Volatility of Car Ownership, Commuting Mode and Time in the UK

Joyce Dargay and Mark Hanly

ESRC Transport Studies Unit
Centre for Transport Studies
University College London

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Joyce Dargay, ESRC Transport Studies Unit, Centre for Transport Studies, UCL, Gower Street, LONDON, WC1E 6BT *e-mail: j.dargay@ucl.ac.uk*
Mark Hanly, ESRC Transport Studies Unit, Centre for Transport Studies, UCL, Gower Street, LONDON, WC1E 6BT *e-mail: m.hanly@ucl.ac.uk*

Abstract

This paper has two objectives: to examine the volatility of travel behaviour over time and consider the factors explaining this volatility; and to estimate the factors determining car ownership and commuting by car. The analysis is based on observations of individuals and households over a period of up to eleven years obtained from the British Household Panel Survey (BHPS). Changes in car ownership, commuting mode and commuting time over a period of years for the same individuals/households are examined to determine the extent to which these change from year to year. This volatility of individual behaviour is a measure of the ease of change or adaptation. If behaviour changes easily, policy measures are likely to have a stronger and more rapid effect than if there is more resistance to change. The changes are "explained" in terms of factors such as moving house, changing job and employment status. The factors determining car ownership and commuting by car are analysed using a dynamic panel-data models.

Keywords: commuting, car ownership, travel demand modelling

Topic area: D1 Passenger Transport Demand Modelling

1. Introduction

This paper has two objectives. The first is to examine the extent to which household car ownership and the individual's commuting behaviour vary over time (volatility of travel behaviour) and to investigate how this volatility relates to other changes experienced by the household or individual. Some of the factors considered are changing household structure, employment status, moving house and changing employer. The second objective is to investigate the determinants car ownership and commuting mode on the household and individual level, taking into account possible state dependence, i.e., the dependence of current choices on past decisions.

In both cases we are specifically concerned with *changes* in the behaviour of the individual or household as their socio-economic and demographic characteristics change rather than in *difference*s between individuals with *different* characteristics. We thus require observations of the car ownership and commuting behaviour of the *same* individuals over time. Such data are available in British Household Panel Survey (BHPS), which has been carried out annually since 1991. Panel data sets have many advantages for the analysis of behavioural change. They can capture changes in a level of detail that is necessary to unravel true causality, thus avoiding spurious correlation attributable to the aggregation of information. In addition, by following the same individuals/households over time, actual changes in travel behaviour can be examined, which are otherwise obscured in the net changes discernible in aggregate data. Finally, the process of change, and cause and effect relationships, are much easier to establish than with a repeated cross-section or single cross-section data. This is useful for detection of response lags, nonoptimal experimentation, experience effects and other inter-temporal effects, which are most meaningful at the level of the behavioural unit (i.e. the individual or household).

The question of the volatility of travel behaviour has been examined using the BHPS in a number of our previous studies. Dargay and Hanly (2003a) gives a descriptive account of changes in commuting mode and travel time on the individual level and the impact of gender, the number of employed in the household and changes in residential and workplace location. Dargay & Hanly (2003b) estimates the impact of a large number of socio-economic and demographic factors on changes in commuting mode and time on the basis of a statistical model, thereby controlling for the interaction between different factors. Dargay, Hanly, Madre, Hivert and Chlond (2003), address the question of reductions in car ownership on a household level, comparing panels of households in Britain, France, and Germany.

Although there is a wide literature on commuting, there are few studies that examine changes in commuting patterns on an individual level on the basis of panel data and statistical models. Some of the earlier work on the volatility of commuting time and mode over time is summarised by Cairns, Hass-Klau and Goodwin (1998). A recent study by Clark *et al* (2003) looks the at relationship between changes in residential and workplace location and commuting distance and travel time using data from the Puget Sound Transportation Panel over the years 1989 to 1997. Rouwendal and Rietveld (1994) examine changes in commuting patterns using the Dutch Housing Demand Survey for 1985 and 1988. Battu and Sloane (2002) and Benito and Oswald (1999) use the BHPS data to investigate commuting behaviour and model the determinants of travelling time. However, neither study exploits the panel nature of the data, so differences in commuting time among individuals are examined rather than changes in commuting time for specific individuals.

Very few dynamic panel models of car ownership are to be found in the literature. This is due in part to the fact that there exist very few transport panel data sources of sufficient length. The three most commonly studied are the Dutch National Mobility Panel (DNMP), the Puget Sound Transportation Panel (PSTP) and the Sydney Automobile Panel. Studies on car ownership using the DNMP include Goodwin (1986), Kitamura (1989), Kitamura and Bunch (1990), Golob (1990), Meurs (1993) and Pendyala, Kostyniuk and Goulias (1995). One of the key studies using the PSTP is Kitamura, Pendyala and Goulias (1993), and using the SAP, Hensher and Le Plastrier (1985). We are the first to use the BHPS.

The outline of the paper is as follows. The next section gives a brief description of the BHPS data and comparison with the data from the National Travel Survey. Volatility in car ownership, commuting mode and travel time is illustrated in Section 3. Section 4 concerns modelling car ownership and commuting by car on the basis of the panel data: the empirical results are presented and the findings of the analysis are discussed. The paper ends with a summary of the conclusions regarding volatility and the factors determining car ownership and commuting by car.

2. The British Household Panel Survey

The British Household Panel Survey (BHPS) was established by the ESRC Research Centre on Micro-Social Change at the University of Essex in 1991 and was primarily designed to further understanding of social and economic change at the individual and household levels in Great Britain. It is not a transport survey per se. However, the BHPS contains some information relating to transport: household car ownership and access to company cars, main mode of travel to work and time taken to travel to work, in addition to a very rich supply of information on a large number of socio-economic and demographic characteristics.

The BHPS was designed to be representative of all households in Great Britain in the year of its inception, 1991. It is, thus, a stratified sample rather than a random sample. So far, 11 years or "waves" of data have been released encompassing the years 1991 to 2001. The initial sample contained over 5000 households and it has not been refreshed over the years. The BHPS has, however, been augmented three times since 1991: first by the addition of UK version of the European Community Household Panel (UKECHP) households in 1997; then the Scottish and Welsh samples were increased in 1999 (from a very small base) to allow independent analysis of the two countries; and finally in 2001 a larger sample was recruited in Northern Ireland to increase the representativeness of the entire United Kingdom (in contrast to Great Britain, for which the BHPS was first established). These 3 additions are excluded from the present study because they change the geographic mix so that the resulting sample is less representative of the population of Great Britain than is the original sample.

There is the usual problem of attrition as with all panel surveys due to non-response, unusable response or because the household or individual cannot be contacted. The attrition rate in the BHPS is lower than in most panel surveys. In the year 2001, 59% of the households initially interviewed in 1991 still remained in the survey, and 52% of the original households gave full interviews in each of the 11 years. As shown in Dargay and Hanly (2001), households who remain in the survey have on average a higher car ownership than those who drop out, so that the sample becomes less representative over time. Despite this, the BHPS has two important advantages, namely, it is based on a relatively large sample and provides a longer panel on a substantial number of households than those available for comparable countries (Dargay, Hanly et al 2003).

Data from all 11 published years of the BHPS are used in this study (1991 to 2001). We use both household and individual data: household data are used to investigate car ownership and individual data are employed for the analysis of commuting. There are 5,294 households in the 1991 sample and 3,053 in the 2001 sample, while the comparable figures for individuals (who travel to work) are 5,439 and 4,942, respectively.

Car ownership is defined as all cars regularly available to the household, i.e. both those privately owned by the household and those used by the household which are formally owned by the companies of the self-employed or employed. Company cars make up around 10% of the car fleet in Britain and approximately 10% of households in the current sample have access to a company car.

A comparison of households with regular use of (access to) cars based on the National Travel Survey (NTS) and the BHPS is shown in Table 1. The NTS data are collected continuously and are based on a stratified sample of households in Great Britain, which can be assumed representative of the population. Even for the first year, the BHPS overestimates car ownership, presumably because of a higher response rate for higher car-owning (and presumably higher income) households. The overestimation becomes greater over time as non-car households drop out of the BHPS to a greater degree than car-owning households. By the year 2001, only 21% of BHPS households do not have cars, while for the country as a whole, 26% do not have cars.

Table 2 shows the share of individuals commuting by the various modes for the full BHPS sample compared with the same information from the NTS, which should be more representative of the population. There appears to be some discrepancy between the two data sources. In particular, the BHPS shows a lower share for car passenger and a higher share for car driver and walk. However, the differences between the two data sources are slight in most cases and growing smaller in the 1999-01 surveys. That the mode shares in the BHPS agree better with the NTS over time is somewhat surprising. The original BHPS sample in 1991 was designed to be representative of the British population at the time, and we would expect it to become less representative over time since the sample is not refreshed. As noted earlier, this seemed to be the case when household car ownership was compared on the basis of the two surveys. These differences between the BHPS and the NTS require further examination.

Table 1 Households with regular use of cars 1991 and 2001. NTS and BHPS, in %

	1991		2001	
	NTS	**BHPS**	**NTS**	**BHPS**
0 cars	32	31	26	21
1 car	45	44	46	44
2 cars	19	22	22	29
3+ cars	4	4	5	7

Table 2 Commuting trips by main mode in %. NTS and BHPS.

	NTS	**BHPS**	**NTS**	**BHPS**
	89-91	**1991**	**99-01**	**2001**
Rail	4.8*	3.4	5.8*	3.5
Underground/tube		1.5		1.9
Bus or coach	8.8**	9.4	7.7	7.5
Motor cycle/moped	1.8	1.6	1.3	1.1
Car or van driver	52.6	56.0	57.1	62.9
Car/van passenger	13.4	8.6	11.5	7.7
Pedal cycle	4.0	3.6	3.8	3.1
Walks all the way	12.6	14.9	11.5	11.8
Other	1.9	1.0	1.3	0.5
Number of individuals		*5439*		*4942*

*includes underground **only local bus

3. Volatility in car ownership and commuting

As mentioned above, the analysis of car ownership is carried out at the household level. Volatility is measured in terms of year-to-year changes. There are 36,123 transitions over 10 pairs of years in the data sample. Table 3 shows car ownership in two consecutive years for individual households for the period 1991 to 2001. The main diagonal of the table, indicating no change in car ownership from one year to the next, contains the majority of households by a good margin. The cases above the diagonal contain households with an increase in car ownership between the two years, while those below the diagonal indicate a reduction in the number of cars. A comparison of these changes in car ownership at the individual household level with the net changes that would be observed if panel data were not available shows that a very small net effect, an increase of 0.2%, corresponds to quite substantial volatility - increases and decreases – in car ownership. Slightly more households increase car ownership (8.2%) each year than reduce it (7.6%) leading to overall growth in car ownership. As expected, the greatest changes in car ownership between any two years are for households increasing from 1 to 2 cars (4.2%) and decreasing from 2 to 1 car (3.8%).

Table 3 Changes in car ownership in two consecutive years, % of households in sample

	Cars year t + 1				
Cars year t	**0**	**1**	**2**	**3+**	**total**
0	23.2	1.8	0.1	0.0	25.2
1	1.8	39.5	4.2	0.4	45.9
2	0.1	3.8	18.4	1.7	24.0
3+	0.0	0.4	1.5	3.1	5.0
Total	25.2	45.5	24.2	5.2	100.0

Changes in car ownership may be associated with a range of other changes occurring in the household. For example, a household is more likely to increase car ownership with the addition of one or more adults of driving age and more likely to reduce car ownership when an adult of driving age leaves the household. As shown in Table 4, 33.8% of households where the number of adults of driving age decreases also reduce car ownership, while 30.5% of households where the number of adults of driving age increases also increase the number of cars owned. In all other instances reductions or increases in car ownership lie around 6-7%. Also, as would be expected, the reductions in car ownership are primarily partial, i.e. from 2 to 1 or 3 to 2 cars, while very few households give up their cars totally. The number of adults changes in about 12% of households each year, with a similar proportion showing increases and reductions.

Table 4 Change in car availability when the number of individuals of driving age changes between two consecutive years, in % of all households within each group and number of cases in each group

Change in number of individuals of driving age	**Change in number of cars**			
	Reduction		**Increase**	
decrease	1+ to 0 cars	7.1	gain 1 car	6.4
cases: 2082 (5.8%)	partial*	26.7	gain 2+ cars	0.6
	both	33.8	both	7.0
no change	1+ to 0 cars	1.6	gain 1 car	6.4
cases: 31835 (88.1%)	partial	4.5	gain 2+ cars	0.3
	both	6.1	both	6.7
increase	1+ to 0 cars	1.3	gain 1 car	27.2
cases: 2206 (6.1%)	partial	4.2	gain 2+ cars	3.3
	both	5.5	both	30.5

* reduction from 3+ to 2, from 2 to 1 or 3+ to 1 car

It has also been noted that car ownership is less stable in young households (where the head is 18 to 24 years old) than in older households. Reducing car ownership to zero is most common for this age group, and is also more prevalent for the over-65s than it is in the middle age groups (25 to 64). Multiple car ownership is less common in the highest age group (over 65) than in the younger groups so that car reduction is more likely to lead to having no cars at all for this age group.

Car ownership is more likely to change when the household moves house than when they stay put; similarly car ownership is more likely to change if one or more individuals in the household switch employer during the year than when there is no change in employer.

Table 5 summarises the effects of these factors. Each year, 1.2% of households move house *and* one or more household member changes employer, while 9% have a member who changes employer only and 5.4% move house only. It is apparent that car ownership is more likely to increase than to decrease when either change occurs separately or when both occur together. However, when there is neither a change in employer or residential location, a reduction in car ownership is slightly more likely. When both changes occur simultaneously (within the same year), i.e., the household moves and at least one household member changes job, the probability of increasing car ownership is far greater.

Table 5 Change in car availability when household moves *and* at least one individual changes employer between two consecutive years, in % of all households within each group and number of cases in each group

Change in employer and/or residence	**Change in number of cars**			
	Reduction		**Increase**	
change employer & move house	1+ to 0 cars	3.6	gain 1 car	20.3
	partial*	8.6	gain 2+ cars	4.8
cases: 418 (1.3%)	both	12.2	both	25.1
change employer only	1+ to 0 cars	1.9	gain 1 car	14.3
cases: 3262 (9.0%)	partial*	8.7	gain 2+ cars	1.0
	both	10.6	both	15.3
move house only	1+ to 0 cars	3.9	gain 1 car	13.2
cases: 1964 (5.4%)	partial*	8.4	gain 2+ cars	1.7
	both	12.3	both	14.9
neither change employer nor move house	1+ to 0 cars	1.8	gain 1 car	6.5
	partial*	5.2	gain 2+ cars	0.3
cases: 30477 (84.4%)	both	7.0	both	6.8

* reduction from 3+ to 2, from 2 to 1 or 3+ to 1 car

The impact of a change in the head of household's employment status is illustrated in Table 6. Both unemployment and retirement are associated with considerable reductions in car ownership, but a reduction in the number of cars is much more prevalent in households where the head becomes unemployed than if s/he retires or remains employed.

Table 6 Change car availability when the head of household changes employment status between two consecutive years, in % of all households within each group and number of cases in each group

Change in employment status	**Change in number of cars**			
	Reduction		**Increase**	
Employed to unemployed	1+ to 0 cars	6.8	gain 1 car	10.8
cases: 424 (2.1%)	partial*	11.3	gain 2+ cars	0.9
	both	18.1	both	11.7
Employed to retired	1+ to 0 cars	1.1	gain 1 car	4.5
cases: 462 (2.2%)	partial	8.2	gain 2+ cars	0.2
	both	9.3	both	4.7
Remains employed	1+ to 0 cars	1.3	gain 1 car	10.3
cases: 19576(95.7%)	partial	7.9	gain 2+ cars	0.6
	both	9.2	both	10.9

* reduction from 3+ to 2, from 2 to 1 or 3+ to 1 car

The analysis of travel to work is based on the individual, rather than the household, and only on those individuals who travel to work. Like the household data above, the individual data are subject to attrition. There are 5,439 individuals in the 1991 sample and in 2001 there are 4,942 individuals. These are not necessarily the same individuals, since some leave our sample as they retire or become unemployed and some enter the sample as when they begin working. All of these individuals are members of the households originally interviewed in 1991. A much smaller sample, 1,541 individuals, was interviewed in all 11 years of the survey. Some characteristics of these individuals and their households are shown in Table 7. Naturally, car ownership in the households of working individuals is significantly higher than for all households, as is the proportion of multi-car households. Individuals who remain in the sample for all 11 years have higher than average car ownership and personal and household incomes, and of course age over the period. Most of the analysis that follows considers changes between two consecutive years for the larger of the two samples, since this is clearly more representative.

Table 7 Sample characteristics of individuals who travel to work in BHPS

	all individuals in original sample		individuals in all 11 waves	
	1991	2001	1991	2001
number of individuals	*5439*	*4942*	*1541*	*1541*
mean age, years	37.4	37.9	35.1	45.1
% male	51.9	49.7	51.1	51.1
mean household size	3.1	3.1	3.2	2.9
mean real household income	30.4	35.5	31.3	38.4
mean real individual income	14.5	17.0	15.4	21.1
cars available:				
0	12.8	8.9	8.4	6.2
1	48.0	40.6	50.0	40.2
2	31.1	39.2	33.2	43.3
3+	7.6	10.5	8.0	10.2

Table 8 shows the main means of commuting for individuals who travel to work for three different survey years. The number of individuals commuting can fluctuate from year to year: it will decrease due to attrition, non-response and when an individual no longer travels to work (for whatever reason) and will increase as individuals who did not previously travel to work start commuting. Over the 11 years, there has been a significant increase in the proportion driving to work, up from 56% in 1991 to 62.9% in 2001. Walk, bus and motorcycle have generally declined over the same period. The trends for other modes are less clear-cut.

Table 8 Commuting trips: main mode only original households

	1991	1996	2001
Rail	3.4	3.2	3.5
Underground/tube	1.5	2.0	1.9
Bus or coach	9.4	8.2	7.5
Motor cycle/moped	1.6	1.1	1.1
Car or van driver	56.0	59.2	62.9
Car/van passenger	8.6	9.3	7.7
Pedal cycle	3.6	4.0	3.1
Walks all the way	14.9	12.8	11.8
Number of individuals	5439	5073	4942

Table 9 shows the distribution of travel time to work over the 11 years as well as the mean travel time in a selection of years. Both have been relatively stable over the time period as a whole. Over a third of individuals have a commute time of 10 minutes or less and about two-thirds have a commute under 20 minutes, while less than a fifth have journey times greater than 30 minutes. Women are more likely to have shorter commute time and men a longer one: in 2001, for example, 31% of men and 39% women had commute times less than 10 minutes; whereas 25% of men and 18% of women travelled 30 minutes or more.

Table 9 Distribution of travel time to work, % BHPS

	Year			Total
	1991	**1996**	**2001**	**All years**
10 minutes or less	36.3	36.8	34.5	36.7
11 to 20 minutes	29.3	28.7	28.0	28.1
21 to 30 minutes	15.8	16.1	16.3	16.1
31 to 40 minutes	4.8	4.8	5.5	5.2
41 to 50 minutes	5.5	5.3	6.2	5.5
51 to 60 minutes	4.9	4.9	5.6	5.0
over 60 minutes	3.5	3.3	3.8	3.4
mean	23.1	22.7	24.1	23.0

Since we have panel data, the changes in commuting mode and time can be examined over time for each individual. There are over 4,000 pairs of observations for the same individual for two consecutive years for each of 10 pairs of years. 17.6% of the sample change commuting mode in any pair of consecutive years and this figure is relatively constant over the 11 years. Table 10 shows commuting mode in two consecutive years by three main modes: public transport (rail, underground and bus), car (passenger and driver) and walk or cycle. The final column (row) shows the mode shares in year t (year t+1). The shares for the three modes are relatively stable between any two consecutive years: car accounts for about 71%, walk or cycle for 16% and public transport for 13%. The main diagonal shows the individuals who do not change mode in 2 consecutive years. 66.5% of them are car users. Each year 4.2% of commuters switch from car to other modes while 5.2% switch from other modes to car. Switching between walk or cycle and public transport is marginal accounting for about 2% of commuters. Although car drivers are least likely to change mode, they make up such a large group of commuters that even small percent changes within the group have a large influence on overall commuting.

Table 10 Commuting mode in two consecutive years (year t and year t+1), % of commuters in each group

	mode in year t+1			
mode in year t	**public transport**	**car or van**	**walk or cycle**	**all modes**
public transport	9.8	2.4	0.8	13.0
car or van	1.9	66.5	2.3	70.7
walk or cycle	0.9	2.8	12.6	16.3
all modes	12.6	71.7	15.7	100

As shown in Table 11, changes in travel time vary greatly by travel mode. For those who do not change mode between the two years, the greatest proportion of those who walk maintain a similar walking time while the smallest proportion of bus users have the same travel time. More users of all modes except motorcycle increase travel time than reduce it. Of those who change mode, far fewer have the same travel time, from only 17.6% of those who initially used bus to 41.8% of motorcycle users. A much greater proportion of those who switch away from public transport experience a reduction in travel time than an increase, in contrast to all other modes.

Table 11 Difference in travel time between 2 consecutive years by mode in the initial year (year t) for individuals who change and who do not change mode, % of individuals who increase or reduce travel time.

	Individuals who do not change mode			**Individuals who change mode**		
Mode year t	**decrease 5+ mins**	**same +/- 4 mins**	**increase 5+ mins**	**decrease 5+ mins**	**same +/- 4 mins**	**increase 5+ mins**
Brit Rail/train	26.4	45.5	28.1	**65.1**	19.3	15.6
Underground	22.8	52.3	24.9	**43.2**	29.7	27.1
Bus or coach	27.2	43.1	29.7	**61.4**	17.6	21.0
Motorcycle/moped	20.7	59.3	20.0	23.6	41.8	**34.6**
Car or van driver	22.4	53.3	24.3	26.6	37.4	**36.0**
Car/van passenger	23.2	53.3	23.4	22.7	37.0	**40.4**
Pedal cycle	15.6	67.8	16.6	30.0	35.2	**34.8**
Walks all way	13.5	72.7	13.8	32.2	23.9	**43.9**
Other	30.0	45.0	25.0	34.5	40.1	25.4
All modes	21.6	55.1	23.3	34.6	30.9	34.5

Table 12 shows the percentages of individuals who change main commute mode and the modes to which they change when the individual's household changes residential location. The main diagonal of the table contains the individuals who travel to work by the same mode in both years, ranging from 36.5% of car passengers to 86.1% of car drivers. This can be compared with 60.8% of car passengers and 90.8% of car drivers who do not move house (not shown in the table). It is clear that individuals who do not move house are far more likely to continue using the same means of transport to work than those commuters who move house. Of those who move house, the greatest proportion of those who do switch modes become car drivers or passengers, overwhelmingly so for most modes except underground users who switch slightly more to bus than car (presumably because of the attractiveness of high density bus networks in the urban areas in which underground systems are built). The most common mode for those who switch from car is walking.

Table 12 Household moves house from year t to t+1 - % of individuals who change main commute mode the same year

	main commute mode year t+1							
mode year t	**Rail**	**Tube**	**Bus**	**Motor-cycle**	**Car/van driver**	**Car/van pass.**	**Cycle**	**Walk**
Rail	59.1	10.5	6.6	1.1	15.5	3.3	1.1	2.8
Tube	15.6	53.2	11.0	0.9	9.2	1.8	3.7	4.6
Bus	5.7	4.7	41.8	0.3	18.5	11.0	2.3	15.4
Motorcycle	4.3	0.0	2.1	48.9	29.8	6.4	0.0	8.5
Car/van driver	1.3	0.4	2.2	0.5	86.1	3.0	1.5	5.0
Car/van pass.	2.2	0.6	10.8	0.0	34.4	36.5	2.2	13.0
Cycle	0.6	0.6	7.9	1.2	21.2	5.5	42.4	20.6
Walk	2.4	2.4	11.2	0.9	23.6	10.0	5.3	43.8

Individuals who move house or who change employer generally have a different commute and thus are more likely to change commuting mode or time than those who do not move house or change employer. As shown in Table 13, nearly 20% of individuals change either job or house in any given year. Individuals who *either* move house *or* change job are twice as likely to change their commuting mode than those who change neither. Changing *both* employer *and* moving house triples the likelihood of changing mode. A similar pattern is noted for travel time, although the differences between groups are not as pronounced. There is also evidence that changing employer has a greater impact on commuting mode and time than moving house does.

Table 13 Change in commuting mode and time when individual moves house and/or changes employer between two consecutive years, in % of all individuals within each group and number of cases in each group

Change in employer and/or residence	**Change in commuting**		
	Change mode	**Decrease time by 5+ minutes**	**Increase time by 5+ minutes**
change employer & move house *cases: 841 (2.0%)*	44.6	39.4	41.7
change employer only *cases: 3867 (9.3%)*	32.7	36.0	37.5
move house only *cases: 3472 (8.3%)*	28.1	30.9	32.4
neither change employer nor move house *cases: 33639 (80.4%)*	14.0	21.4	22.3

4. Modelling car ownership and commuting by car

The study of car ownership follows earlier work with the BHPS by the same authors. Dargay and Hanly (2000a, 2000b) use data for the years 1993 to 1996 to estimate a dynamic car ownership model and investigate the question of state dependence versus unobserved heterogeneity. Dynamics and dependence on past experience are incorporated by including lagged endogenous variables amongst the explanatory variables, and heterogeneity is specified as a random effects model. The results support the importance of state dependence. The lagged terms are highly significant and models excluding state dependence perform more poorly. In addition, unobserved heterogeneity is far less important than state dependence. Dargay and Hanly (2001) estimate a similar model, and also investigate the question of asymmetric response to rising and falling income. In the latter study, the data are extended to include the years 1993 to 1999.

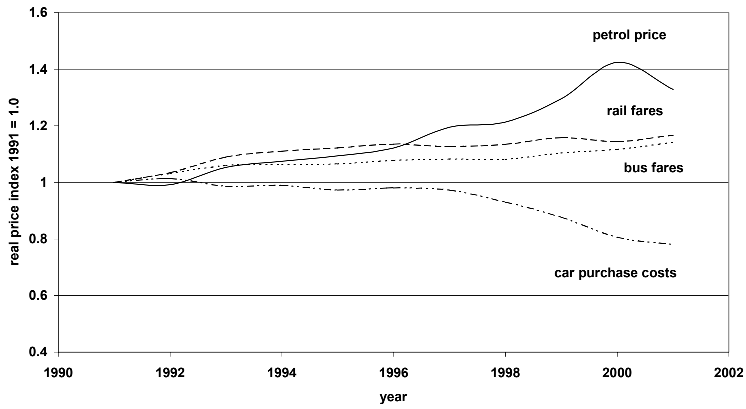
This paper applies the same sort of model: a dynamic ordered probit model with random effects to allow for unobserved heterogeneity. The data set is extended to all 11 waves currently available (1991 to 2001) and the effects of motoring costs on car ownership are estimated. The dependent variable is number of cars owned or used by the household (car availability, as defined earlier) in each of the eleven waves. This is a discrete variable which can take on one of three values – 0 (no car), 1 (1 car), and 2 (2or more cars). Only about 8% of households own 3 or more cars.

Dynamics are incorporated in the model by including a state variable, which is defined as the number of cars owned by the household in the previous year. This specification implies that the impact of the state variable is the same for all ownership levels. The implication of the state variable (i.e. the lagged dependent variable) is that car ownership in the current period is influenced by car ownership in the past. In other words, two households which are otherwise observationally equivalent in time period t may have different choice probabilities due to latent preference shifts associated with having experienced the choice made during the previous period.

It is well known that state dependence could be confused with unobserved variation amongst households, i.e., heterogeneity (see, e.g. Kitamura and Bunch, 1990). If these variations are random across households over time, then heterogeneity is of little consequence and has no effect on the parameter estimates. If, on the contrary, these variations are not random and are correlated over time, the estimation results will be biased if the variations are not accounted for. In this paper, we assume (any) unobserved errors are cross-sectionally independent but correlated over time for each household. This is achieved by introducing a household-specific, time invariant error component into the error term. In this approach, unobserved attributes are assumed to be distributed across households that are otherwise observationally identical, and this endowment of attributes does not vary over time. The specification of the model is presented more thoroughly in Dargay and Hanly (2000b). The model is estimated by Maximum Likelihood methods using the ordered probit routine with random effects in LIMDEP 8.0.

The explanatory variables included in the model are household income, the number of adults of driving age, the number of children, the number of adults in full and part-time employment and population density of the local authority area where the household is resident. There are also a number of dummy variables indicating whether the head of the household is a woman and of pension age and five regional dummies: Scotland, Wales, Greater London, other metropolitan areas, and the rest of England. Since the dummy variables are binary, equal to 1 if the condition holds and equal to zero otherwise, the perfect collinearity of groups of variables requires that one in each group be omitted from the estimation. This, the reference group, is a household with a male head, less than 65 years of age, living in the "rest of England". To account for transport costs, various measures have been included: car purchase costs, the petrol price and public transport fares. As shown in Figure 1, car purchase costs have declined around 20% since 1991, while the petrol price has increased by 40%. In comparison, public transport fares have increased by less than 20%.

Figure 1 Transport prices in the UK, in relation to the retail price index



The estimates for the car ownership model are shown in Table 14. All variables are significant at the 5% probability level, with the exception of the dummies for Wales and Scotland, which are nearly so. In addition, all parameters are of the expected signs. Car ownership (the number of cars) is lower in households where the head is a woman or a pensioner and increases with income, the number of adults, the number employed and the number of children. The number of full-time workers has a greater effect than the number of part-time workers, even when income is controlled for. Of these household characteristics, the number of children is the least important in determining car ownership. Regarding regional effects, car ownership is lower in London, the other metropolitan areas, Wales and Scotland than in the rest of England. The smallest effect appears to be for London, but it should be noted that outer London, as well as inner London, is included. The lower car ownership in London and the metropolitan areas can be explained by the problems and costs encountered in owning and using cars in large urban areas along with a better access to public transport. That car ownership is lower in Wales and Scotland, even after controlling for income and household characteristics, is less explicable, but is in agreement with our earlier studies. Car ownership also declines with population density, as would be expected, and the effects are separate from the regional effects.

Car purchase costs have a strong negative impact on car ownership. However, none of the other cost measures were found to have significant effects and are thus not included in the model presented. In addition, we see that estimation results indicate the importance of both state dependency (significance of Cars in the previous period) and heterogeneity (the significance of Sigma). As expected, car ownership is positively related to car ownership in the previous period. Finally, the model appears to perform very well; over 80% of the observations on car ownership are predicted correctly.

Table 14 Regression results: random effects ordered probit model for car ownership (dependent variable = 0 if no car; = 1 if 1 car; =2 if 2or more cars)

	Coef.	S.E.	P-value
Constant	-0.369	0.145	0.000
Woman head of HH	-0.386	0.036	0.000
Real HH income	0.019	0.000	0.000
No. Adults ≥ 17 years	0.389	0.018	0.000
No. full-time workers	0.298	0.017	0.000
No. part-time workers	0.178	0.022	0.002
No. children < 17 years	0.131	0.012	0.000
Pensioner HH	-0.225	0.035	0.000
London	-0.135	0.072	0.000
Metropolitan areas	-0.176	0.042	0.000
Wales	-0.266	0.072	0.071
Scotland	-0.499	0.050	0.069
Population density	-0.079	0.011	0.000
Car purchase costs	-0.998	0.143	0.004
Cars (t-1)	1.969	0.015	0.000
Mu*	3.546	0.027	0.003
Sigma**	0.737	0.022	0.000
Log Likelihood	-14424		
Chi squared	356.5	Prob.	0.000
Correct predictions			
0 car	84.9%		
1 car	88.9%		
2 + cars	80.3%		

* Threshold parameters for index ; ** standard deviation of the unobserved heterogeneity

The second model estimated is for main commuting mode. To simplify matters, we consider only two modes: car and non-car, thus having binary choice model. As for car ownership, dynamics or state dependence is allowed for by introducing a lagged dependent variable amongst the explanatory variables, and unobserved heterogeneity is modelled as a random effects specification. The model is estimated by Maximum Likelihood methods using the probit routine with random effects in LIMDEP 8.0.

The estimates are based on data for individuals who travel to work. The continuous exogenous variables are real income of the individual, real income of the household to which the individual belongs and population density. Both individual and household incomes are included since both can be thought to affect commuting mode. Transport costs are represented by the price indices in Figure 1. A number of dummy variables are also included: whether the individual is full- or part-time employed, whether they are self-employed or not, gender, whether they are in a single-person household, whether there are children in the household, and the regional variables listed earlier. The reference group is a non-self-employed male, working full time in a household with more than one adult and without children, living in the "rest of England".

The commuting mode model is a reduced form since car ownership characteristics, which also affect commuting mode, are excluded. This is preferable from an econometric point of view since car ownership is not exogenous to the model, but is itself determined by the other explanatory variables, particularly income.

The estimates for the commuting mode are shown in Table 15. The significance of the variables is somewhat poorer than for the car ownership model. This is perhaps not surprising since the model for commuting mode is less comprehensive. Many variables that influence commuting mode have been omitted because of lack of data, for example, distance between home and work, the access to other modes and the actual costs of the alternatives available to the particular individual. Never the less, many variables are significant and the model performs well in terms of prediction (84% for car and 92% for other modes). With the exception of gender, all socio-economic variables are highly significant. Part-time workers and those in single-person households are less likely to commute by car than full-time workers and those in households with more than one adult, while the self-employed and those with children are more likely to travel by car than others. On the other hand, women are equally as likely to commute by car as men are. This may seem surprising, but the lower car travel noted for women is explained in the model by the lower car use by part-time workers, which are more likely to be women than men. Commuting by car increases both with individual and household income; with individual's income having the much greater effect. Of the household characteristics, having children is the least important in determining commuting mode (as was also the case for car ownership).

As expected, commuting by car declines with population density, reflecting the costs involved in using cars in densely populated areas and the better access to public transport. Regarding regional effects, commuting by car is lower in London and Scotland, and higher in Wales, but there is no statistical difference between the other metropolitan areas and the rest of England. Again, it must be noted that London includes the outer suburbs, and if these were excluded the effect would probably be greater.

Both car purchase costs and the petrol price have a negative impact on commuting by car, although these variables are only significant at around the 9% probability level. Neither of the public transport fares was found to significant at reasonable levels, thus both are omitted from the model presented. As was the case with car ownership, there is strong evidence of both state dependency (significance of Mode in the previous period) and heterogeneity (the significance of Rho). As expected, commuting mode is positively related to commuting mode in the previous period.

Table 15 Regression results: random effects probit model for commuting mode (dependent variable = 1 if individual commutes by car, dependent variable = 0 otherwise)

	Coef.	S.E.	P-value
Constant	0.160	0.523	0.760
Part-time worker	-0.162	0.025	0.000
Self employed	0.297	0.044	0.000
Woman	0.005	0.023	0.827
Single-person HH	-0.163	0.029	0.000
Children in HH	0.059	0.021	0.005
Real individual income	0.007	0.001	0.000
Real HH income	0.002	0.001	0.002
Population density	-0.064	0.009	0.000
London	-0.259	0.051	0.000
Metropolitan areas	0.038	0.031	0.217
Wales	0.103	0.055	0.060
Scotland	-0.222	0.036	0.000
Car purchase costs	-0.559	0.327	0.088
Petrol price	-0.329	0.196	0.093
Mode (t-1)	2.200	0.016	0.000
Rho	0.135	0.015	0.000
Log Likelihood	-12819		
Chi squared	76.0	Prob.	0.000
Correct predictions			
travels by car	84.2%		
travels by other mode	92.0%		

* reduced form parameter related to the variance of the unobserved heterogeneity

5. Conclusions

Regarding changes in car ownership and commuting, we find a great deal of volatility from year to year:

- 8.2% of households increase car ownership, while 7.6% reduce it; the greatest changes are between 1 and 2 cars, while very few households give up their cars totally (1.8%);
- when an adult leaves the household, 33.8% of households reduce car ownership; car ownership increases in 30.5% of households where the number of adults increases;
- about 25% of households that either move house or change job change car ownership; nearly 40% of those that move house *and* change job, change car ownership and the majority increase the number of cars owned;
- both unemployment and retirement are associated with reductions in car ownership; the effects of unemployment are greatest;
- 17.6% of commuters change main commuting mode between any two years;
- each year, 4.2% of commuters switch from car to other modes and 5.2% switch from other modes to car;

- around 30% of individuals who either move house or change job also switch main mode; nearly 45% of those that move house *and* change job, also change mode;
- 30% of households who move house increase travel time by 5 minutes or more and 30% reduce travel time by 5 minutes or more; the effect is greater (36-37%) for those who change job;
- 40% of households who both move house and change mode increase/decrease travel time.

The results of the dynamic modelling of car ownership and commuting mode can be summarised as follows:

- state dependence (i.e. previous car ownership level or commuting mode) appears to be an important determinant of the of car ownership and commuting mode;
- heterogeneity as specified in the random effects model is found to be significant for both car ownership and commuting mode;
- car ownership increases with income, the number of adults, the number employed and the number of children and decreases with car purchase costs and population density; it is lower for pensioner households and when the head of household is a woman;
- part-time workers and those in single-adult households are less-likely to commute by car, while the self-employed and those with children are more likely to commute by car; commuting by car increases with individual and household income, and decreases with population density, car purchase costs and petrol prices; woman and men are equally likely to commute by car, *ceteris paribus*.

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