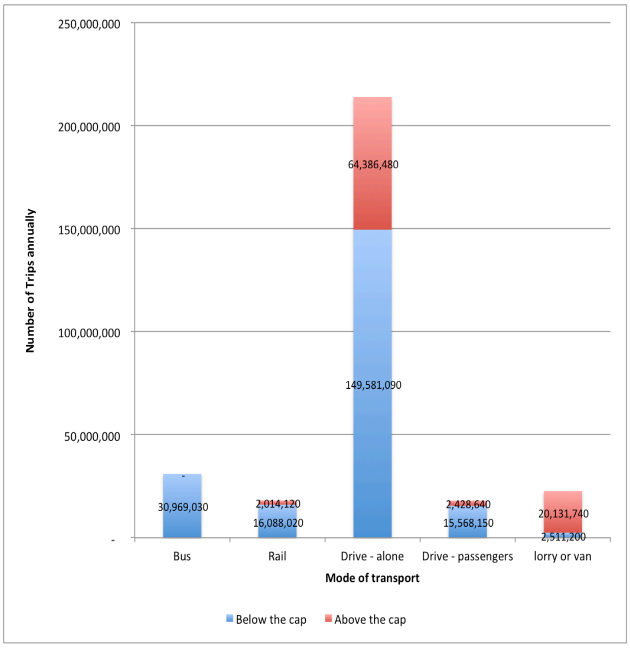

Figure 2 Annual National Trips

3.3 Logistic model formulation

This model is based on a binary logistic regression as outlined in Washingtonet et al. (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 1. The dependent variable is the log of the odds ratio of the event Y occurring or the logit of Y as shown in equation 2.

Equation 2

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

where β_0 is the model constant and β_i are the parameter estimates for the set of socio-economic independent variables ($X_i, i = 1,\ldots,$n). $\hat{\text{Y}}$ is the predicted probability of the event which takes binary values of 1 (continue analysis) or 0 (stop the analysis). Thus when an independent variable X_i increases by one unit, all other factors remain constant as shown in equation 3.

Equation 3

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

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

The factor EXP^{β_i} is the odd ratio (OR) ranging from zero to infinity. It indicates the relative amount by which the odds of the outcome increases or decreases when the value of the independent variable X_i increases by one unit. A Wald test is used to test the significance of each parameter (β) in the model as shown in equation 4.

Equation 4

$$z = \frac{\hat{\beta}}{SE}$$

The Z-value is then squared, creating a Wald statistic with a chi-squared distribution. Table 3 presents the set of independent variables estimated in the logistic model. In this case four models are estimated, two each for the national dataset and Dublin dataset. Two models are based on a cap calculated from average annual emissions and two based on average annual emissions less 20%. Table 3 defines each of the variables examined in the logit models.

Table 3 Details of variables examined

Variable	Definition
Distance	
Commute Distance: 0-5 km	= 1 if Distance: 0-5 km
Commute Distance: 6-10 km	= 1 if Distance: 6-10 km
Commute Distance: 11-15 km	= 1 if Distance: 11-15 km
Commute Distance: 16-20 km	= 1 if Distance: 16-20 km
Commute Distance: 21-30 km	= 1 if Distance: 21-30 km
Commute Distance: 31 -40 km	= 1 if Distance: 31 -40 km
Commute Distance: 41 + km	(Reference category = Distance: 41 + km)
Age	
Age: 15-24	= 1 if Age: 15-24
Age: 25-34	= 1 if Age: 25-34
Age: 35-44	= 1 if Age: 35-44
Age: 45-54	= 1 if Age: 45-54
Age: 55-64	= 1 if Age: 55-64
Age: 65-74	= 1 if Age: 65-74
Age: 75+	(Reference category = Age: 75+)
Gender	
Gender: Male	= 1 if Gender: male
Gender: Female	(Reference category = Gender: Female)
Socio-economic group	
Socio-economic group: Employers and managers	= 1 if Socio-economic group: Employers and managers
Socio-economic group: Higher professional	= 1 if Socio-economic group: Higher professional
Socio-economic group: Lower professional	= 1 if Socio-economic group: Lower professional
Socio-economic group: Non-manual	= 1 if Socio-economic group: Non-manual
Socio-economic group: Manual skilled	= 1 if Socio-economic group: Manual skilled
Socio-economic group: Semi skilled	= 1 if Socio-economic group: Semi skilled
Socio-economic group: Unskilled	= 1 if Socio-economic group: Unskilled
Socio-economic group: Self employed	= 1 if Socio-economic group: Self employed
Socio-economic group: Farmers	= 1 if Socio-economic group: Farmers
Socio-economic group: Agricultural workers	= 1 if Socio-economic group: Agricultural workers
Socio-economic group: Other	(Reference category = Socio-economic group: Other)
Number of cars/vans	
Number of Cars/vans: 1	=1 if number of cars/vans: 1
Number of Cars/vans: 2	=1 if number of cars/vans: 2
Number of Cars/vans: 3	=1 if number of cars/vans: 3
Number of Cars/vans: 4 or more	=1 if number of cars/vans: 4 or more
Number of Cars/vans: None	(Reference category = Number of Cars/vans: 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 = Household Composition: Other Households)

4. RESULTS AND ANALYSIS

4.1 Setting the cap

This section of the paper presents the results of the various analyses carried out. Table 4 presents the annual emissions calculated for trips in Dublin city. As expected driving a car accounts for the bulk of emissions due to 50% of trips being taken by car. Table 5 presents a breakdown of commute travel for the national dataset and the Dublin sample. The percentage difference column (D) represents Dublin having a higher percentage of total modal share while (N) represents the national figure being higher. Driving accounts for 58.1% of trips nationally while 9% use public transport. Driving a car in Dublin accounts for 49% of trips in comparison to 21.8% of trips made by public transport. This result is much higher than the national average due to the availability of public transport in Dublin city. Another interesting result is that nationally more people work from home (3.1%) than in Dublin (1.5%). Table 6 presents the average emissions per commuter on a daily and annual basis. As is expected average emissions per capita are lower in Dublin city compared to the national average. These values will be used as the base point to set the cap in the model.

Table 4 Emissions calculations for Dublin

Means of Travel	Daily km travelled	Annual Km travelled	CO2 Emissions ($Kg\ CO_2$ km)	% of Total Emissions
Bus	1,196,986	257,351,990	4,117,632	2.29
Rail	1,551,486	333,569,490	3,669,264	2.04
Motorcycle	143,192	30,786,280	3,694,354	2.05
Car-Driver	5,841,858	1,255,999,470	150,719,936	83.83
Car-Passenger	346,614	74,522,010	6,334,371	3.52
Lorry/Van	280,236	60,250,740	11,086,136	6.17

Table 5 Modal split of commuters

Dublin			National			
Mode	**N**	**%**	**Mode**	**N**	**%**	**% Difference**
Walk	70,080	13.2	Walk	197,622	10.9	2.3(D)
Cycle	20,602	3.9	Cycle	35,310	1.9	2(D)
Public transport	116,350	21.8	Public transport	164,066	9.0	12.8(D)
Motorcycle	39,534	1.2	Motorcycle	12,678	0.7	0.5(D)
Driving	260,754	49	Driving	1,052,795	58.1	9.1(N)
Driving – Passenger	19,977	3.8	Driving – Passenger	102,483	5.7	1.9(N)
Lorry or van	19,239	3.6	Lorry or van	138,208	7.6	4(N)
Other means	1,028	0.2	Other means	6,228	0.3	0.1(N)
Work from home	8,218	1.5	Work from home	56,897	3.1	1.6(N)
NA	9,364	1.8	NA	45,634	2.5	0.7(N)
Total	532,219	100.0	Total	1,811,921	100.0	

Table 6 Average emissions per individual ($Kg\ CO_2$ KM)

	Dublin	National
Daily CO_2	2.13	4.42
Annual CO_2	458.5	952.1

4.2 Descriptive statistics

Table 7 presents descriptive statistics associated with the variables of interest across the four models. The number of individuals above and below the cap is tabulated and each sub-group's percentage share of the total number of commuters 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. This result demonstrates that distance travelled, as one would expect, has the greatest impact on if an individual is above or below the cap. The age profile of the largest group above the cap is 25-34 year olds. However, the majority of this age group were found to be under the cap at both levels nationally and in Dublin.

The gender variable shows more males falling above the cap than females across all four models; this was shown to be highest in the Dublin results. The socio-economic group variables relate to the professions of the individuals examined. The results show little difference in the breakdown of individuals above and below the cap. Employers & managers are consistently the largest group above the cap, particularly in Dublin. Non-manual workers are shown to be the largest group of individuals consistently under the cap.

The cars/vans variable shows that the largest group above the cap are commuters who own two vehicles. The largest groups below the cap are commuters owning one vehicle, as one would expect. Household composition is an important variable in determining the socio-economic characteristics of individuals. An individual's travel behaviour will inevitably be constrained by the number of dependent children present and this is evident in the results. The largest group above the cap in all four models are couples with dependent children. The means of travel variable shows that the vast majority of commuters drive to work. However, the majority of drivers fall below the cap. This indicates that many journeys are over short distances. One of the variables that would have been desirable to examine in this section is individuals' income. Unfortunately this variable is not provided in the POWCAR dataset and therefore it is not possible to draw conclusions on how income might impact the cap and share scheme.

Table 7 Descriptive statistics associated with variables of interest

Variable	National cap average emissions				National cap lowered by 20%				Dublin cap average emissions				Dublin cap lowered by 20%			
	Above cap		Below cap		Above cap		Below cap		Above cap		Below cap		Above cap		Below cap	
Distance	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
0-5 km	8,693	2	517,330	50	12,413	2	513,610	55	2,925	2	167,971	59	2,925	2	167,971	64
6-10 km	22,059	6	289,106	28	22,059	4	289,106	31	38,454	28	87,808	31	55,183	34	71,079	27
11-15 km	12,241	3	146,430	14	59,154	12	99,517	11	37,281	27	18,461	7	41,720	26	14,022	5
16-20 km	75,063	19	65,086	6	117,890	24	22,259	2	28,846	21	5,963	2	29,954	19	4,855	2
21-30 km	112,503	28	14,603	1	118,490	24	8,616	1	18,707	13	2,122	1	18,707	12	2,122	1
31 -40 km	69,418	17	3,199	0	70,101	14	2,516	0	7,333	5	583	0	7,333	5	583	0
41 + km	100,002	25	3,257	0	100,002	20	3,257	0	5,526	4	369	0	5,585	3	310	0
Age																
15-24	38,598	10	153,499	13	48,641	10	143,456	14	11,161	8	47,006	15	13,142	8	45,025	16
25-34	133,387	33	337,260	29	164,818	33	305,829	29	46,820	34	106,482	35	53,936	33	99,366	35
35-44	115,735	29	276,654	24	143,541	29	248,848	24	37,457	27	66,220	21	43,122	27	60,555	21
45-54	76,514	19	231,668	20	97,093	19	211,089	20	27,714	20	54,746	18	32,384	20	50,076	17
55-64	32,996	8	127,119	11	42,447	8	117,668	11	14,266	10	30,032	10	16,865	10	27,433	10
65-74	2,521	1	15,988	1	3,253	1	15,256	1	1,482	1	3,537	1	1,758	1	3,261	1
75+	228	0	2,667	0	316	0	2,579	0	172	0	521	0	200	0	493	0
Gender																
Male	271,016	68	598,798	52	326,553	65	543,261	52	90,484	65	151,667	49	102,587	64	139,564	49
Female	128,963	32	546,057	48	173,556	35	501,464	48	48,588	35	156,877	51	58,820	36	146,645	51
Socio-economic group																
Employers & managers	73,998	19	171,537	15	91,472	18	154,063	15	33,524	24	50,682	16	38,878	24	45,328	16
Higher professional	29,341	7	86,271	8	37,474	7	78,138	7	15,291	11	33,118	11	18,236	11	30,173	11
Lower professional	58,700	15	156,664	14	75,521	15	139,843	13	20,719	15	48,471	16	24,698	15	44,492	16
Non-manual worker	70,956	18	313,996	28	95,019	19	295,933	28	27,945	20	96,538	31	33,603	21	90,880	32
Manual skilled	73,637	18	111,820	10	86,994	17	98,463	9	18,617	13	20,720	7	20,396	13	18,941	7
Semi skilled	35,870	9	125,248	11	46,136	9	114,982	11	8,811	6	25,903	8	9,991	6	24,723	9
Unskilled workers	14,041	4	45,096	4	16,898	3	42,239	4	2,902	2	11,960	4	3,250	2	11,612	4
Self employed	26,361	7	37,686	3	29,409	6	34,638	3	6,475	5	7,737	3	6,918	4	7,294	3

Farmers	4,336	1	41,742	4	5,282	1	40,796	4	211	0	578	0	229	0	560	0
Agricultural workers	1,958	0	8,065	1	2,440	0	7,583	1	127	0	411	0	137	0	401	0
Other	10,781	3	40,730	4	13,464	3	39,047	4	4,450	3	12,426	4	5,071	3	11,805	4
Number of cars/vans																
One	86,956	22	371,492	32	111,679	22	346,769	33	41,746	30	114,345	37	49,205	30	106,886	37
Two	222,579	56	460,594	40	276,182	55	406,991	39	71,050	51	97,627	32	81,558	51	87,119	30
Three	52,774	13	117,641	10	65,698	13	104,717	10	16,046	12	23,760	8	18,488	11	21,318	7
Four or more	28,475	7	51,732	5	34,966	7	45,241	4	5,680	4	7,168	2	6,453	4	6,395	2
None	4,665	1	125,678	11	5,905	1	124,438	12	2,766	2	60,144	19	3,656	2	59,254	21
Not stated	4,530	1	17,718	2	5,679	1	16,569	2	1,784	1	5,500	2	2,047	1	5,237	2
Household Composition																
Single	28,965	7	94,558	8	36,159	7	87,364	8	12,269	9	29,057	9	14,351	9	26,975	9
Lone Parent with Children	11,216	3	54,668	5	14,847	3	51,037	5	4,168	3	15,760	5	4,913	3	15,015	5
Lone Parent no Children under 19	13,660	3	47,117	4	17,206	3	43,571	4	4,335	3	13,011	4	5,077	3	12,269	4
Couples with Children	187,925	47	432,926	38	233,282	47	387,569	37	55,598	40	91,137	30	63,965	40	82,770	29
Couple no Children under 19	46,484	12	141,166	12	58,615	12	129,035	12	16,693	12	36,716	12	19,746	12	33,663	12
Couple no Children	78,710	20	185,652	16	97,503	19	166,859	16	27,484	20	50,246	16	31,805	20	45,925	16
Other Households	33,019	8	188,768	16	42,497	8	179,290	17	18,525	13	72,617	24	21,550	13	69,592	24
Means of Travel																
Walk	0	0	197,622	17	0	0	197,622	19	0	0	70,080	23	0	0	70,080	24
Cycle	0	0	30,708	3	0	0	30,708	3	0	0	18,190	6	0	0	18,190	6
Public transport	7227	2	127,782	11	10,301	2	124,708	12	7,935	6	86,097	28	12,811	8	81,221	28
Motorcycle	2511	1	8,757	1	3,621	1	7,647	1	3,129	2	2,732	1	3,674	2	2,187	1
Driving	287,912	72	636,747	56	376,542	75	548,117	52	111,508	80	110,539	36	127,692	79	94,355	33
Driving – Passenger	11,351	3	73,928	6	14,947	3	70,332	7	3,629	3	12,275	4	4,359	3	11,545	4
Lorry or van	90,978	23	12,414	1	94,698	19	8,694	1	12,871	9	413	0	12,871	8	413	0
Work from home	0	0	56,897	5	0	0	56,897	5	0	0	8,218	3	0	0	8,218	3

4.3 Logit model results

This section of the paper examines the characteristics of people who fall above the average emission cap and the average cap lowered by 20% on both the national and Dublin datasets. Presented in Table 8 are the results of the four models estimated. R^2 values are adequately high across all four models, with slightly lower values for the Dublin models which may be due to the smaller dataset used.

The socio-economic group variables are the first set of variables examined. A national cap based on average emissions finds that only three categories of employment would be below a cap. These are higher professionals, lower professionals and non-manual workers are likely to be below a cap. The majority of individuals would be above the cap. When the cap is lowered the results show that manual skilled and semi-skilled workers are likely to fall below the cap. The results for the Dublin models follow the same trends as the national model with the exception of unskilled workers being shown to be below the cap for both of the caps estimated. The gender variable shows that males are more likely to be above the cap across all four models. However the coefficients are lower for Dublin compared to the national average.

The household composition variables are all highly significant across the four models with positive coefficients suggesting the majority of families would 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.

The age variable demonstrates a clear generational difference. As would be expected the 15-24 age group has a negative coefficient across all four groups suggesting this group would be below any potential cap. All other age groups are likely to be above a cap with the exception of the 25-34 age group in model 3. This group has a slightly negative coefficient, however concluding this group would be below a potential cap is not conclusive due to the insignificant p-value of .915. The distance travelled variable is also highly significant across 3 of the 4 groups. Commuters who travel less than 3km per trip are highly unlikely to be above any potential cap across all four models. These coefficients become less negative as commuters distance travelled increases suggesting the chance of being above a cap increases with distance travelled. The results for model 4 in this case are inconclusive due to the insignificance of the majority of variables.

As expected, people owning cars or vans are likely to be above any potential cap across all four 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. The results presented in Table 8 demonstrate the importance of owning a car and driving long distances to work as the main socio-economic characteristics associated with commuters who fell above the cap across all four models. Moreover individuals in certain socio-economic groupings and in the higher age groups were shown to be most negatively impacted by the cap. Under a cap and share scheme it is this section of society that would have to pay a price for higher emissions.

Table 8 Regression analysis results

	Model 1 – National Cap Average Emissions		Model 2 – National Cap Average lowered 20%		Model 3 – Dublin Cap Average Emissions		Model 4 – Dublin Cap Average lowered 20%	
		Sig		Sig		Sig		Sig
Intercept	-.430	.000	-.556	.000	-.196	.182	.035	.811
Socio-economic group		sig		sig		sig		sig
Employers and managers	.149	.000	.212	.000	.027	.361	.122	.000
Higher professional	-.606	.000	-.404	.000	-.284	.000	-.163	.000
Lower professional	-.270	.000	-.089	.000	-.132	.000	-.030	.311
Non-manual	-.402	.000	-.250	.000	-.304	.000	-.256	.000
Manual skilled	.888	.000	-.916	.000	.667	.000	.660	.000
Semi-skilled	.024	.314	-.143	.000	.086	.010	.052	.109
Unskilled	.453	.000	.427	.000	-.145	.000	-.232	.000
Own account workers	1.756	.000	1.661	.000	1.120	.000	1.105	.000
Farmers	.526	.000	.488	.000	.704	.000	.743	.000
Agricultural workers	.342	.000	.409	.000	.377	.021	.198	.224
All others gainfully occupied and unknown	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Gender								
Male	.821	.000	.676	.000	.396	.000	.354	.000
Female	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Household Composition								
Single	1.03	.000	1.10	.000	1.040	.000	1.086	.000
Lone Parent with Children	.744	.000	.789	.000	.735	.000	.763	.000
Lone Parent no Children under 19	.371	.000	.389	.000	.238	.000	.232	.000
Couple with Children	.493	.000	.496	.000	.326	.000	.371	.000
Couple no Children under 19	.136	.000	.086	.000	-.152	.000	-.127	.000
Couple no Children	.496	.000	.513	.000	.414	.000	.477	.000
Other Households	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Age								
15-24	-.431	.000	-.606	.000	-.794	.000	-.754	.000
25-34	.303	.010	.190	.074	-0.14	.915	.014	.911
35-44	.410	.001	.335	.002	.198	.128	.268	.037
45-54	.339	.004	.243	.022	.161	.217	.244	.058
55-64	.284	.016	.198	.064	.201	.124	.315	.015
65-74	.210	.089	.122	.277	.205	.138	.386	.005
75+	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Distance (KM)								
0-3	-7.95	.000	-7.56	.000	-.7.210	.000	-7.439	.001
6-10	-6.58	.000	-6.56	.000	-4.017	.000	-3.581	.028
11-15	-6.55	.000	-4.28	.000	-2.270	.000	-2.018	.133
16-20	-3.56	.000	-1.75	.000	-1.255	.000	-1.173	.309
21-30	-1.33	.000	-.681	.000	-.509	.000	-.739	.478
31-40	-2.46	.000	0.13	.642	-.177	.021	-.409	.664
41+	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Number of Cars								
1	2.70	.000	2.83	.000	2.465	.000	2.280	.000
2	2.28	.000	2.43	.000	2.326	.000	2.166	.000
3	3.16	.000	3.41	.000	3.261	.000	3.138	.000
4 or more	3.42	.000	3.67	.000	3.504	.000	3.392	.000
None	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
- 2 log-likelihood at convergence	581007.216		625595.82		265512.762		267300.31	
N	1,438,990		1,438,990		422,389		422,349	
Nagelkerke R2	.780		.794		.657		.683	

5. Conclusions and discussion

The introduction of a cap and share scheme is one of a number of proposals currently being considering by policymakers to reduce GHG emissions. Ireland, like many other countries, is currently searching for the appropriate policies to reduce emissions from transport and move individuals more sustainable modes of transport. Other policies currently under consideration include the promotion of walking and cycling, the introduction of new public transport services, the electrification of the private car fleet and the introduction of road pricing. One of the benefits that a downstream cap and share scheme policy, as presented in this paper, has over these other policies is that at the it uses tangible and financial benefits and costs to encourage behavioural change. Another benefit of a cap and share scheme is that it would provide individuals with real information on market value of carbon emissions of their trips and this could be used as a tool to encourage the use of alternative modes of transport.

The research presented in this paper provides an indication to the possible impacts of a cap and share scheme. While such a scheme has many benefits, implementing a cap and share scheme like the one proposed in this paper has a number of obstacles and further research needs to be conducted in this area. One of the main technical barriers to implementing this scheme is to obtain a reliable, accurate and cost effective method of collecting information on individuals' trips to measure the emissions per individual. A second large technical barrier is to develop a market personalised emissions trading, on which individuals that go above their allocated allowance are able to purchase unused allocations from others. The creation of such a market and the associated transaction cost also inhibit the development of this policy. Further research on the cost effectiveness of a cap and share scheme would inform the debate in this area and enable policymakers to compare the costs and benefits of this scheme with alternative policy options.

The results presented in this paper provide a useful indicator of the effects of a cap and share scheme in a small country. Larger families and those constrained to using a car as their primary mode of transport are the socio-economic groups most significantly affected by the introduction of a cap. This is particularly true of rural families with no access to alternative forms of transport. Theses equity impacts on which travellers are likely to be worse affected need to be addressed to ensure the scheme is equitable. With this in mind future research will need to determine the potential equity effects of the transfer of wealth created by a cap and share scheme and the merits of introducing a Dublin only cap as opposed to a national cap based on the above findings. Extending the research beyond commuting trips to non-work relating travel would also give a clearer conclusion about which sections of the population would fall above a cap.

Acknowledgements
The authors would like to thank the Central Statistics Office of Ireland for providing the data for this study. The authors would also like to thank the referees sincerely for their helpful suggestions to improve the original manuscript.

References

1. Brand, C. and J. M. Preston *`60-20 emission'--The unequal distribution of greenhouse gas emissions from personal, non-business travel in the UK.* Transport Policy *Transport Policy*, 17: 9-19, 2010

2. California Air Reseources Board, Market Advisory Committee to the California Air Resources Board. *Recommendations for Designing a Greenhouse Gas Cap-and-Trade System for California.* California Air Resources Board, Sacramento, Calif., 2007.

3. Department of Transport, *Smarter Travel - A sustainable Transport Future*. Department of Transport, Dublin, Ireland, 2009

4. Environmental Protection Agency, *Ireland's National Greenhouse Gas Emissions Inventory for 2007*, Environmental Protection Agency, Dublin, Ireland, 2008

5. Ellerman, A. D. *Tradable Permits for Greenhouse Gas Emissions: A primer with particular reference to Europe*. MIT Joint Program Report no. 69, Mass, 2000

6. Fawcett, T. *Investigating carbon rationing as a policy for reducing carbon dioxide emissions from UK household energy use.* PhD. University College, London, 2005

7. Fleming, D. *Tradable Quotas: Using information technology to cap national carbon emissions*. European Environment 7(5):139-148., 1997

8. Harwatt, H. *Reducing carbon emissions from personal road transportation through the application of a Tradable carbon Permit scheme: Empiracal findings and policy implications from the* UK. Institute for Transport Studies, University of Leeds, 2008

9. Millard-Ball, A. *Cap-and-Trade: Five Implications for Transportation Planners*. 88th Annual Meeting of the Transportation Research Board. Washington D.C, 2008

10. Millard-Ball, A. Municipal Mobility Manager: New Transportation Funding Stream from Carbon Trading? In *Transportation Research Record: Journal of the Transportation Research Board, No. 2079,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 53–61.

11. Niemeier, D., G. Gould, A. Karner, M. Hixson, B. Bachmann, C. Okma, Z. Lang and D. Heres Del Valle. *Rethinking downstream regulation: California's opportunity to engage households in reducing greenhouse gases*. Energy Policy 36(9):3436-3447, 2008

12. Raux, C. and Marlot, G. *A system of tradable CO2 permits applied to fuel consumption by motorists. Transport Policy,* 12**,** 255-265, 2005
13. Sustainable Development Council, *A study in Personal Carbon Allocation: Cap and Share.* Sustainable Development Council, Dublin, Ireland, 2008

14. Starkey, R., K. Anderson. *Domestic Tradable Quotas: A policy instrument for reducing greenhouse gas emissions from energy use.* Tyndall Centre for climate change Research, Technical report 39, 2005

15. Tietenberg, T. *The tradable permits approach to protecting the commons: what have we learned*. Presented at the 1st CATEP Conference: 'Trading scales: linking industry, local/regional, national and international emission trading schemes', Fondazione Eni Enrico Mattei, Venice, 3–4 December, 2001

16. Wadud, Z. *Personal carbon permits for road transport: Why, why noy and who wins?* Transportation Research Part A: Policy and Practise, In Press, 2010

17. Walsh, C., P Jakeman, et al. *A comparison of carbon dioxide emissions associated with motorised transport modes and cycling in Ireland.* Transportation Research Part D: Transport and Environment, 13(6) : 392-399, 2008

18. Washinton, S., Karlaftis, M. & Mannering, F. *Statistical and econometric methods for transportation data analysis*, CRC Press, 2003