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The effect of income on car ownership: evidence of asymmetry

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Abstract

This paper examines the effect of income on car ownership, and specifically the question of hysteresis or asymmetry. Although there is little doubt that rising income leads to higher car ownership, less is understood about the effect of falling income. Traditional demand modelling is based on the implicit assumption that demand responds symmetrically to rising and falling income. The object of this study is to test this assumption statistically. Using a dynamic econometric model relating household car ownership to income, the number of adults and children in the household, car prices and lagged car ownership, income decomposition techniques are employed to separately estimate elasticities with respect to rising and falling income. The equality of these elasticities – no hysteresis – is tested statistically against the inequality – hysteresis – hypothesis. Various functional specifications are tested in order to assure the robustness of the results to assumptions concerning functional form. The estimation is based on cohort data constructed from 1970 to 1995 UK Family Expenditure Surveys, and a pseudo-panel methodology is employed. The results indicate that car ownership responds more strongly to rising than to falling income – there is a 'stickiness' in the downward direction. In addition, there is evidence that the income elasticity is not constant, but instead declines with increasing car ownership.

1. Introduction

It is well established that income is a primary impetus to car ownership. Increasing real income during the second half of the 20th century has allowed car ownership to flourish in all industrialised countries, and more recently in many parts of the developing world. [1] This development

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[1] The relationship between income and car ownership in the OECD and in LDCs is analysed in Dargay and Gately (1997), and projections are made for the coming decades. The study shows that the income elasticity declines from well over unity to well below unity as income and car ownership increases.

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is apparent in the UK – in 1950 less than 14% of households had regular access to a car, today the figure has risen to around 70%. [2] Over the same period, real incomes have more than tripled. The relationship between car ownership and income, however, has not been constant over the period. As shown in Goodwin et al. (1995), car ownership increased more rapidly than income up until the early seventies, indicating an income elasticity substantially in excess of unity. For the last 25 years, on the other hand, the development of car ownership more closely followed that of income: the income elasticity appears to have declined to around one. The declining income elasticity is supported by Dargay and Gately (1997), which estimates an average long-run elasticity for OECD countries declining from well above, to around, unity in 1992 and continuing to decline thereafter. The inverse relationship between the income elasticity and the car ownership (and income) level is also noted in the differences between developed and developing countries: on average the income elasticity was 1.6 in the LDCs in 1992, compared to 1.0 in the OECD. Following the economic definition of luxury and necessary goods, what was once a luxury, appears now to have become a necessity.

Income's effect on car ownership can also be seen on a household level using data from UK Family Expenditure Surveys. In 1995, only 41% of households in the lowest income decile had regular access to a car, compared to 91% of those in the highest income decile. [3] The effect of income on car ownership is even more apparent if we consider cars per person. For the lowest income decile, the average is 0.16 cars per person as compared to 0.83 for the highest income decile. In 1970, the figures were 0.10 and 0.51, respectively. Estimates on the basis of these data show the cross-section income elasticity to have declined from well above, to significantly below, unity during this period.

A conclusion that can be drawn from these and other studies [4] is that the income elasticity is not constant over time, but instead is dependent on the level of car ownership. Since car ownership, in turn, is determined largely by income, it follows that the income elasticity will also be dependent on the level of income. Increasing income gives rise to increasing motorization, but the effects diminish over time as saturation is approached, so that the income elasticity declines.

A related issue concerns the effects of an income change on car ownership in different time perspectives. Individuals do not respond instantaneously to changes in income (or prices); instead adjustment occurs slowly over time. Reasons for this include the pervasiveness of habits, inertia, search costs, uncertainty and imperfect information. The importance of dynamics in transport behaviour has been recognised for some time [5] and the inability to capture such dynamic effects with static models and cross-section data has been argued by many authors. In empirical work, such dynamic effects have been taken into account by the inclusion of transaction dummies, [6]

[2] Transport Statistics Great Britain, HMSO.

[3] Income deciles are formed using disposable income per person.

[4] Pendyala et al. (1995), using repeated cross-section data from the Dutch National Mobility Survey, find that the relationship between car ownership and income is not constant over time and conclude that the income elasticity changes with the level of motorization.

[5] See Goodwin et al. (1987) or more recently Goodwin (1998).

[6] For example, see Train and Lohrer (1982).

lagged dependent variables [7] or lagged exogenous variables. [8] The problems involved in including lagged dependent variables in panel data models and the issue of heterogeneity versus true state dependence have also been examined. [9]

The empirical evidence confirms the importance of dynamics on car ownership decisions. For example, Golob (1990) using a dynamic structural model and panel data shows that income exhibits both contemporaneous and dynamic influences on car ownership. Dargay and Vythoulkas (1999) using a dynamic model and pseudo-panel data for the UK estimate the income elasticity for car ownership to be 0.3 in the short run (one year) and 0.7 in the long run. In general, studies based on explicit dynamic formulations indicate that the long-run elasticity is generally 2–3 times the short-run elasticity.

Another aspect of the income elasticity, which has received less attention in the literature, is that of asymmetry, i.e., whether falling income reduces car ownership to the same extent that rising income increases it. Although the question of asymmetry of response or hysteresis in travel and car ownership decisions has been addressed by a number of authors, [10] few studies exist which examine the issue empirically. Two exceptions are Goodwin (1998) and Pendyala et al. (1995), which look at successive waves in panels and relate changes in car ownership to periods of income increases and reductions separately. Both studies show a clear indication of asymmetry: the elasticity with respect to falling income is appreciably smaller than the elasticity relating to falling income. However, neither study is based on the explicit specification of an asymmetric model and the statistical testing of the asymmetry hypothesis.

Clearly, the concepts of asymmetry and hysteresis are only pertinent in a dynamic context since by their very nature they embody a time dimension. However, most dynamic models do not allow for these possibilities since symmetry is generally implicit in the model formulation.

There are two types of asymmetry that can be considered. The first concerns the effects of short-term, temporary income reductions, while the second relates to long-term trends in income and car ownership over the life cycle. In both cases the main question is whether or not car ownership is reversible to upward and downward income changes, i.e. if there is a symmetric response. If not, the situation is one of hysteresis: the effect of rising income on car ownership is not totally reversed as income falls. Hysteresis may be caused by habit or resistance to change or addiction asymmetry – the tendency to acquire habits to consume more easily than to abandon them. Increasing income has given individuals the possibility of owning a car and the convenience of its use. This is difficult to give up, even if the economic consequences – in terms of alternative consumption foregone – are greater than previously.

Hysteresis can be defined in terms of the income elasticity. If such asymmetry exists, the elasticity of car ownership with respect to rising income will be greater than that with respect to falling income. The acquisition of a car is seen as a luxury, but once acquired the car becomes a necessity, so that disposing of a car is much more difficult. The importance of hysteresis is that it is an indication of the difficulty of reducing car dependence.

[7] Mannering and Winston (1985) provide an early example of this approach.

[8] See Hensher et al. (1987).

[9] See Hensher and Wrigley (1986) discuss the nature of true versus spurious state dependence. Kitamura and Bunch (1990) examine this question empirically.

[10] Goodwin (1977) is one of the first references to hysteresis.

Analysis of hysteresis requires information on how peoples' car ownership changes when income rises and falls. This cannot be obtained from aggregate time series data or from cross-sectional data. The problem with aggregate time series data is that 'aggregate' income is generally rising over time, so that we have few – if any – observations of falling income on which to test for differential response. With cross-sectional data 'falling' and 'rising' income or car ownership cannot be distinguished – there is no time element, so that questions concerning symmetry of response – or hysteresis – cannot be analysed. Ideally, panel data – i.e., observations of individuals over time– are preferred, so that the individual's (or household's) changes in car ownership can be followed over time in relation to their income changes. Panel data, however, are rarely available, and generally not over a sufficient time period to analyse long-term behavioural changes. Cohort data, which follows groups of individuals in cross-section surveys over time, can, however, allow certain questions relating to asymmetry to be examined, particularly those related to long-term changes in income and car ownership over the life cycle. [11] Such data allow one to examine *changes* in car ownership *over time* on a cohort level, and to relate these to *changes* in income or other explanatory factors, also *over time*, for the same cohorts.

This study employs cohort data constructed from the UK Family Expenditure Surveys for the past two decades. The cohorts are defined in terms of the age of birth of the household head, and these cohorts are traced over time in the consecutive annual surveys. These data provide a picture of car ownership patterns as income rises and then falls over the life cycle, so that the hypothesis of long-term asymmetry can be tested. A dynamic model which explicitly allows for asymmetry is employed along with income decomposition techniques to separately estimate elasticities with respect to rising and falling income. The equality of these elasticities – no hysteresis – is tested statistically against the inequality – hysteresis – hypothesis. Various functional specifications are estimated in order to assure the robustness of the results to the functional form employed as well as to test assumptions regarding the relationship between the elasticity and the car ownership/income level.

2. Hysteresis

The notion of hysteresis can be illustrated using a simple example. Fig. 1 shows a traditional demand curve, D_R. As income rises from Y_0 to Y_1, car ownership increases from C_0 to C_1; when income falls back to Y_0, car ownership returns to C_0. Demand is reversible with respect to income changes – an income rise followed by an income fall returns car ownership to its initial level. With hysteresis, however, demand will not be completely reversible. Car ownership may decline as income falls – but not to the extent indicated by the reversible demand curve, D_R. Instead, it may follow demand curve D_F. In this case, car ownership falls from C_1 to C_2 as income declines from Y_1 to Y_0. Clearly, C_2 is greater than C_0 – the effect of increasing income on car ownership is not totally reversed as income falls.

Car ownership modelling – as well as most traditional demand analysis – is based on the assumption of the existence of a unique equilibrium relationship between demand and income, for

[11] Panel data are still required for the analysis of short-term asymmetry or 'stickiness'.

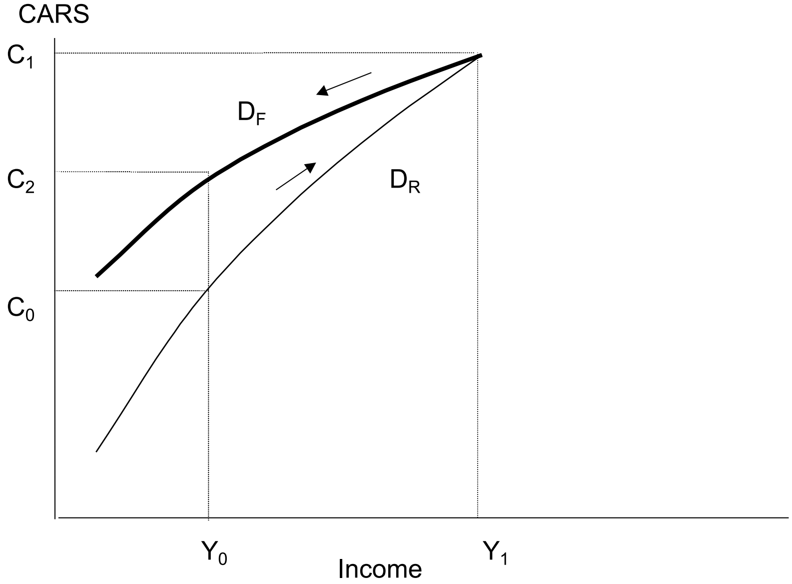

Fig. 1. Demand function exhibiting hysteresis.

example as shown by demand curve D_R, so that a rise in income followed by an equal fall will *ceteris paribus* return demand to its original level. With hysteresis, this will not be the case. Instead, we have a 'kinked' demand curve, with the kink occurring at the maximum income over the life cycle. There is thus no single equilibrium relationship between car ownership and income. Instead car ownership will also depend on whether income has been rising or falling. The curve shown by D_R–D_F illustrates a 'hysteresis loop'.

3. Cohort data from the family expenditure survey

The analysis of hysteresis is based on cohort data constructed from the UK Family Expenditure Surveys for the years 1970–1995. This survey has been carried out continuously on an annual basis since the 1960s, each survey providing a random sample of around 7000 households. The data set is constructed by grouping individuals or households into cohorts, defined in terms of the year of birth of the household head using 5-year bands. These cohorts are then traced over time in each of the cross-section data sets. The cohort averages for car ownership, income etc. for each year are treated as observations in a panel. As shown in Dargay and Vythoulkas (1998, 1999), this 'pseudo-panel' [12] methodology provides a useful basis for exploring household transport behaviour, particularly in the absence of true panel data. Most importantly, by exploiting observations of specific cohorts over time, the dynamics of car ownership can be analysed.

Car ownership – the average number of cars owned or used per household – for the various cohorts over time is shown in Fig. 2. The age of the household head is given on the horizontal

[12] The use of 'pseudo-panel' data was introduced by Deaton (1985) for the analysis of consumer demand systems.

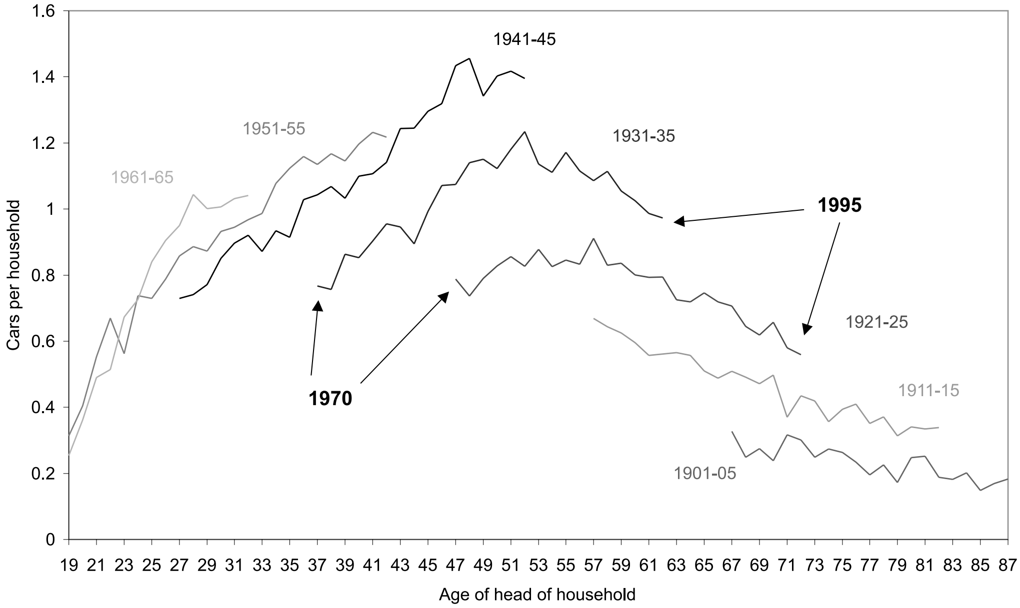

Fig. 2. Car ownership by cohort 1970–1995. Every second cohort shown with year-of-birth bands, FES data.

axis, and car ownership on the vertical. The lines represent the different cohorts, with the birth-year bands given adjacent. The initial data point for each cohort is obtained from the first survey in which an observation for the cohort containing at least 100 households is available, generally 1970, while the final data point is obtained from the last survey containing a comparable observation, generally 1995. For example, for the cohort labelled 1931–1935 (with a mean year of birth 1933), the mean age of the head was 37 in the 1970 survey and 62 in the 1995 survey. The data shown for this cohort thus cover the ages 37–62, with household car ownership averaging about 0.75 cars at the age of 37, reaching a maximum of 1.2 cars at the age of 50 and thereafter declining to 1 car by the age of 62.

Fig. 2 shows two dominant trends: the life-cycle effect – car ownership increases until the head is in his/her early 50s, and then declines; and the generation effect – at every 'age' car ownership is higher for more recent than for earlier cohorts. As discussed in Dargay and Vythoulkas (1999), these effects are largely explained by differences in income and the number of adults per household over the life-cycle and differences in income between generations.

The data on car ownership and corresponding income data for the cohorts can be used to show the relationship between income and car ownership. This is illustrated in Fig. 3. The vertical axis shows the number of cars per household while the horizontal axis is real total household expenditures. [13] Only three cohorts are shown for legibility. The earliest cohort shown, with the head born between 1911–1915, is an example of declining income and car ownership. This is

[13] Total household expenditure is used as a proxy for income. Expenditures are converted into real terms using the retail price index.

Fig. 3. Relationship between household car ownership and income, 1970–1995, FES data.

representative of pensioner households – the head ages from 59 to 80 over the observed time period. The most recent cohort shown – 1961 to 1965 – is an example of a relatively young household, with the head ageing from 20 and 30. [14] Both income and car ownership are increasing rapidly. Comparing these two cohorts, it is apparent that the slope of the line indicating the car ownership – income relationship is greater for the increasing income case (1961–1965) than it is for the decreasing income case (1911–1915). Since the slope of the line is directly related to the magnitude of the income elasticity, this suggests that car ownership responds more strongly to rising incomes than it does to falling incomes. Rising incomes lead to a higher car ownership level, but when incomes fall car ownership is not reduced correspondingly.

This asymmetry is clearly exemplified in the middle-aged cohort (1931–1935), where the hysteresis loop is particularly apparent. Here, we follow the cohort as the age of the head increases from 35 to the age of 60. Between the ages of 35 and 50, household income and car ownership are increasing, while after the age of 50 or so both income and car ownership begin to decline. But the same path is not followed. As income declines, car ownership declines, but to a lesser degree than it rose as income increased. For each income level we have two rather than one car ownership level. There is no unique car-ownership–income relationship, rather a hysteresis loop. The explanation for this is a simple one: households have become accustomed to owning cars and the convenience that they afford. Such car dependency is not easily reversed, so there is a tendency to maintain car ownership in spite of falling income. Again, there is an indication that the income elasticity is greater for rising than for falling income.

[14] This cohort is only observed in the surveys from 1983 onwards.

In the following section, an econometric model is used to statistically test the notion of hysteresis. Specifically, we test the equality of the long-run income elasticity with respect to rising and falling incomes. If this elasticity is greater as incomes rise than it is when incomes fall, there is no unique car ownership – income relationship.

4. Econometric analysis of asymmetry

4.1. The car ownership model

The analysis of asymmetry in the response of household car ownership to income changes is carried out on the basis of a simple car ownership model. It is assumed that the desired car ownership, $C^*_{i,t}$, for cohort i in period t can be expressed as

$$C^*_{i,t} = f(Y_{i,t}, A_{i,t}, K_{i,t}, P_t, G_i, L_{i,t}), \tag{1}$$

where $Y_{i,t}$, $A_{i,t}$, and $K_{i,t}$ are total household expenditures (used a proxy for income), the number of adults of driving age and the number of children per household included in cohort i in period t. P_t is an index of real car purchase prices, which includes both new and second-hand cars, and is assumed to be identical for all households. G_i is a cohort-specific generation effect, and $L_{i,t}$ is a dummy life-cycle variable. [15] The life-cycle variable is related to the age of the household head and is specified in terms of age dummies. Since the inclusion of dummy variables for each 'age' would drastically reduce the degrees of freedom, the life-cycle variables are defined in 6 age bands.

Lags in adjustment of car ownership to changes in the explanatory variables are specified by a simple partial adjustment mechanism, so that actual car ownership, $C_{i.t}$ for each cohort i in period t can be expressed as

$$C_{i,t} = \theta f(Y_{i,t}, A_{i,t}, K_{i,t}, P_t, G_i, L_{i,t}) + (1-\theta)C_{i,t-1}, \tag{2}$$

where $C_{i,t-1}$ is car ownership in period $t-1$ and θ is the adjustment parameter. Three different functional forms are specified for the car ownership relationship, which results in the following models:

$$\begin{aligned}
&\text{linear} \quad C_{i,t} = \alpha_i + \beta_Y Y_{i,t} + \beta_A A_{i,t} + \beta_K K_{i,t} + \beta_P P_t + \sum_{j=1}^{6} \gamma_j L_{j,i,t} + \phi C_{i,t-1} \\
&\text{double-logarithmic} \quad \mathrm{Ln}C_{i,t} = \alpha_i + \beta_Y \mathrm{Ln}Y_{i,t} + \beta_A \mathrm{Ln}A_{i,t} + \beta_K \mathrm{Ln}K_{i,t} + \beta_P \mathrm{Ln}P_t \\
&\qquad\qquad + \sum_{j=1}^{6} \gamma_j L_{j,i,t} + \phi\, \mathrm{Ln}C_{i,t-1}, \\
&\text{semi-logarithmic} \quad C_{i,t} = \alpha_i + \beta_Y \mathrm{Ln}Y_{i,t} + \beta_A A_{i,t} + \beta_K K_{i,t} + \beta_P P_t + \sum_{j=1}^{6} \gamma_j L_{j,i,t} + \phi C_{i,t-1},
\end{aligned} \tag{3}$$

[15] The generation and life-cycle effects are similar to the age-cohort model developed by INRETS, see, for example, Madre et al. (1995).

where

$L_{1,i,t} = 1$ if $\text{age}_{i,t} < 25$ and $L_{1,i,t} = 0$ otherwise,
$L_{2,i,t} = 1$ if $25 \leqslant \text{age}_{i,t} \leqslant 34$ and $L_{2,i,t} = 0$ otherwise,
$L_{3,i,t} = 1$ if $35 \leqslant \text{age}_{i,t} \leqslant 44$ and $L_{3,i,t} = 0$ otherwise,
$L_{4,i,t} = 1$ if $45 \leqslant \text{age}_{i,t} \leqslant 54$ and $L_{4,i,t} = 0$ otherwise,
$L_{5,i,t} = 1$ if $55 \leqslant \text{age}_{i,t} \leqslant 64$ and $L_{5,i,t} = 0$ otherwise,
$L_{6,i,t} = 1$ if $\text{age}_{i,t} \geqslant 65$ and $L_{6,i,t} = 0$ otherwise.

The α_i are cohort-specific intercept terms relating to the generation effects, G_i , and $\phi = 1 - \theta$. The short-run elasticities are obtained from the coefficients, β, while the long-run elasticities are obtained as the short-run values divided by $(1 - \phi)$.

The double-logarithmic model is the normal constant elasticity model, while the linear model assumes that the income elasticity is related to the relationship between income and car ownership and the semi-log model assumes that the income elasticity declines with increasing car ownership.

4.2. Asymmetric specification

The method used to analyse possible differences in response to rising and falling income is based on that used in Dargay and Gately (1997) to examine the issue of price-reversibility. It is based on decomposing the variable of interest, in this case, income. In order to distinguish between the responses to rising and falling income, the income variable Y_t is decomposed into two monotonic variables: the cumulating series of income rises, $Y^{\mathrm{R}}_{i,t}$, which is non-negative and non-decreasing, and the cumulating series of income falls, $Y^{\mathrm{F}}_{i,t}$, which is non-positive and non-increasing. These are defined as follows:

$$Y^{\mathrm{R}}_{i,t} = \sum_{t=0}^{T} \max\left\{0, Y_{i,t} - Y_{i,t-1}\right\},$$

$$Y^{\mathrm{F}}_{i,t} = \sum_{t=0}^{T} \min\left\{0, Y_{i,t} - Y_{i,t-1}\right\}, \tag{4}$$

where

$$Y_{i,t} = Y_{i,0} + Y^{\mathrm{R}}_{i,t} + Y^{\mathrm{F}}_{i,t}.$$

In the double- and semi-logarithmic models, the decomposition is based on the logarithm of income, so that the Ys in the above equations are replaced by $\mathrm{Ln}\,Y$.

By replacing the original income variable in Eq. (3) with $Y^{\mathrm{R}}_{i,t}$ and $Y^{\mathrm{F}}_{i,t}$ (or with the log-decompositions) we obtain the asymmetric specification, which in the case of the linear model can be written as

$$C_{i,t} = \alpha_i + \beta_{Y\mathrm{R}} Y^{\mathrm{R}}_{i,t} + \beta_{Y\mathrm{F}} Y^{\mathrm{F}}_{i,t} + \beta_A A_{i,t} + \beta_K K_{i,t} + \beta_P P_t + \sum_{j=1}^{6} \gamma_j L_{j,i,t} + \phi\, C_{i,t-1}, \tag{5}$$

where $\beta_{Y\mathrm{R}}$ and $\beta_{Y\mathrm{F}}$ denote the response to rising and falling income, respectively. If $\beta_{Y\mathrm{R}} > \beta_{Y\mathrm{F}}$ the response of car ownership to rising income will be greater than that to falling income. If $\beta_{Y\mathrm{R}} = \beta_{Y\mathrm{F}}$

the response of car ownership will be the same to rising and to falling income, and the model will revert to the symmetric specification.

4.3. Estimation results

The asymmetric forms of the alternative functional specifications described in Eq. (3) are estimated from the cohort data described earlier. There are 16 cohorts with an observation period ranging from 1976 to 1995. [16] Only those cohort-year observations containing at least 100 households are included in the estimation to assure that the sample cohort data are reasonable estimates of the population cohorts. The data for all but the two eldest and 3 most recent cohorts cover the entire 20 years. In all, we have 265 observations.

Since the numbers of households in each cohort and for every time period are not the same, the disturbance term will be heteroskedastic so that the estimates of the coefficients will not be efficient. In order to correct for this heteroskedasticity, all variables are weighted by the square root of the number of households in each cohort. Since we have included cohort-specific intercept terms in the equations, these can be treated as normal fixed-effects (LSDV) models and are estimated by OLS procedures. From the definitions of the life-cycle dummies, the $L_{j,i,t}$s are linearly dependent, so that one of them must be dropped in the estimation. The first is excluded (and thus γ_1 constrained to be 0).

The summary statistics for the estimation of the three functional specifications in Eq. (3) are shown in Table 1. From the $\bar{R}^2$ values, all specifications explain the data very well. Choice of functional form can be based on statistical tests. The linear and semi-log models have the same dependent variable and same number of regressors, so that the choice between these can be based on the Likelihood values shown in the table. From these, the semi-log model explains the data better than the linear model, and is thus the preferred statistically. Comparison of these models with the double-log model is not as straightforward since the dependent variables are not the same. Using a procedure developed by MacKinnon et al. (1983), the PE Test, the double-log model is rejected in favour of both the linear and semi-log models. Thus on the basis of the statistical tests, the semi-log model is the preferred. This model also makes the most sense economically: the income elasticity declines with increasing car ownership, so that saturation can be accounted for explicitly. [17]

In order to test the hypothesis of symmetry, we need to test the significance of the difference between the coefficients of the decomposed income variables. This is done with the t-test shown at the bottom of the table. For all functional specifications the hypothesis is clearly rejected, thus strongly supporting asymmetric response to income changes.

The estimation results for the statistically preferred model, the semi-log specification, are presented in Table 2. In most cases, the estimated coefficients are highly significant and of the expected signs. The most obvious exception is the number of children, which has no explanatory

[16] Data for 1970–1975 are excluded because of missing data for some variables.

[17] This supports the finding of Pendyala et al. (1995) that the income elasticity declines over time and confirms that the decline is due to increasing motorisation.

Table 1
Summary statistics for estimation of different functional forms, tests for functional form and income asymmetry

	Linear	Double-log	Semi-log
$\bar{R}^2$	0.99	0.98	0.99
Log likelihood	500.73	371.58	507.80
Tests for functional form			
Linear vs double-log			
PE test: t-statistic (p-value)	0.19 (0.851)	6.14 (0.000)	
Test result	Reject double-log in favour of linear		
Semi-log vs double-log			
PE test: t-statistic (p-value)		6.75 (0.000)	0.50 (0.617)
Test result	Reject double-log in favour of semi-log		
Linear vs semi-log	LL(semi-log) = 507.80 > LL(linear) = 500.73		
Test result	Reject linear in favour of semi-log		
Tests for symmetry			
H_0: $\beta_{YR} - \beta_{YF} = 0$			
t-test (p-value)	2.62 (0.009)	2.35 (0.020)	3.24 (0.001)
Test result: symmetry	Rejected	Rejected	Rejected

power. The coefficient of the cost variable is negative as it should be, but significantly different from 0 only at the 0.066 probability level.

The coefficient of the lagged car ownership variable is of a reasonable order of magnitude and highly significant, confirming the validity of the dynamic specification. Car ownership clearly does not adjust instantaneously to income changes. From the estimated adjustment coefficients, 99% of the complete adjustment occurs in around 5 years.

The αs generally increase from the eldest to the more recent generations, suggesting that the generation effect noted in Fig. 2 is not totally explained by increasing real income. The life-cycle effects indicate an increase in car ownership over the life cycle, at least to the age of 65. This suggests that the decline in household car ownership when the head of household reaches the early 50s noted in Fig. 2, is entirely explained by the decreasing real income and number of adults in the household, primarily as adult 'children' leave home. The most pronounced pure life-cycle effect is the large rise in car ownership between the ages of 25 and 34. The number of adults is clearly an important determinant of household car ownership: an additional adult increases car ownership on average by 0.4 cars in the long run.

The income and cost elasticities resulting from the model are shown in Table 3. These are not constant with the semi-log model. The income elasticities are inversely related to the level of car ownership, while the cost elasticity declines with increasing car ownership and increases at higher prices. The elasticities are calculated at various levels of car ownership, as well as at the mean car ownership in 1995. The cost elasticities are calculated at car purchase costs in 1995.

The estimated elasticities with respect to rising income are in line with those obtained in other studies. The values obtained by Dargay and Vythoulkas (1999) based on a symmetric model lie between those for rising and falling income. There is a substantial (and statistically significant) difference in the elasticity for rising and falling income – the response of car ownership to increasing income is over twice the response to an equal fall in income. These results confirm the panel-data findings of Goodwin (1998) and Pendyala et al. (1995).

Table 2
Semi-log car ownership model[a]

	Coefficient	Standard error	p-value
ϕ Cars(−1)	0.355	0.042	0.000
β_{YR} rising income	0.418	0.047	0.000
β_{YF} falling income	0.255	0.057	0.001
β_A adults	0.243	0.048	0.000
β_K children	−0.001	0.013	0.955
β_P car purchase costs	−0.080	0.047	0.066
Generation effects			
α_1 before 1900	−1.424	0.198	0.000
α_2 1901–1905	−1.431	0.200	0.000
α_3 1906–1910	−1.408	0.205	0.000
α_4 1911–1915	−1.408	0.208	0.000
α_5 1916–1920	−1.396	0.210	0.000
α_6 1921–1925	−1.373	0.212	0.000
α_7 1926–1930	−1.362	0.211	0.000
α_8 1931–1935	−1.328	0.209	0.000
α_9 1936–1940	−1.285	0.208	0.000
α_{10} 1941–1945	−1.226	0.210	0.000
α_{11} 1946–1950	−1.241	0.208	0.000
α_{12} 1951–1955	−1.257	0.208	0.000
α_{13} 1956–1960	−1.237	0.213	0.000
α_{14} 1961–1965	−1.239	0.216	0.000
α_{15} 1966–1970	−1.280	0.211	0.000
α_{16} 1971–1975	−1.295	0.219	
Life-cycle effects			
γ_2 25–34	0.069	0.018	0.001
γ_3 35–44	0.078	0.025	0.003
γ_4 45–54	0.085	0.030	0.008
γ_5 55–64	0.115	0.033	0.001
γ_6 65 or over	0.121	0.036	0.001
$\bar{R}^2$	0.995161	Observations	256
Log likelihood	507.7992		
SE of regression	0.035197	Mean dep. var.	0.869516
H_0: $\beta_{YR} - \beta_{YF} = 0$			
t-test (p-value)	3.24(0.001)	Symmetry	Rejected

[a] Dependent variable: cars per household.

The variation in elasticities is considerable – a factor of 5 between, 0.3 and 1.5 cars per household. For rising incomes, the long-run income elasticity is unity at a car ownership level of about 0.7 cars per household. Below this, the elasticity is greater than 1 and above this it is less than 1. This is equivalent to about 0.3 cars per capita, the ownership level for a unitary income elasticity found in Dargay and Gately (1999) on the basis of international data.

The functional specification used implies that the cost elasticity declines (in absolute value) as car ownership increases. This is not unreasonable, as higher car ownership is associated with higher incomes. The elasticities appear to be quite small for all but the lowest car ownership levels.

Table 3
Short- and long-run income and cost elasticities of car ownership calculated at different car ownership levels

Cars per household	Rising income		Falling income		Car purchase costs	
	Short run	Long run	Short run	Long run	Short run	Long run
0.3	1.40	2.15	0.53	0.82	−0.24	−0.37
0.5	0.84	1.29	0.32	0.49	−0.14	−0.22
1.0	0.42	0.65	0.16	0.25	−0.07	−0.11
1.2	0.35	0.54	0.13	0.21	−0.06	−0.09
1.5	0.28	0.43	0.11	0.16	−0.05	−0.07
Mean car ownership 1995	0.48	0.74	0.18	0.28	−0.08	−0.13

The cost elasticities shown, however, are calculated at 1995 purchase prices. As mentioned earlier, with the functional specification used, the cost elasticities are themselves dependent on the level of costs. In the UK, car purchase costs declined substantially in real terms during the 1980s and 1990s. If the elasticities are calculated at higher cost levels, for example that of 1979, long run values of −0.5 and −0.1 are obtained for ownership levels of 0.3 and 1.5 cars per household.

5. Conclusions

In the previous sections we have seen that household car ownership increases over the life cycle up until the ‘head’ reaches about the age of 50 and declines thereafter. This pattern closely follows that of household income and the number of adults in the household over the life cycle. The relationship between household income and car ownership, however, does not appear to be symmetric. There is evidence of hysteresis. The statistical results confirm this – the elasticity with respect to rising income is significantly greater than the elasticity with respect to falling income. Rising income makes it easier for households to own cars. They become accustomed to car use, and this trend is not so easily reversed as income falls. The acquisition of a car is seen as a luxury, but once acquired the car becomes a necessity, so that disposing of a car is much more difficult. Car ownership is clearly associated with habit and resistance to change. Once the habit of motoring is acquired, it is not so easy to abandon, even if the economic consequences – in terms of alternative consumption foregone – are greater than previously. The existence of hysteresis is an indication of the difficulty of reducing car dependence in favour of other transport modes.

The statistical results also confirm that the income elasticity is not constant, but that it declines with increasing car ownership, from well over unity at low car ownership levels to under unity at higher ownership levels, as saturation is approached.

The evidence of asymmetry is found on the basis of a dynamic model, which allows car ownership decisions to be partially determined by previous car ownership, so that state dependence or habit persistence is simultaneously taken into account along with the possibility of asymmetry. The estimation shows that the dynamic effects are important. The response to income changes is not instantaneous, but takes place slowly over time.

The results presented in this paper were obtained on the basis of cohort data, i.e. groups of households, rather than on individual household data. Although this may not be ideal, the results do support less rigorous statistical evidence of income asymmetry obtained from panel data.

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References

Dargay, J., Gately, D., 1997. The demand for transportation fuels: imperfect price reversibility? Transportation Research 31B (1), 71–82.

Dargay, J., Gately, D., 1999. Income's effect on car and vehicle ownership worldwide: 1960–2015. Transportation Research Part A 33, 101–138.

Dargay, J.M., Vythoulkas, P.C., 1998. Estimation of dynamic transport demand models using pseudo-panel data. The Eighth World Conference on Transport Research, Antwerp, Belgium, July.

Dargay, J.M., Vythoulkas, P.C., 1999. Estimation of a dynamic car ownership model: a pseudo panel approach. Journal of Transport Economics and Policy 33 (3), 283–302.

Deaton, A., 1985. Panel data from time series of cross-sections. Journal of Econometrics 30, 109–126.

Golob, T.F., 1990. The dynamics of household travel time expenditure and car ownership decisions. Transportation Research 24A (6), 443–463.

Goodwin, P.B., 1977. Habit and hysteresis in mode choice. Urban Studies 14, 95–99.

Goodwin, P.B., Dix, M.C., Layzell, A.D., 1987. The case for heterodoxy in longitudinal analysis. Transportation Research 21A (45), 363–376.

Goodwin, P.B., et al., 1995. Car Dependence. A Report to The RAC Foundation for Motoring and the Environment, ISBN 0 86211355 5.

Goodwin, P.B., 1998. The end of equilibrium. In: Garling, T., Laitila, T., Westin, K. (Eds.), Theoretical Foundations of Travel Choice Modeling. Elsevier, Amsterdam.

Hensher, D.A., Barnard, P.O., Smith, N.C., Milthorpe, F.W., 1987. Modelling the dynamics of car ownership and use: a methodological and empirical synthesis. In: Proceedings of the Fifth International Conference on Travel Behavior. Gower Publishing, Aldershot.

Hensher, D.A., Wrigley, N., 1986. Statistical modelling of discrete choices in discrete time with panel data. Behavioral Research for Transport Policy. VNU Science Press, Utrecht, Netherlands, pp. 97–116.

Kitamura, R., Bunch, D.S., 1990. Heterogeneity and state dependence in household car ownership: a panel analysis using ordered-response probit models with error components. In: Koshi, M. (Ed.), Transportation and Traffic Theory. Elsevier, Amsterdam.

MacKinnon, J., White, H., Davidson, R., 1983. Tests for model specification in the presence of alternative hypotheses: some further results. J. Econometrics 21, 53–70.

Madre, J.L., Bussière, Y., Armoogum, J., 1995. Demographic dynamics of mobility in urban areas: a case study of Paris and Grenoble. In: Proceedings of the Seventh World Conference on Transport Research, 16–21 July, Sydney, Australia. Elsevier, Amsterdam.

Mannering, F., Winston, C., 1985. A dynamic empirical analysis of household vehicle ownership and utilization. Rand J. Economics 16 (2), 215–236.

Pendyala, R.M, Kostyniuk, L.P., Goulias, K.G., 1995. A repeated cross-sectional evaluation of car ownership. Transportation 22, 165–184.

Train, K., Lohrer, M., 1982. Vehicle Ownership and Usage: An Integrated System of Disaggregate Demand Models. Cambridge Systematics, Berkeley, CA.