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Commute mode choice dynamics: Accounting for day-to-day variability in longer term change

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It is of interest to transport policy makers to know whether interventions promoting sustainable transport modes can produce long-term changes in commute mode choices. Recent evidence has shown that a significant minority of commuters are variable in their day-to-day commute mode choices. This suggests that recognition should be given to day-to-day variability in investigating longer term commute behaviour changes. This paper introduces a panel survey that has been specifically designed to capture both day-to-day variability in commuting behaviour and longer term change in commuting behaviour. The analysis of the data accounts for day-to-day variability in commuting behaviour by identifying commute mode choice patterns at the weekly level. It then analyses transitions in commute mode choice patterns over time based on observations at three-monthly intervals. The results show that about one in four commuters mix driving alone to work with using other modes in a typical week and this is more likely for males, those with access to a bicycle and those working in another location during the week and less likely for those who work part-time. Changes in commute mode choices over a three month period are influenced by employment situational characteristics, access to mobility resources, satisfaction with commuting, awareness of sustainable transport measures and changes in life circumstances. Inspection of trajectories for those panel participants who responded to all five waves of the panel indicates that there are more cases of sustained switches between intermediate groups (e.g. car alone commuting to partial car alone commuting) than switches between extreme commuting groups (e.g. car alone commuting to non-car alone commuting).
The styles are described in more detail in the remaining of this document.

Keywords: commute mode, multimodality, dynamics, behavioural change, transitions, panel data

1. Introduction

The journey to work is a main target for transport policy interventions given the impacts that commuting has on the daily lives of individuals and on society in general. In Great Britain in 2014, 65% of commute trips were made by car (DfT, 2015). Policy interventions will be better

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informed if they are based on a good understanding of individual commuting behaviour. It is widely regarded that commuting, as a frequently repeated behaviour, becomes habitual and is repeated without conscious deliberation, unless there are changes in situational context (Verplanken et al., 2008). This has led to research investigating how contextual changes influence changes in commute mode choices in the longer run (for example, Clark et al., 2016). These have made the assumption that a single mode of transport is used at any time, such as prior to and after a contextual change. However, evidence has emerged that this is an over-simplification with a significant minority of commuters exhibiting day-to-day variability in commute mode choices (Kuhnimhof, 2009). This suggests the need to take account of day-to-day variability in commute mode choices when investigating longer term commute behaviour changes.

The paper addresses this requirement by presenting findings from analysis of a panel survey which was specifically designed to capture both day-to-day variability in commuting behaviour and longer term change in commuting behaviour. The panel data was collected for commuters in Bristol (England) during a period of time in which measures were implemented to encourage travel by alternatives to driving a car alone to work.

The advantages of using panel data for analysis of travel behaviour have been articulated by many authors (Bradley, 1997; Goodwin, 1998; Kitamura, 2000; Chatterjee, 2011). Analysis of panel data takes advantage of both cross-sectional variation and longitudinal changes in the phenomenon of interest to reveal dynamic properties of the phenomenon and explanations for change. The panel survey collected self-reported weekly commuting data on five occasions at three month intervals between July 2014 and July 2015. The objectives of the analyses reported in this paper are to identify weekly mode choice patterns, the extent of change in these over time and factors which influence these to change.

The paper first reviews previous research investigating the dynamics of commuting mode choice behaviour, identifying the gap in knowledge being addressed by this study. It then describes the data that has been collected before reporting results of the analysis and reflecting on the contributions of the findings and further research that can be undertaken.

2. Previous work

The review starts by considering studies which have examined day-to-day variability in commute mode choices before moving to studies which have examined changes in commute mode choices over the longer run.

Within a manuscript, up to three levels of headings may be used, not including the title of the manuscript. The first two levels are numbered, the third is not, but is typed in Italic. Figures, tables and mathematical expressions are numbered throughout the manuscript, not by section.

2.1 Day-to-day variability in commute mode choices

There has been an upsurge of interest in recent years in the variability of modes that people use in their travel routines. Multimodality has been referred to as the use of more than one transport mode within a given period of time (Kuhnimhof et al., 2012). Heinen and Chatterjee (2015) reviewed literature on the topic of multimodality and found most research has considered the variability of modes used by individuals across all travel purposes, but little research has considered variability of modes used for specific journey purposes such as commuting.

It would be expected that individuals might use different transport modes across different journey purposes (involving different destinations for example) but less expected for a single journey purpose such as commuting. However, Kuhnimhof (2009) found from one week travel diary data from the German Mobility Panel (MOP) that 28% of people used more than one main mode of transport for travel to work over a week (i.e. 28% used different modes on different

days). Block-Schachter (2009) found from survey data for about 10,000 staff and students at MIT (Cambridge, United States) that 19% varied their commuting mode during the survey week.

Vij et al. (2013) used six week Mobidrive travel diary data to test the idea that individuals have modality styles (defined as behavioral predispositions characterized by a certain travel mode or set of travel modes that an individual habitually uses). They used a two-step process of first identifying modality styles and then modelling the effect of modality styles on mode choices for work tours and non-work tours. They identified two modality styles: habitual automobile drivers and multimodal individuals. Multimodal individuals were further sub-categorised as time sensitive or time insensitive. Habitual automobile drivers were more likely to be male and in employment. Time sensitive multimodals were more likely to be non-working women and time insensitive multimodals were more likely to have low car ownership and a transit season pass.

The findings above suggest that, although there are habitual commuters who use the same mode every day, there is a significant minority of commuters who vary the modes they use in their short-term (weekly) schedules. An important question is what time period should be used to capture short-term variability in commute mode choice or, in other words, the wavelength of commuting routines. Cherchi and Cirillo (2014) show that there is more variation in mode choice within a week than between day of week across different weeks in an analysis of the six week Mobidrive data. This indicates that a week is the natural 'wavelength' of commuting routines and obtaining data for a week is likely to capture well the short-term variability of commute mode choice behaviour.

2.2 Longer run changes in commute mode choices

We now review studies which have used panel data to analyse longer term changes in commute mode choice. These studies have obtained repeated observations of individual commuting behaviour with time intervals ranging from two weeks apart to three years apart. Some of the studies have focused on investigating how commute mode choices are affected by changes in people's daily schedules and life circumstances, while others have investigated the effect of transport interventions. They have all assumed that on each survey occasion there is a single main commute mode (often because this is all the data has provided) without any recognition of day-to-day variability in commute mode choice.

Heinen et al. (2011) conducted a 12-month panel survey of commuters who cycled to work in the Netherlands where they were contacted every fortnight on random days of the week and asked to indicate their commute mode on that day. Analysis showed that about one half of respondents were 'occasional' cyclists, reporting cycling to work on one-third or less of occasions, and the other half were 'frequent' cyclists. In modelling the commute mode choices of the participants, the authors found that longer commuting distance, the need to wear business attire, the need to carry goods, the need to use a car in office hours, commuting in the dark and facing a higher wind speed and higher rainfall reduced likelihood of cycling to work for any particular observation. This study shows that mode choice is affected by daily work requirements and seasonal influences.

Panter et al. (2013) identified predictors of changes in commuting mode occurring over a 12 month interval for a sample of 655 workers in Cambridge, UK. They found switching to walking to work from another commute mode was associated with not having children, perception of convenient public transport and lack of free workplace parking. Switching to cycling to work from another commute mode was predicted by perception of convenient cycle routes and more frequent bus services. The study did not test the influence of change variables, but is useful in showing how people in certain circumstances are more likely to make a change to their commute mode choice.

Oakil et al. (2011) conducted a multiple regression analysis of the relationship between a range of life events and commute mode changes using data from a retrospective survey capturing 21 year

life histories of nearly 200 respondents in Utrecht, Netherlands. Switches from commuting by car from one year to the next were associated with changing to part time work, changing employer, and separation from a partner (one year before the mode change). Switches to commuting by car were associated with birth of the first child, changing employer, and separation from a partner (one year before the mode change).

Clark et al. (2016) examined the effect of life events on the likelihood of changing commute mode, while controlling for a wide range of socio-economics, spatial context and environmental attitude. This was conducted for a large, representative sample of the English working population using data from the first two waves of the UK Household Longitudinal Study. One third of those that cycle or get the bus to work, and one quarter of those that walk to work, are shown to change commuting mode by the following year. Car commuting is more stable, with only one in ten car commuters changing mode by the following year. Commute mode changes are found to be primarily driven by alterations to the distance to work which occur in association with changing job or moving home. Switching to non-car commuting becomes much more likely (9.2 times) as the distance to work dropped below three miles. High quality public transport links to employment centres are shown to encourage switches away from car commuting and mixed land uses are shown to encourage switches to active commuting (walking and cycling). Switches away from car commuting are found to be more likely (1.3 times) for those with a pro-environmental attitude.

Bradley (1997) investigated the effect on commute mode choice of a new rail commuter line in the Netherlands. Before and after panel data for 475 commuters collected a year apart showed that 119 of the 475 car and bus commuters switched to the train. Mode choice models estimated from the data showed that mode choices after the introduction of the rail commuter line adapted to the change in relative travel times by car, bus and rail, although they had not fully adjusted at the time of the after survey.

Heinen et al. (2015) investigated changes in commute mode choices of 470 workers in Cambridge after introduction of a guided busway with a path for walking and cycling in 2011. Seven-day travel to work diaries were obtained in 2009 and 2012. The diaries recorded the number of commute trips made by different modes. While net changes in mode share were small, they found that those living close to the new infrastructure were more likely to increase walking and cycling mode share and reduce car mode share (with no significant effect on bus use).

Thøgersen (2009) evaluated the impact of a free one month public transport card targeted at commuters who owned a car in Copenhagen. An intervention group (n=373) received a free public transport travel card and a control group (n=224) did not receive the card. The study showed that it was only those in the intervention group who had moved home or changed workplace within the last three months that increased their public transport use. This highlights the potential importance of the interactive effect of life events with transport interventions.

The above studies of the longer term dynamics of commuting demonstrate influences on mode choice of seasonality (Heinen et al. 2011), being in a more susceptible baseline state for change to occur (Panter et al. 2013; Clark et al., 2016), changes in life circumstances (Oakil et al., 2011; Clark et al., 2016) and transport interventions (Bradley, 1997; Heinen et al., 2015; Thøgersen, 2009).

2.3 Gaps in knowledge
Recent evidence has shown that a significant minority of commuters are variable in their day-to-day commute mode choices. This suggests that recognition should be given to day-to-day variability in investigating longer term commute behaviour changes. This has not been investigated up to now. This gap in research motivates the work reported in this paper which involves the collection of data that captures commute mode choices made over a one week period on five repeated occasions over a twelve month period. The analysis of this data seeks to identify

weekly mode choice patterns, the extent of change in these over time and factors which influence these to change.

One recent study by Kroesen (2014) had similar objectives to this but considering travel behaviour across all purposes rather than commuting travel. Kroesen investigated whether modality is stable or changeable using travel diary data from Dutch Mobility Panel. His analysis first involved latent class cluster analysis to identify five modal pattern clusters before using transition analysis to explore the dynamics of modal patterns over a one year period. Multimodal users were more likely to switch clusters than single mode clusters and younger people, people who moved house and people who changed jobs were found to have lower probabilities of staying in the same cluster and higher probabilities of transitioning.

Our aim, like Kroesen (2014), is to analyse transitions in modal behaviour but with a specific focus on commuting behaviour. By focusing on a specific travel purpose we anticipate greater potential to identify explanatory factors for mode choice change that will be useful to policy makers. In the analysis we consider the role of different types of explanatory factors previously indicated to be important to commuting mode choice dynamics in the literature: daily schedules; seasonal factors; baseline susceptibility to change; changes in life circumstances; changes in travel context. Further to this, commuting has been argued to be strongly habitual and we aim to critically assess this claim by examining the extent of variability in commute mode choices.

3. North Bristol Commuter Panel

The North Bristol Commuter Panel (NBCP) collected longitudinal data on the commuting behaviour of workers at 24 employers located in two strategic employment areas on the western and northern edges of the city of Bristol, south-west England – the 'Bristol Ports area' and the 'Bristol North Fringe'. In both employment areas, interventions were being carried out to encourage the take up of alternatives to driving a car alone to work.

The Ports area is situated to the west of the city, alongside the Severn Estuary, and is separated from central/west Bristol by a semi-rural area. The North Fringe is located to the north of the city, and merges with more densely populated suburban areas. It is subject to greater road congestion and pressure on parking than the Ports area. Both areas are well connected to inter-urban highways. The North Fringe is better served by public transport, cycling and walking routes generally, although there is some variation in provision across the North Fringe area.

The interventions in the employment areas included new and improved bus services, new and improved off-site and on-site cycling and walking infrastructure, marketing and promotion campaigns and support for employer-led initiatives. The interventions form part of an on-going programme of activities in the Bristol area which has received Local Sustainable Transport Fund (LSTF) grants from the UK Department for Transport. The grants have applied to the period 2012 to 2015. The NBCP is a follow on to a travel to work survey which was conducted in March 2014 across the 24 employers. A total of 9,684 employees responded to the March 2014 survey which is estimated to represent 27% of the total workforce in the participating employers.

The objective of the NBCP was to monitor changes in commuting behaviour for a sample of employees of the two strategic employment areas between July 2014 and July 2015. The sampling frame for the Panel was the employees who responded to the March 2014 travel to work survey and were willing to be contacted about further research. The timing of the five waves of the Panel were as follows:

- Wave 1: July 2014

- Wave 2: October 2014

- Wave 3: January 2015

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- Wave 4: April 2015

- Wave 5: July 2015

At Wave 2, those who had not responded to the Wave 1 survey were re-invited to join the panel and participate in the Wave 2 survey. By Wave 3, those who had responded to the panel survey at either Wave 1 or 2 were considered to be members of the panel (N=1947). It was decided to return to these same people at each subsequent wave, unless they notified the researchers that they wished to leave the panel.

Table 1 identifies the number of people invited to participate at each wave and the number of responses received and also provides a breakdown of mode share at each wave based on the question 'what form of transport do you normally use to travel to work?'. Originally 3233 respondents to the Match 2014 travel to work survey were invited to participate in the Panel. There were a total of 1526 responses at wave 1, 1539 responses at wave 2, 1494 responses at wave 3, 1383 responses at wave 4 and 1255 responses at wave 5. The percentage of commuters who normally drive a car alone to work is lower in the panel wave response samples than in the Match 2014 response sample and the percentage of cycle users is higher. Otherwise, mode shares are similar between the panel wave response samples and March 2014 response sample.

The questions covered at each wave of the Panel are summarised in Table 2. The survey was distributed online only, and was created using Survey Monkey software. Socio-demographic, employment and home/work address information was collected in the March 2014 travel to work survey with respondents asked to give details of any changes in circumstances at each panel wave.

Table 1: Response numbers and mode share for travel to work in March 2014 and panel waves

	March 14		Wave 1		Wave 2		Wave 3		Wave 4		Wave 5	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Response numbers												
Invited	35578	-	3233	-	3104	-	1947	-	1917	-	1909	-
Resp.	9528	27	1526	47	1539	50	1494	77	1383	72	1255	66
Mode shared based on question 'What form of transport do you normally use to travel to work?'												
Car own	4969	52	708	46	737	48	702	47	620	45	580	46
Car shar	1448	15	210	14	211	14	221	15	201	15	188	15
M'cycle	175	2	39	3	44	3	39	3	45	3	40	3
Cycle	1206	13	294	19	290	19	269	18	268	19	235	19
Walk	604	6	86	6	85	6	87	6	78	6	66	5
Bus	537	6	84	6	83	5	84	6	76	6	65	5
Train	475	5	101	7	85	6	82	6	84	6	76	6
At home	16	0	2	0	3	0	5	0	6	0	5	0
Other	98	1	2	1	1	0	5	0	5	0	0	0

Resp. = response numbers, Car own = Car alone, Car shar = car shared with others, M'cycle = Motorcycle

Table 2: Panel survey topic areas and questions

Topic area	Questions
Commuting mode choice behaviour	What form of transport do you normally use to travel to work? (form of transport used for the longest distance if use more than one)
	What main form of transport did you use on each day you worked this week? (form of transport used for the longest distance if use more than one)
	If relevant, what secondary form of transport did you use on each day you worked this week?
	Were you based at a location other than your normal place of work on any day this week?
Commuting satisfaction and normal mode perceptions	How satisfied or dissatisfied are you with your journey to work on a typical day?
	Agreement with (six) statements that normal form of transport is convenient/ cheapest option/ quickest option/reliable/ safe/good for my health
Awareness of travel measures in the area where you work	Tick box list where respondent asked to indicate if aware of specific measures such as sustainable travel events, improved cycling routes and new bus services.
	Closed question (yes/no) asking whether any measure has influenced respondent.
Change of circumstances since previous survey completed	Change of employer (if so, address of new employer)
	Change of work location (if so, address of new work location)
	Change of home location (if so, address of new residence)
	Gained or lost access to car
	Gained or lost access to bicycle

4. Research questions

Our analysis focuses on the modes of transport used by panel members for their weekly commuting and how these changed over the course of a one year period between July 2014 and July 2015. Panel members were asked to report on their commuting travel for a specific week at each wave (with those away from work asked to report it for the week when they returned). They were asked for the main mode used on each day of the week (the mode used for the longest distance if more than one mode was used), and any secondary mode if that was used.

In the analysis reported in this paper we have only considered the main mode used each day the participant travelled to work. Examination of the wave 1 data showed that 23% of respondents reported using a secondary mode in their travel to work in the week of the survey with walking used as a secondary mode by 12% of respondents. However, inspection of the data showed inconsistencies in how respondents reported secondary modes. Furthermore, the focus of our analysis is not on whether different modes are combined for each journey to work but on the variability in mode usage across different days.

The analysis sought to answer the following specific questions:

1. How prevalent is it for commuters to vary how they get to work from day to day during a one week period and what socio-demographic, employment and journey to work characteristics are predictors of this?

2. How prevalent is it for commuters to change their weekly mode choice patterns and what socio-demographic, employment, journey to work, time of year characteristics, life events and transport intervention measures are predictors of this?

5. Results

5.1 Data description

The data sample consists of responses recorded across the five waves by the panel participants. Details of the wave 1 analysis sample are presented in Table 3. The distribution of characteristics is similar for the other waves.

Table 3: Characteristics of wave 1 analysis sample

CHARACTERISTIC	n	%
DEMOGRAPHIC		
Male	830	56.5
Disability	74	5.04
Age: 17 to 29	162	11.03
Age: 30 to 39	333	22.67
Age: 40 to 49	431	29.34
Age: 50 to 59	464	31.59
Age: 60+	77	5.24
EMPLOYMENT		
Employment: Manual	130	8.85
Employment: Junior/clerical	320	21.78
Employment: Middle management	321	21.85
Employment: Professional / Management	690	46.97
Part-time employed [Ref: No]	196	13.34
COMMUTE JOURNEY		
Commute distance: 0 to 5mi	376	25.59
Commute distance: 5 to 10mi	412	28.05
Commute distance: 10 to 25mi	400	27.23
Commute distance: 25mi+	253	17.22
Empl location: Filton	471	32.06
Empl location: Fringe	122	8.3
Empl location: Portside	80	5.45
Empl location: Stoke Gifford	796	54.19
Car parking spaces per employee *(mean / SD)*	*0.48*	*0.18*
Worked in another location during diary week	242	16.47
MOBILITY RESOURCES		
Access to a bicycle for work	654	44.52
Access to a car for work	1182	80.46
Driving licence	1334	90.81
LIFE EVENTS		
Moved home	68	4.63
Changed workplace	109	7.42
Sample size	1469	

The analysis sample (N=1469) was created by excluding responses where no travel to work was reported during the survey week, or responses which contained illegitimate responses which

could not be resolved (such as more than one primary mode being recorded on any day or 'other' being selected as primary mode on any day (these responses were unsuitable for identifying weekly mode use patterns).

Table 4 shows that about 61% of employees travelled to work for the conventional five days a week with most other employees travelling to work on three or four days. For the purposes of our analysis those reporting that they worked from home on a particular day were considered as not travelling to work.

Table 4: Number of days travelled to work

No. commuting days	Wave 1		Wave 2		Wave 3		Wave 4		Wave 5	
	n	%	n	%	n	%	n	%	n	%
1	11	0.75	9	0.6	6	0.42	6	0.46	9	0.77
2	56	3.81	35	2.35	43	3.01	50	3.83	33	2.83
3	167	11.37	163	10.95	160	11.2	132	10.12	132	11.31
4	282	19.2	331	22.23	284	19.89	293	22.47	287	24.59
5	902	61.4	908	60.98	881	61.69	788	60.43	672	57.58
6	20	1.36	12	0.81	21	1.47	12	0.92	12	1.03
7	31	2.11	31	2.08	33	2.31	23	1.76	22	1.89
Total	1469	100	1489	100	1428	100	1304	100	1167	100

The total number of person-days recorded using different modes of transport (as main mode) is presented in Table 5. This shows that driving alone is the most common option (reported for 48% of days travelled to work in wave 1) with cycling and car sharing the next most common options (reported for 18% and 13% respectively of days travelled to work in wave 1). These are similar mode shares to those reported in Table 1 for wave 1 based on the question 'which form of transport do you normally use to travel to work?'.

Table 5: Number of person-days using different modes of transport (as main mode)

Mode	Wave 1		Wave 2		Wave 3		Wave 4		Wave 5	
	n	%	n	%	n	%	n	%	n	%
Car alone	3141	47.6%	3344	49.8%	3203	49.5%	2780	47.5%	2521	48.4%
Car share	835	12.7%	941	14.0%	959	14.8%	768	13.1%	719	13.8%
Motorcycle	194	2.9%	205	3.1%	143	2.2%	212	3.6%	181	3.5%
Bicycle	1214	18.4%	1076	16.0%	1008	15.6%	1017	17.4%	885	17.0%
Walk	345	5.2%	374	5.6%	394	6.1%	324	5.5%	261	5.0%
Bus	377	5.7%	382	5.7%	364	5.6%	357	6.1%	296	5.7%
Rail	493	7.5%	399	5.9%	399	6.2%	389	6.7%	342	6.6%
Total	6599		6721		6470		5847		5205	

5.2 Weekly commute mode choice patterns

Table 6 provides an initial indication of the extent of multimodality in weekly commute mode choice patterns. It shows for the wave 1 data (N=1469) the numbers of panel respondents reporting that they used each mode option (as a main mode) during the survey week and the

number of respondents that solely used each mode option (that were unimodal users of that mode). This shows that in total 70% (1033/1469) of panel participants were unimodal at wave 1. 61% of wave 1 participants had at least one day driving alone with 39% solely driving alone (64% of car alone users). The percentage of those that reported cycling to work that were unimodal was lower at 46% and percentage of those that reported driving with others that were unimodal was 36%.

Table 6: Number of users of different modes and number of unimodal users at wave one

	No. of users		No. of unimodal users		
Mode	n	% of total	n	% of total	% of mode users
Car alone	896	61.0%	573	39.0%	64.0%
Car share	289	19.7%	104	7.1%	36.0%
Motorcycle	55	3.7%	25	1.7%	45.4%
Bicycle	340	23.1%	155	10.6%	45.6%
Walk	107	7.3%	48	3.3%	44.9%
Bus	120	8.2%	55	3.7%	45.8%
Rail	151	10.3%	73	5.0%	48.3%
Total			1033	70.3%	

Table 7 shows the most prevalent weekly commute mode pattern groups at wave 1. It shows that apart from the seven unimodal groups, the groups which are highly prevalent are car alone and car share (7%) and car alone and cycle (6%). A cluster analysis was performed on the mode use frequencies reported by each participant in wave 1 and produced groups similar to those in Table 7 (i.e. the first four groups plus a miscellaneous other group were produced for a five cluster solution).

Table 7: Weekly commute mode pattern groups at wave 1

Weekly commute mode pattern	**Frequency**	**%**
Car alone unimodal	573	39
Cycle unimodal	155	11
Car alone and car share	106	7
Car share unimodal	104	7
Car alone and cycle	95	6
Rail unimodal	73	5
Bus unimodal	56	4
Walk unimodal	48	3
Car alone and rail	33	2
Motorcycle unimodal	25	2
Car share and cycle	23	2
Car alone and bus	22	2
Car alone and walk	21	1
Cycle and train	11	1
Car alone and motorcycle	11	1
Other	113	8
Total	1469	100

Figure 1 shows the distribution of the proportion of days of car alone commuting in the wave 1 sample. This shows that about two in five respondents made no car alone commutes and a similar proportion only commute by car alone (car alone unimodals). Between these extremes, there is a fairly even distribution of proportion of days when commuters drive alone.
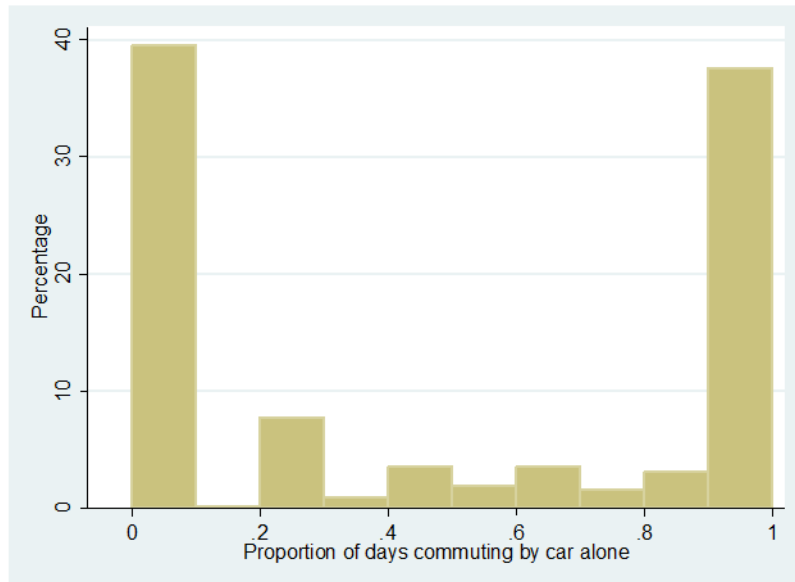

Figure 1.   Distribution of days commuting by car alone at wave 1

The main policy goal of sustainable transport promotion in North Bristol was to reduce the amount of car alone commuting by encouraging individuals who only drive alone to try using other modes (at least some of the time) and to encourage individuals already using alternatives to driving alone to do so more often. Our analysis therefore considers three groups: those who only use car alone to commute to work (car alone), those who partially use car alone to commute to work (partial car alone) and those who do not use car alone to commute to work (no car alone). Many different permutations of multimodality are possible and were observed in the data but a simplified classification is necessary in order to focus analysis. Defining multimodality groups based on driving alone is justifiable given policy interest in reducing this and the high prevalence of commuters who partly drove alone and partly travelled to work in other ways (at wave one there were 106 respondents who drove alone and travelled by car with others and 95 who drove alone and cycled).

Table 8 shows the number of members of these groups at each wave. It shows a similar share of commuters who only drive alone to work and who do not drive alone to work at all (39% in each group at wave one) and a smaller group who partly but not fully drive alone to work (22% at wave one). Table 8 shows stability at the aggregate level in the share of commuters in each of the three groups over the panel waves, but it does not tell us anything about the number of commuters switching groups between waves.

Table 8: Car alone commuting group prevalence over panel waves

Group	Wave 1 n	Wave 1 %	Wave 2 n	Wave 2 %	Wave 3 n	Wave 3 %	Wave 4 n	Wave 4 %	Wave 5 n	Wave 5 %
Car alone	573	39.01	574	38.55	558	39.08	478	36.66	453	38.82
Partial car alone	323	21.99	361	24.24	335	23.46	319	24.46	268	22.96
No car alone	573	39.01	554	37.21	535	37.46	507	38.88	446	38.22
Total	1469	100	1489	100	1428	100	1304	100	1167	100

5.3 Predictors of weekly commute mode choice patterns

A multinomial logit model was run with STATA 12 to identify predictors of belonging to the commuting groups at wave 1. The purpose of the multinomial logit model was to explain the nominal outcome variable (weekly commute mode choice pattern as defined above) and the independent variables should not be interpreted as elements of a utility function. Results are shown in Table 9. The reference group is commuting by car alone only. Being male, having access to a bicycle for commuting and working in another location during the survey week increase the odds of being in partial car alone group. Working part-time and working in Filton and Portside areas (two of the four sub-areas included as part of the study) decrease the odds of being in partial car alone group. Having a bicycle, being younger and having a commute distance up to 5 miles increase the odds of being in no car alone group. More car parking spaces, working part-time, working in another location during survey week and having a commute distance between 10 and 25 miles decrease the odds of being in no car alone group. Having access to a car for commuting to work decreases the odds of being in no car alone group substantially (relative to being in car alone group or partial car alone group). This variable is not strictly independent and exogenous, as it is not possible to drive alone to work without access to a car. However, it does indicate that having access to a car makes a commuter likely to at least partially drive alone, if not always drive alone.

Table 9: Predictors of commuting group membership at wave 1

	Partial car alone		No car alone	
Variable	Odds ratio	P>z	Odds ratio	P>z
DEMOGRAPHIC				
Male [Ref: No]	1.401	0.053	1.062	0.699
Age: 17 to 29	1.552	0.113	1.659	0.043
Age: 30 to 39	1.423	0.088	1.464	0.044
Age: 50 to 59	0.881	0.510	1.071	0.692
Age: 60+ [Ref: 40 to 49]	0.758	0.445	0.810	0.510
EMPLOYMENT				
Employment: Manual	0.707	0.257	0.981	0.940
Employment: Junior/clerical	1.141	0.544	1.216	0.295
Employment: Middle management [Ref: Professional]	1.023	0.908	0.933	0.699
Part-time employed [Ref: No]	0.492	0.006	0.536	0.003
MOBILITY RESOURCES				
Access to a bicycle for work	3.612	0.000	3.775	0.000
Access to a car for work*	0.783	0.307	0.177	0.000
COMMUTE JOURNEY				
Empl location: Filton	0.705	0.048	0.777	0.107
Empl location: Portside	0.456	0.035	0.656	0.196
Empl location: Fringe [Ref: Stoke Gifford]	1.062	0.828	1.029	0.916
Parking spaces per employee	0.687	0.402	0.195	0.000
Commute distance: 0 to 5mi	1.460	0.136	2.604	0.000
Commute distance: 5 to 10mi	1.219	0.401	1.135	0.555
Commute distance: 10 to 25mi	1.102	0.664	0.657	0.047
Commute distance: Unknown [Ref: 25+mi]	0.304	0.145	0.771	0.612
Worked in another location during survey week	1.779	0.003	0.560	0.004
Constant	0.364	0.012	4.584	0.000
	Reference group: Car alone			
n	1452			
Pseudo R-Squared	0.141			

Notes: Grey shading indicates significance at 95% level

* Not strictly independent/exogenous variable, as only possible to be in car alone group or partial car alone group if have access to a car for work.

5.4 Transitions in weekly commute mode choice patterns

Table 10 shows the frequency of transitions between commuting groups across the four different wave-pairs (wave 1 to 2, wave 2 to 3, wave 3 to 4, wave 4 to 5) for all valid cases where responses were received from panel participants at consecutive waves. It is apparent that transitions from car alone commuting to partial car alone commuting are more probable (0.13 transition

probability) than from car alone commuting to no car alone commuting (0.03 transition probability). Similarly, transitions from no car alone commuting to partial car alone commuting are more probable (0.14 transition probability) than from no car alone commuting to car alone commuting (0.03 transition probability). Transitions from partial car alone commuting are equally probable to either of the other groups (0.22 transition probabilities). Probabilities of transitions appear to be consistent over time.

Table 10: Transition frequencies between commuting groups

	Wave 1 to 2		Wave 2 to 3		Wave 3 to 4		Wave 4 to 5		Pooled wave pairs	
Transition	n	%	n	%	n	%	n	%	n	%
car alone to car alone	336	31	373	31	357	31	330	32	1396	31.48
car alone to partial car alone	64	6	50	4	63	5	43	4	220	4.96
car alone to no car alone	16	1	16	1	14	1	2	0	48	1.08
subtotal	*416*		*439*		*434*		*375*		*1664*	
partial car alone to partial car alone	131	12	169	14	167	15	146	14	613	13.82
partial car alone to car alone	56	5	79	7	49	4	49	5	233	5.25
partial car alone to no car alone	58	5	60	5	58	5	57	6	233	5.25
subtotal	*245*		*308*		*274*		*252*		*1079*	
no car alone to no car alone	333	31	372	31	369	32	324	32	1398	31.52
no car alone to car alone	11	1	9	1	18	2	12	1	50	1.13
no car alone to partial car alone	63	6	66	6	56	5	59	6	244	5.50
subtotal	*407*		*447*		*443*		*395*		*1692*	
missing	421		234		153		145		2422	
Total (excluding missing)	1068	100	1194	100	1151	100	1022	100	4435	100

5.5 Predictors of transitions in weekly commute mode choice patterns

Multinomial logit models have been estimated with STATA 12 for each of the three commuting groups to identify predictors of transitions to other groups (the reference group is stay in the same group). The data has been pooled. For example, for transitions from the car alone group all wave-pairs have been considered where the commuter started in the car alone group (and for which there was a valid response at the next wave). The cluster option is used (in estimating the multinomial logit models) to produce robust standard error estimates which account for intra-individual correlation in outcomes. Results are shown in Table 11 (at the end of the paper). Independent variables tested include state variables at the first observation period and change variables for changes occurring between the observation periods. Hence probability of transition is considered with respect to starting state and change of state. Previous behavioural history (before first observation of the pair of observations) is not taken into account.

The following different types of independent variables were tested:

- Demographic and employment characteristics - fixed (time constant) dummy variables.

- Access to mobility resources - dummy variables for access to car and bicycle at the second observation period.

- Commute journey characteristics – fixed variables based on employer (employment location and car parking spaces per employee[4]) and variables measured at second observation period for commute distance and worked in another location during survey week and measured at first observation period for satisfaction with commuting.

- Season of year - dummy variables for season at second observation period.

- Sustainable transport promotion - dummy variables for sustainable transport promotional visit to workplace between first and second observation period (based on employer) and individually reported awareness of recent sustainable transport measures at second observation period.

- Life events - dummy variables for individuals who had changed workplace (but not employer) and moved home between first and second observation period.

Change variables were tested for other variables than the life event variables (such as access to mobility resources) but the number of panel participants experiencing change between waves was small and hence it was preferable to include state variables which captured the influence of the variable at the second observation period.

Firstly, it is noted that the explanatory power of the models is modest, although not unusually low for mode choice models. The model for partial car alone has a particularly low pseudo R-squared value of 0.05 which indicates that the independent variables tested provide only limited explanation of transitions from partial car alone commuting and there are unobserved factors that have not been identified.

Demographic and employment characteristics are not strongly associated with the probability of making any of the transitions. Gender is not associated with increased or decreased probability of making any of the transitions. Being aged 30 to 39 (compared to other age groups) increases probability of moving from car alone to no car alone and staying as a no car alone commuter. Being aged 50 to 59 increases probability of moving from partial car alone to no car alone. Those in part-time employment are more likely to move to car alone (perhaps explained by these workers wanting the flexibility of their own car to fulfil wider activity and lifestyle needs).

Those with access to a bicycle are more likely to switch from car alone to partial car alone and to no car alone and less likely to switch from no car alone to car alone. Cycling to work is the most common alternative to car alone commuting in North Bristol and it may be interpreted that having access to a bicycle creates the opportunity to try an alternative to car alone commuting. Having access to a car increases probability of transitions away from no car alone to both car alone and partial car alone. This shows that if a car is available then people will tend to use it, at least occasionally. Having access to a car also reduces probability of transitions from car alone to no car alone. This result needs careful interpretation. All those in car alone group or partial car alone group need to have had access to a car to be able to drive alone to work. A very small number of respondents lost access to a car to drive to work and these would not subsequently have been able to drive alone to work – it is these cases that generate this result.

Working in Portside, the least accessible of the employment sub-areas by non-car modes, reduces the probability of moving from car alone to no car alone, and increases the probability of moving from partial to car alone. Having greater car parking availability at the workplace increases probability of transitions away from no car alone, and from partial to car alone. Thus the availability of a parking space at work draws people towards single occupancy car use. Those with short commute distances are more likely to switch from car alone and less likely to switch away from no car alone. This suggests that with longer commute distances it is less feasible or attractive to use alternatives to car alone commuting.

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[4] Panel participants who changed employer were removed from analysis.

Working in another location (than the usual workplace) during the survey week increases probability of moving to partial car alone commuting and decreases probability of moving away from partial car commuting. This shows that working in multiple work locations tends to involve using multiple commute mode options. It is not a surprising result but shows that this is a facet of working life that should be taken into account when considering commuting behaviour.

Partial car alone commuters who are satisfied with their typical commute in the first observation period are more likely to switch to no car alone and less likely to switch to car alone. This suggests that a positive experience when using alternatives to car alone commuting is important in determining whether they continue to be used.

Season of year is not strongly associated with the probability of making transitions. Moving from partial car alone to car alone was less likely between January 2015 and April 2015. This is expected given that commuting by non-car modes is more favourable during the spring and summer months (which in the UK tend to be drier, warmer and have longer daylight hours). However, moving from car alone to partial car alone or no car alone was less likely between April 2015 and July 2015. This is a counter-intuitive result, as commuting by walking or bicycle would be expected to be more prevalent during the warmer summer months. One possible explanation is that roads in North Bristol are less congested in July as further and higher education students are not present. This makes car commuting more favourable.

No statistically significant association was found between sustainable transport promotion visits to the workplace and any of the transitions. However, individually reported awareness of sustainable transport measures increases probability of a transition both from car alone commuting to partial car alone commuting and from partial car alone commuting to no car alone commuting. This suggests that sustainable transport measures can facilitate commuters in taking incremental steps to reduce their car alone commuting. It is acknowledged that the causal relationship is uncertain. Those workers making these transitions may have been prompted to do so for other reasons and actively sought information about sustainable transport options.

Moving home was shown to increase the probability of switching away from car alone commuting, but was not associated with the other transitions. This may be indicative of movers actively seeking residential locations that make it easier to commute to work by non-car modes, or it may be that moving home encourages deliberation over commuting after the move. Moving home has been shown in other research (Clark et al., 2016) to be strongly associated with commute mode changes. Moving workplace was not shown to be associated with any of the transitions.

5.6 Trajectories over five waves in commuting group membership
The analysis in sections 5.4 and 5.5 considered the probability of transitions in commute mode behaviour between waves at three month time intervals and predictors of this. Given the five waves of data available we can extend the analysis to consider the stability and change in individual commuting behaviour over a one year period.

For each panel participant who provided a valid response for their weekly commuting at all five waves (balanced panel members, N=667) we identified their sequence of commuting group membership over the five waves (referred to as a run-pattern), where 1 denotes car alone, 2 denotes partial car alone and 3 denotes no car alone. A run pattern of '1-1-1-1-1' denotes a commuter who drove alone on each day they commuted at all five waves. From the run patterns, we identified the extent of change that took place in commuting mode choice behaviour. This is reported in Table 12.

Table 12: Run pattern categories for balanced panel members

Run pattern category		Frequency	%	Cum %
Same group for 5 waves	Car for 5/5 waves	153	22.94%	22.94%
	Partial for 5/5 waves	26	3.90%	26.84%
	No car for 5/5 waves	156	23.39%	50.22%
Two groups (one group for four waves)	Car for 4/5 waves	58	8.70%	58.92%
	Partial for 4/5 waves	63	9.45%	68.37%
	No car for 4/5 waves	55	8.25%	76.61%
Two groups (one group for three waves)	Car & partial	45	6.75%	83.36%
	Car & no car	9	1.35%	84.71%
	Partial & no car	58	8.70%	93.40%
All three groups	Car to partial to no car	7	1.05%	94.45%
	No car to partial to car	11	1.65%	96.10%
	Other	26	3.90%	100.00%
Total		667	100.00%	

Table 12 shows that 335 of the balanced panel participants (50%) were in the same commuting group at every wave. 176 balanced panel participants (26%) were in the same commuting group at four of the five waves and a different group at one wave. 112 balanced panel participants (17%) were in the same commuting group at three of the five waves and a different group at two waves with most of these (103) mixing being in one of the extreme groups (car alone or no car alone) and being in the partial car alone group. Only 9 of these mixed being in car alone group and no car alone group. 44 balanced panel participants (7%) were found to be observed in all three groups with 18 of these making transitions incrementally between car alone, partial car alone and no car alone or vice versa. In summary, the trajectories show how unusual it is for commuters to switch from fully driving alone to fully using other modes, or vice versa, and where this was observed to occur it is more likely to be an incremental process with a period of mixing modes.

6. Summary and conclusions

The results are first summarised below with respect to the research questions:

1. How prevalent is it for commuters to vary how they get to work over a week and what are predictors of this? About one in four commuters mix driving alone to work with using other modes in a typical week and it is more likely for males, those with access to a bicycle and those working in another location during the week and less likely for those who work part-time.

2. How prevalent is it for commuters to change their weekly mode choice patterns and what are predictors of this? One out of four commuters changed their weekly pattern of commuting three months later and likelihoods of making a change are influenced by part-time working, access to car and bicycle, car parking availability, commute distance, working in a another location, satisfaction with commuting, awareness of sustainable transport measures and home moves.

In terms of specific behavioural and policy insights, the results suggest car parking availability encourages switches away from non-car commuting (more so than switches in the other

direction) and is therefore an important barrier to sustained use of alternatives to driving alone (this is a similar finding to that of Panter et al. (2013) who found lack of car parking availability encouraged walking to work). Awareness of sustainable transport measures is associated with transitions away from car alone commuting (and not the counter direction), suggesting that information about alternatives to driving alone can encourage deliberation about commuting behaviour. Sustainable transport promotional visits to the workplace were not associated with transitions immediately afterwards but this does not mean that they do not play a positive role in encouraging behavioural change in the longer run.

Satisfaction with mixed mode commuting patterns is associated with increased probability of switching to full non-car alone commuting immediately afterwards and suggests that efforts should be made to encourage commuters to try alternatives to driving alone and ensure a positive experience from it. Moving home was found to be associated with moves away from car alone commuting, indicating that this life event is taken as an opportunity to reduce reliance on the car for work for some employees and is an opportunity for targeted promotion of non-car alternatives. Residential relocations have been found to be associated with increased likelihood of commute mode changes in other studies (Thøgersen (2009), Clark et al. (2016))

Having access to a bicycle increases the likelihood of transitioning away from car alone commuting and therefore measures to increase access to bicycles (such as employer assisted bicycle purchase schemes and employer pool bicycles) have good potential. Seasonality was not found to exert a strong influence on transitions with the groups defined in this analysis, which may be a consequence of the car alone/non-car alone distinction used. Variation in weather conditions was found to influence likelihood of cycling to work by Heinen et al. (2011) and it merits further analysis whether this is the case for cycling to work in the Bristol context.

Transition analysis has been conducted using groups defined by their extent of car alone commuting but could be performed based on different (a priori) classifications of commute mode choice patterns (for example, cyclists/partial cyclists/non-cyclists). Alternatively, post-hoc classification could be performed using cluster analysis and latent class transition analysis used to analyse transition probabilities (as conducted by Kroesen (2014)). However, the cluster analysis that we performed suggested that groupings would be similar to those that we identified. Furthermore, our groups were specifically defined to be policy relevant and help assess the impact of sustainable transport promotion.

Transition analysis can be extended to consider second-order or higher-order Markov transitions where transitions between commute mode choice patterns are dependent not only on the previous pattern but the pattern(s) preceding that. This would allow assessment of whether transitions are temporary and returns are likely to be made to starting behaviour after one observation. This is a possible direction for further analysis of the data.

Finally, the availability of multiple waves of data allows analysis of trajectories over more than two waves. Inspection of trajectories for those panel participants who responded to all five waves indicates that there are few cases over the five waves of commuters switching between extreme commuting groups (car alone commuting to no car alone commuting or vice versa) and sustaining it for at least two observations. There are more cases of sustained switches between intermediate groups (e.g. car alone commuting to partial car alone commuting). Latent growth modelling could be used to identify if there are commonly occurring types of development trajectories and factors that are associated with these.

Reflection should be made on the terminology we have used to describe behavioural dynamics. We have referred to day-to-day variability and long-term changes in commute mode choices with the assumption that the former can be measured using weekly commuting data and the latter with observations (of weekly commuting) three months apart. It is possible, however, that variation in commute mode choices observed within a one week period could represent lasting change being made and variation in commute mode choices observed over a three month interval

could represent day to day variability. Continuous monitoring of commuting behaviour would be necessary to fully distinguish between temporary and lasting change and it should be acknowledged that even a commuter themselves may not be sure what a change of behaviour represents until some time after they have made it.

Acknowledgements

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Table 11: Predictors of transitions between commuting mode choice patterns

Variable	Car alone to partial		Car alone to no car alone		Partial to car alone		Partial to no car alone		No car alone to car alone		No car alone to partial	
	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z
DEMOGRAPHIC												
Male [Ref: No]	1.123	0.553	1.151	0.706	0.953	0.819	0.917	0.672	1.173	0.654	0.953	0.801
Age: 17 to 29	1.629	0.162	2.139	0.285	1.289	0.461	1.558	0.146	0.877	0.820	0.964	0.899
Age: 30 to 39	1.089	0.720	2.900	0.012	1.420	0.138	0.871	0.580	1.643	0.275	0.591	0.032
Age: 50 to 59	1.014	0.950	1.420	0.441	1.198	0.422	1.735	0.009	1.440	0.394	1.118	0.592
Age: 60+ [Ref: 40 to 49]	0.818	0.613	0.383	0.343	1.308	0.573	1.109	0.836	0.303	0.177	0.807	0.621
EMPLOYMENT												
Employment: Junior/clerical	0.798	0.381	0.705	0.440	0.977	0.925	0.777	0.355	0.763	0.518	0.957	0.853
Employment: Manual	0.710	0.324	1.476	0.531	0.527	0.115	0.696	0.353	1.192	0.759	0.971	0.929
Employment: Middle management [Ref: Professional]	1.050	0.814	0.951	0.920	0.792	0.346	0.887	0.578	0.734	0.554	0.908	0.665
Part-time employed	1.010	0.969	1.310	0.562	1.896	0.022	0.936	0.835	3.631	0.003	0.782	0.455
MOBILITY RESOURCES												
Access to a car for work*	0.704	0.208	0.235	0.003	1.112	0.697	0.987	0.960	7.050	0.000	4.165	0.000
Access to a bicycle for work	2.036	0.000	3.204	0.002	0.744	0.135	1.080	0.681	0.246	0.001	0.974	0.885
COMMUTE JOURNEY												
Empl location: Filton	0.780	0.211	1.287	0.526	0.915	0.691	1.070	0.758	1.914	0.090	0.975	0.894
Empl location: Portside	0.322	0.020	0.259	0.193	2.462	0.084	2.143	0.147	2.078	0.408	0.960	0.927
Empl location: Fringe [Ref: Stoke Gifford]	0.837	0.554	0.612	0.473	1.182	0.593	1.573	0.159	2.628	0.152	1.329	0.362
Parking spaces per employee	0.907	0.851	0.445	0.399	2.601	0.073	0.571	0.339	21.527	0.001	4.923	0.002
Commute distance: 0 to 5mi	1.940	0.024	5.675	0.005	0.732	0.301	0.883	0.638	0.569	0.300	0.572	0.039
Commute distance: 5 to 10mi	1.629	0.057	2.783	0.093	0.634	0.110	0.606	0.058	0.722	0.598	0.998	0.994
Commute distance: 10 to 25mi	1.373	0.184	1.267	0.697	1.124	0.670	0.625	0.075	1.327	0.640	1.382	0.244
Commute distance: Unknown [Ref: 25+mi]	0.806	0.701	2.625	0.272	0.847	0.784	0.425	0.134	3.266	0.202	1.163	0.769
Worked in another location during survey week	3.136	0.000	1.316	0.480	0.707	0.101	0.491	0.002	1.287	0.626	2.941	0.000
Satisfaction with commute in previous wave	0.990	0.918	1.074	0.710	0.829	0.078	1.307	0.016	0.949	0.792	0.970	0.771
SEASON												

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Variable	Car alone to partial		Car alone to no car alone		Partial to car alone		Partial to no car alone		No car alone to car alone		No car alone to partial	
	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z	Odds ratio	P>z
Season: January 2015	0.672	0.070	1.027	0.946	0.974	0.901	0.763	0.234	0.729	0.496	1.013	0.948
Season: April 2015	1.058	0.784	1.125	0.755	0.626	0.041	0.785	0.307	1.548	0.300	0.782	0.237
Season: July 2015 [Ref: October 2014]	0.665	0.080	0.154	0.012	0.771	0.300	0.719	0.164	1.202	0.684	1.048	0.825
SUSTAINABLE TRANSPORT PROMOTION												
Visit to workplace since previous wave	1.130	0.490	0.568	0.147	1.192	0.344	1.182	0.335	1.077	0.828	0.975	0.886
Awareness of recent sustainable transport measures	1.460	0.029	1.050	0.889	1.021	0.907	1.469	0.037	0.953	0.895	0.892	0.492
LIFE EVENTS												
Workplace change (same employer)	0.728	0.719	3.920	0.147	0.624	0.696	1.437	0.702	0.769	0.771	0.843	0.795
Home move	3.994	0.000	11.248	0.000	0.839	0.698	1.341	0.530	2.245	0.357	1.617	0.220
Constant	0.089	0.000	0.036	0.000	0.327	0.027	0.522	0.185	0.001	0.000	0.034	0.000
Reference group	Car alone to car alone				Partial to partial				No car alone to no car alone			
n	1633				1051				1660			
Pseudo R-Squared	0.133				0.050				0.122			

Note: Grey shading indicates significance at 95% level
* Not strictly independent/exogenous variable, as only possible to be in car alone group or partial car alone group if have access to a car for work.