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# A repeated cross-sectional evaluation of car ownership

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**Abstract.** This paper studies changes in the relationship between household car ownership and income by household type. Ordered response probit models of car ownership are estimated for a sample of households repeatedly at six time points to track the evolution of income elasticities of car ownership over time. Elasticities of car ownership are found to change over time, questioning the existence of a unique equilibrium point between demand and supply that is implicitly assumed in traditional cross-sectional discrete choice car ownership models. Moreover, different household types and households that underwent household type transitions showed differing patterns of change in elasticities. Observed trends in car ownership and income clearly show behavioral asymmetry where the elasticity of procuring an additional car is greater than that of disposing a car. This too shows the inadequacy of traditional cross-sectional models of car ownership which tend to predict symmetry in behavior. The study suggests the importance of incorporating dynamic trends into the forecasting process, which can be accomplished through the use of longitudinal data.

## Introduction

Car ownership has long been used as one of the major determinants of travel behavior. It can be argued that, at any point in time, in almost any industrialized country, knowledge of a household's income, car ownership, along with the lifecycle stage and/or household structure leads to a fairly reasonable estimate of that household's travel patterns. Based on this, models which describe the current patterns of trip generation are developed and calibrated. Whenever specific relationships between car ownership of a particular type of household and income are called for, cross classification tables (e.g., Stopher & Meyburg 1975) or econometric models (e.g., Train 1980; Lerman & Ben Akiva 1976) are employed. In cross-classification tables, the demand for cars is inferred from the observed levels of car ownership for particular household types and income levels. In the econometric models the demand for cars is described analytically and the change in demand with respect to income is tracked by elasticities. Quantifications of the relationship between car ownership and income are used in travel forecasting procedures.

The forecasting procedures implicitly assume that the relationships between household car ownership, income, and household structure do not change over time. Discrete choice models implicitly assume the existence of a unique equilibrium point, where the utility is maximized (McFadden 1981). There are reasons to question this implicit assumption when the time range of the forecast is not short because many effects of time on car ownership are ignored. Included in these time effects are motorization,[1] increase of women in labor force, or any other societal changes. There is evidence in the literature that indeed effects of car ownership and travel patterns are changing (Kostyniuk & Kitamura 1986; Jansson 1988; Madre 1988; Kawashima 1988; Kitamura 1990). However, it would be interesting to examine the relationships between car ownership and income at a series of neighboring cross-sections and see if these relationships remain relatively stable for periods of time used in mid-range transportation planning.

Another unsatisfying aspect of the forecasting procedure is that a symmetrical relationship between car ownership and income is implied, i.e., car ownership decreases when income decreases in the same way that it increases when income increases. However, experience indicates that once a household acquires a car, it is reluctant to give it up and that there is a lagged effect between income and car ownership and that this effect is not symmetrical (Kitamura 1989). Observations of car ownership and income over time could help to sort out this phenomenon. The objective of this inquiry was to quantitatively examine household car ownership and income over a time period and address the following questions:

- How sensitive is car ownership to changes in income?
- How well do cross-sectional measures such as elasticities describe changes in car-ownership over time?
- Are changes in elasticities over time (if any) different for different household types?
- Is elasticity of car ownership with respect to income symmetrical? Does car-ownership decrease with decreases in income the same way it increases with increases in income?
- Are households who change their structure more elastic with respect to their vehicular ownership than households who do not change?
- Are there lagged effects of income on car ownership?

The next section of this paper describes the data used in this study. The third section presents the methodology adopted to estimate income elasticities of car ownership. Results of the analysis conducted on the Dutch National Mobility Panel Data Set are provided in the fourth section, while a summary of the main findings and conclusions drawn from this study make up the last section.

## Data

A set of household observations with information on income, car ownership, demographics, and the transportation systems available to them would be ideal for this exploration. The time period over which this information is available should be equal to that used in mid-range planning, i.e., between 5 and 10 years.

Given that such data are available, cross-sectional car ownership models could be repeatedly estimated for each year. Car ownership elasticities with respect to income could be calculated for each household category of interest at each time point and the resulting elasticities could be examined and compared. The model results could also be compared against actual observations, particularly with regard to the car ownership changes that result from increases and decreases in income.

Data from the Dutch National Mobility Panel Survey (Golob et al. 1986; Wissen & Meurs 1989) were suitable and available for this study. The data consist of repeated observations of travel behavior of a panel of households at 10 waves over a six year period from 1984 through 1989. While the Dutch National Mobility Panel Survey tried to retain the same individuals for the duration of the survey, there were some changes in individuals in each wave. For this study we selected a sample of the same 485 individuals from waves 1, 3, 5, 7, 9, and 10. A disadvantage of using the same sample repeatedly is that any changes in income-car ownership relationships attributable to the natural aging process of the sample cannot be isolated. However, at the same time, selection of the same individuals minimizes intra-category variation in the analysis, making the comparison of elasticities across time points meaningful and insightful.

As can be expected, there were a few households which experienced changes in household type. Table 1 shows the distribution of the 485 households by household type at each one of the six time-points. In the first wave, the sample was made up of 58% families, 24% couples, 9% single persons, and 7% single parents. The distribution of the sample varied a little at each time-point but the variation was small. It is acknowledged that care must be exercised whenever data from households that experience household category transitions are used in an analysis of this type. Later, we will compare the income-car ownership relationships exhibited by households that do not change household categories against those that do.

*Table 1.* Distribution of households by household type.

| Household type | Wave 1 | Wave 3 | Wave 5 | Wave 7 | Wave 9 | Wave 10 |
|---|---|---|---|---|---|---|
| Single person | 45 | 45 | 44 | 45 | 47 | 46 |
| Couple | 117 | 117 | 106 | 108 | 109 | 116 |
| Family | 282 | 282 | 296 | 291 | 286 | 280 |
| Single parent | 33 | 33 | 34 | 33 | 23 | 21 |
| Other | 8 | 8 | 5 | 8 | 20 | 22 |
| Total | 485 | 485 | 485 | 485 | 485 | 485 |

Table 2 shows the car ownership and income by household type at each time point. Families consistently had the highest car ownership in the sample, one car per household in the first wave and 1.1 cars (on average) six years later. Couples were next in terms of car ownership and they also showed an increase from 0.82 to 0.94 cars per household over the six year period. Single parents had car ownership between 0.64 and 0.73 during the course of the survey. Single persons had the lowest car ownership levels, from 0.36 to 0.44 during this time. Unlike families and couples, single persons and single parents did not show a consistent increase in car ownership over the 6 year period.

*Table 2.* Average car ownership and income by household type.

| Household type | Wave 1 | Wave 3 | Wave 5 | Wave 7 | Wave 9 | Wave 10 |
|---|---|---|---|---|---|---|
| Income | | | | | | |
| Single person | 19791 | 21611 | 20675 | 21899 | 19458 | 20061 |
| Couple | 33124 | 31312 | 32445 | 33971 | 34914 | 35233 |
| Family | 34810 | 33739 | 33755 | 34776 | 36927 | 37312 |
| Single parent | 21302 | 21833 | 22235 | 22257 | 19989 | 21492 |
| Other | 25562 | 33313 | 38323 | 27117 | 32232 | 30124 |
| Total | 31960 | 31211 | 31522 | 32424 | 33785 | 34168 |
| Car ownership | | | | | | |
| Single person | 0.44 | 0.42 | 0.36 | 0.40 | 0.40 | 0.37 |
| Couple | 0.82 | 0.86 | 0.81 | 0.83 | 0.89 | 0.94 |
| Family | 1.01 | 1.02 | 1.02 | 1.03 | 1.10 | 1.11 |
| Single parent | 0.73 | 0.73 | 0.74 | 0.64 | 0.65 | 0.67 |
| Other | 0.63 | 0.75 | 1.20 | 1.13 | 0.90 | 0.86 |
| Total | 0.88 | 0.90 | 0.89 | 0.91 | 0.96 | 0.97 |

*Note:* Income is in Dutch Guilders and is adjusted for inflation to 1985 values.

**Methodology**

Ordered-response probit models of car ownership were estimated at each time point. The ordered-response probit model probabilistically describes the choice of an alternative from among a set of ordered discrete alternatives (Maddala 1983).

Car ownership may be considered an ordered polychotomous variable with each level of car ownership being a discrete state. As such, this method is very appropriate for modeling car ownership. It has been used in the past to study heterogeneity and state-dependence in car ownership (Kitamura & Bunch 1990). Moreover, maximum likelihood estimation of the ordered-probit is found to be computationally tractable with convergence usually achieved within ten iterations. Also, it yields robust parameter estimates with the iterative procedure converging to the same values with different initial values (Maddala 1983).

In this case, the choice variable was the number of cars owned by a household. The alternative choices were no cars, one car, and two or more cars. The ordered-response probit model assumes the presence of a latent variable that cannot be measured directly, but is related to the observed choice, the number of cars in this case. Corresponding to a level of car ownership is a range of the latent variable value which is defined by unknown threshold values to be estimated. Mathematically,

$$A(i, t) = \beta' X(i, t) + \varepsilon(i, t) \quad \text{(1a)}$$

$$Y(i, t) = \begin{cases} 0, & \text{if } A(i, t) \leq \alpha_1 \\ 1, & \text{if } \alpha_1 < A(i, t) \leq \alpha_2 \\ 2, & \text{if } \alpha_2 < A(i, t) \end{cases} \quad \text{(1b)}$$

where $i$ refers to the household, $t$ represents the time (year), and

$A(i, t)$ = latent variable of car ownership for household $i$ at time $t$,
$X(i, t)$ = vector of explanatory variables,
$\varepsilon(i, t)$ = random error term,
$Y(i, t)$ = observed number of cars available,
$\alpha_1, \alpha_2$ = threshold parameters, and
$\beta$ = vector of model coefficients

Given a set of explanatory variables, $X(i, t)$, the objective of model estimation is to determine $\beta$, $\alpha_1$ and $\alpha_2$. This can be accomplished using the maximum likelihood method. The choice probabilities are then given by the following set of equations,

$$P_1 = F(\alpha_1 - \beta'X) \qquad (2a)$$

$$P_2 = F(\alpha_2 - \beta'X) - F(\alpha_1 - \beta'X) \qquad (2b)$$

$$P_3 = 1 - F(\alpha_2 - \beta'X) \qquad (2c)$$

Once the choice probability is obtained from the ordered-probit model, the income elasticity of demand for car ownership can be formulated as per Winston (1981).

The Market Income Elasticity of alternative *n* may be formulated as,

$$E_n = \frac{\partial C_n(I)}{\partial I} \frac{I}{C_n(I)} \qquad (3)$$

To obtain the first term of the above product, we note that

$$C_n(I) = \sum_i P_{in}(I_i) \qquad (4)$$

Then, substituting equation (4) into equation (3) yields,

$$E_n = \frac{\partial \sum_i P_{in}(I_i)}{\Delta I} \frac{I}{\sum_i P_{in}(I_i)} \qquad (5)$$

Imposing a uniform percentage change of ΔI/I on each households' income, the formula becomes,

$$E_n = \frac{\Delta \sum_i P_{in}(I_i)}{\Delta I} \frac{I}{\sum_i P_{in}(I_i)} \qquad (6)$$

where
- I = Income
- C = Car Ownership (Consumption)
- E = Market Income Elasticity of Car Ownership
- P = Probability of choice
- *i* = individual
- *n* = alternative chosen where *n* = 1, 2, 3

## Model estimation

The vector of explanatory variables used in the model is given in Table 3. The variables consist of a set of household descriptors, measures of transit accessibility to work and shopping, and descriptors of the size of the community and its level of public transit.

*Table 3.* Definition of variables in the ordered response probit models.

| Variable | Definition |
|---|---|
| NPRCRD | Number of persons in the household |
| NCHLD11 | Number of children less than 11 years old |
| TPINCOME | Annual household income in Dfl/1000 (1 Dfl ≈ \$0.50) |
| NDRIVERS | Number of drivers in the household |
| DACCESS1 | Difference of accessibility between car and transit for work |
| DACCESS2 | Difference of accessibility between car and transit for shopping |
| BOVLARG | 1 if the household resides in a large metropolitan area with highly developed multi-mode transit systems; 0 otherwise |
| BOVSMALL | 1 if the household resides in a small metropolitan area with highly developed multi-mode transit systems; 0 otherwise |
| BOS | 1 if the household resides in a medium sized community that is served by rail; 0 otherwise |
| NOTRAIN | 1 if the household resides in a small community that is not served by rail; 0 otherwise |

The household descriptors give the household size, number of children younger than 11 years of age, income, and the number of drivers. The accessibility measures represent the car and transit service level available to the household. The accessibility differences used in the model are based on accessibility indices developed by the Hague Consulting Group using a set of destination choice models (Geinzer & Daly 1981). The accessibility measures represent the car and transit levels of service available for the residential zone in which the household is located. The difference (auto accessibility – transit accessibility) is taken for work and shopping trips respectively, and used in the estimation. The third set of variables indicate the size of the community where the household resides and whether or not it is served by rail.

The ordered probit model of car ownership was estimated for each time point. The results of the model estimation are shown in Table 4 in terms of the estimated coefficients, threshold values of the latent variable, $A(i, t)$, $t$-statistics and overall model goodness-of-fit statistics.

The model estimation shows that the variable with the greatest effect on auto ownership is the number of drivers in the household, followed by the household income. These variables were highly significant at all 6 time points.

*Table 4.* Ordered response probit models of car ownership.

| Variable name | Wave 1 | | Wave 3 | | Wave 5 | | Wave 7 | | Wave 9 | | Wave 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | *t*-stat | β | *t*-stat | β | *t*-stat | β | *t*-stat | β | *t*-stat | β | *t*-stat |
| NPRCRD | 0.028 | 0.38 | –0.023 | –0.32 | –0.023 | –0.30 | –0.033 | –0.46 | –0.023 | –0.30 | 0.121 | 1.79 |
| NDRIVERS | 1.180 | 10.46 | 1.320 | 11.24 | 1.471 | 11.40 | 1.251 | 11.01 | 1.299 | 10.69 | 1.072 | 10.31 |
| TPINCOME | 0.020 | 4.17 | 0.011 | 2.33 | 0.017 | 2.89 | 0.022 | 4.08 | 0.021 | 3.94 | 0.033 | 6.23 |
| NCHILD11 | –0.061 | –0.93 | –0.100 | –1.46 | –0.098 | –1.37 | –0.108 | –1.56 | –0.066 | –1.04 | –0.097 | –1.49 |
| DACCESS1 | 0.291 | 2.07 | 0.178 | 1.30 | 0.396 | 2.69 | 0.236 | 1.71 | 0.325 | 2.34 | 0.267 | 2.02 |
| DACCESS2 | 0.276 | 1.55 | 0.254 | 1.49 | 0.072 | 0.42 | 0.143 | 0.92 | –0.184 | –1.16 | 0.032 | 0.20 |
| BOVLARG | 0.392 | 0.92 | 0.565 | 1.39 | 0.189 | 0.44 | –0.024 | –0.06 | –0.514 | –1.20 | –0.229 | 0.56 |
| BOVSMALL | 0.216 | 0.70 | 0.002 | 0.01 | –0.245 | –0.80 | –0.101 | –0.36 | –0.117 | –0.40 | 0.257 | 0.90 |
| BOS | 0.580 | 2.38 | 0.428 | 1.82 | 0.558 | 2.24 | 0.257 | 1.10 | 0.045 | 0.19 | –0.076 | 0.33 |
| NOTRAIN | 0.421 | 1.77 | 0.449 | 1.90 | 0.459 | 1.85 | 0.212 | 0.92 | –0.133 | –0.58 | –0.136 | –0.59 |
| $\alpha_1$ | 2.496 | 4.73 | 1.837 | 3.65 | 2.240 | 4.25 | 1.979 | 4.20 | 1.476 | 3.09 | 2.205 | 4.58 |
| $\alpha_2$ | 5.566 | 9.58 | 4.917 | 9.03 | 5.680 | 9.54 | 5.092 | 9.85 | 4.606 | 8.75 | 5.203 | 9.72 |
| L(0) | 679.1 | | 682.6 | | 684.0 | | 681.2 | | 678.4 | | 677.6 | |
| L(β) | 258.8 | | 257.2 | | 230.0 | | 249.7 | | 258.6 | | 270.9 | |
| L(c) | 395.6 | | 389.6 | | 384.8 | | 393.5 | | 405.6 | | 408.0 | |
| chi sq = –2(L(0) – L(β)) | 840.5 | | 850.9 | | 908.0 | | 863.0 | | 839.4 | | 813.4 | |
| chi sq = –2(L(c) – (L(β)) | 273.5 | | 265.0 | | 309.7 | | 287.8 | | 294.0 | | 274.1 | |
| Zero car | 105 | | 100 | | 101 | | 100 | | 91 | | 89 | |
| One car | 333 | | 338 | | 340 | | 336 | | 332 | | 331 | |
| > One car | 47 | | 47 | | 44 | | 49 | | 62 | | 65 | |
| Total sample | 485 | | 485 | | 485 | | 485 | | 485 | | 485 | |

The difference between the accessibility to work by car and transit appears to have some bearing on the choice, in that this variable was significant at the 5% level in 4 out of the 6 time points. The greatest effects, however, are from the number of drivers and the income. The number of drivers in a household is closely related to the category of the household, supporting the use of income as the strongest descriptor of car ownership of a household category at any time point.

## Elasticities

The market income elasticities of car ownership by household type at each time point are computed using equation (6) for a unit percent increase in income. The elasticities are computed by alternative to show how the probability of choosing a certain alternative changes with a unit percent increase in income.

The first aspect to be examined is that of stability over time. Figures 1 through 4 graphically show the elasticities across the six timepoints. It is clear that the elasticities do change over time for each household category. This implies that the factors contributing to car ownership change in such a way that the relationship between income and car ownership does not remain constant over time. This questions the existence of a unique equilibrium point (Hildenbrand & Kirman 1988; Ortuzar & Willumsen 1990; Kanafani 1983). We are observing the existence of multiple equilibria where each time point represents an equilibrium point which is reset from time to time. It is interesting to note that elasticities of owning no cars show a decreasing tendency while the elasticities of owning two or more cars show an increasing tendency. In general, households seem to exhibit increasing flexibility to changes in income as time passes. This could be interpreted as evidence of motorization. It also casts doubts on the appropriateness of the use of cross sectional elasticities for forecasts in mid-range planning.

An examination of the specific entries in Table 5 shows that single persons have a high propensity to move to at least one car ownership when there is an increase in income. In the first wave, the probability that they would own one car increases by 0.284% while the probability of owning two or more cars increases by 2.102% for a unit percent increase in income. For example, if the probabilities of owning zero cars, one car and two or more cars before the increase in income are 0.7, 0.2 and 0.1 respectively, then after a one percent increase in income, the probabilities are $0.7 \times (100 - 0.218)/100 = 0.698$, $0.2 \times (100 + 0.284)/100 = 0.201$ and $0.1 \times (100 + 2.102)/100 = 0.102$ respectively. Based on this explanation, we can see that single persons show a propensity to move from lower to higher car ownership. Similarly, couples

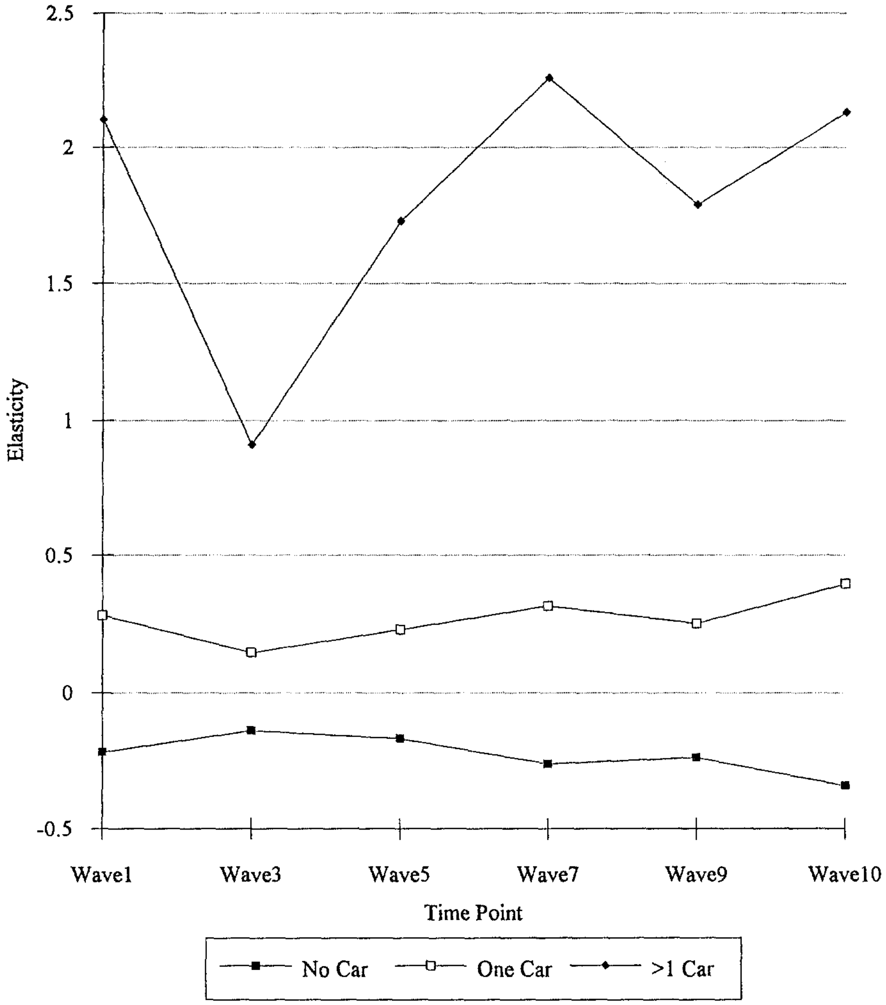


*Fig. 1.* Evolution of elasticities for single person households.

and families tend to increase car ownership with increases in income also. Couples and families have negative elasticities associated in choosing no car or one car because they are already at one-car ownership levels (see Table 2 for the average car ownership level of different household types). So, their elasticities show that these household types tend to move to a level of higher car ownership, which in their case is two or more cars. Single parents, on the other hand have car ownership levels in between single persons and couples and tend to move to one car or two or more car ownership levels when their income increases.

In general it was found that single persons are the most elastic. This can

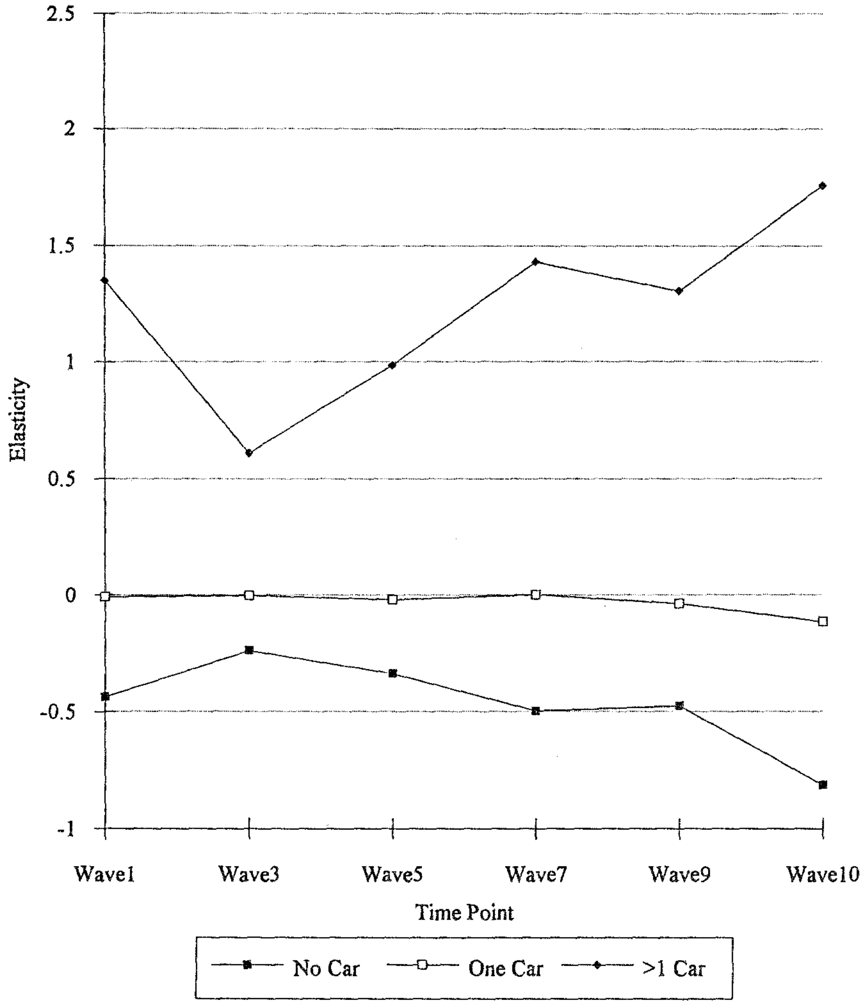


*Fig. 2.* Evolution of elasticities for couples.

probably be attributed to the absence of household constraints stemming from collective decisions and the need to share the household budget. Families, on the other hand, who tend to have such constraints, show more resistance to change. If there is an increase in income they show the smallest increase in propensity to own two or more cars. This pattern is found at all six time points. Single parents tend to behave like single persons, but the elasticities are slightly smaller, most likely from the presence of some household constraints.

Differences across household types support the need to account for household structure in demand forecasting. The weighted average elasticity replicates

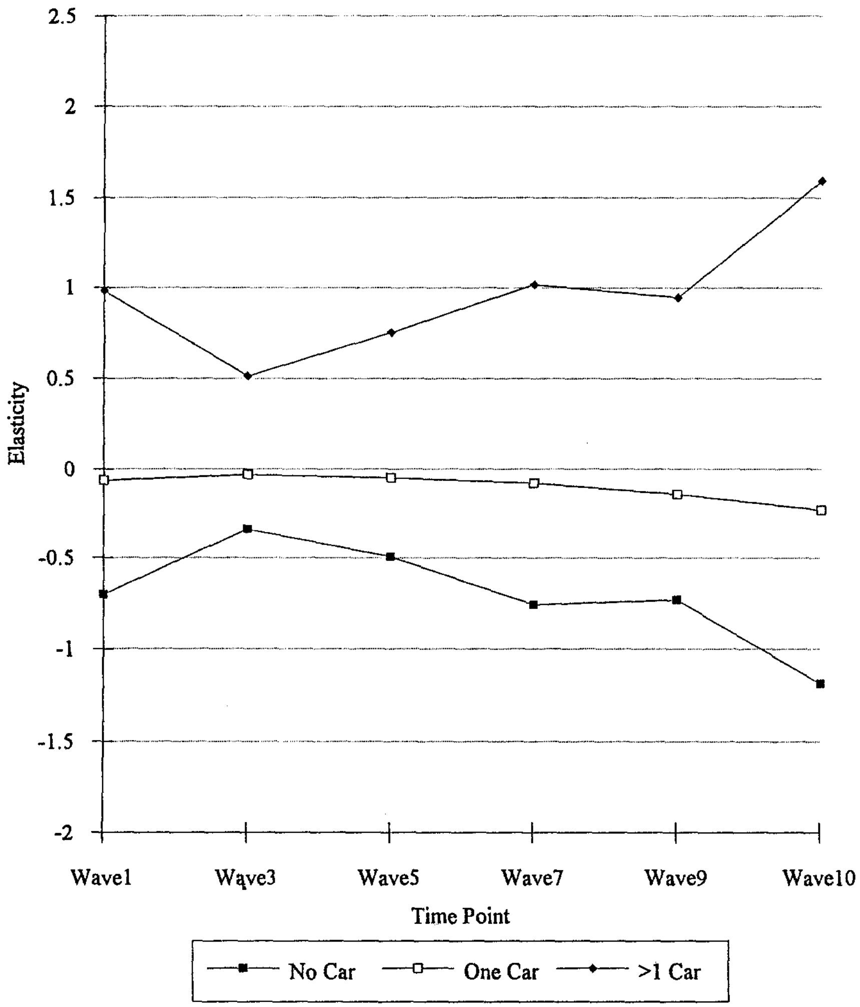


*Fig. 3.* Evolution of elasticities for families.

that of couples and families who account for the largest percentage of the sample. With the growth in the proportions of single-parent and other non-traditional households (Rosenbloom 1989) it is clear that accounting for differences across household structures will become increasingly important when making forecasts.

The fluctuations in elasticities seen in Table 5 and Figs. 1 through 4 may have been due to the changes in the composition of the sample in each household type. Recall that the households belonging to each category did not remain constant through the six time periods. A few households changed categories during the course of the panel study due to the transition of single person house-

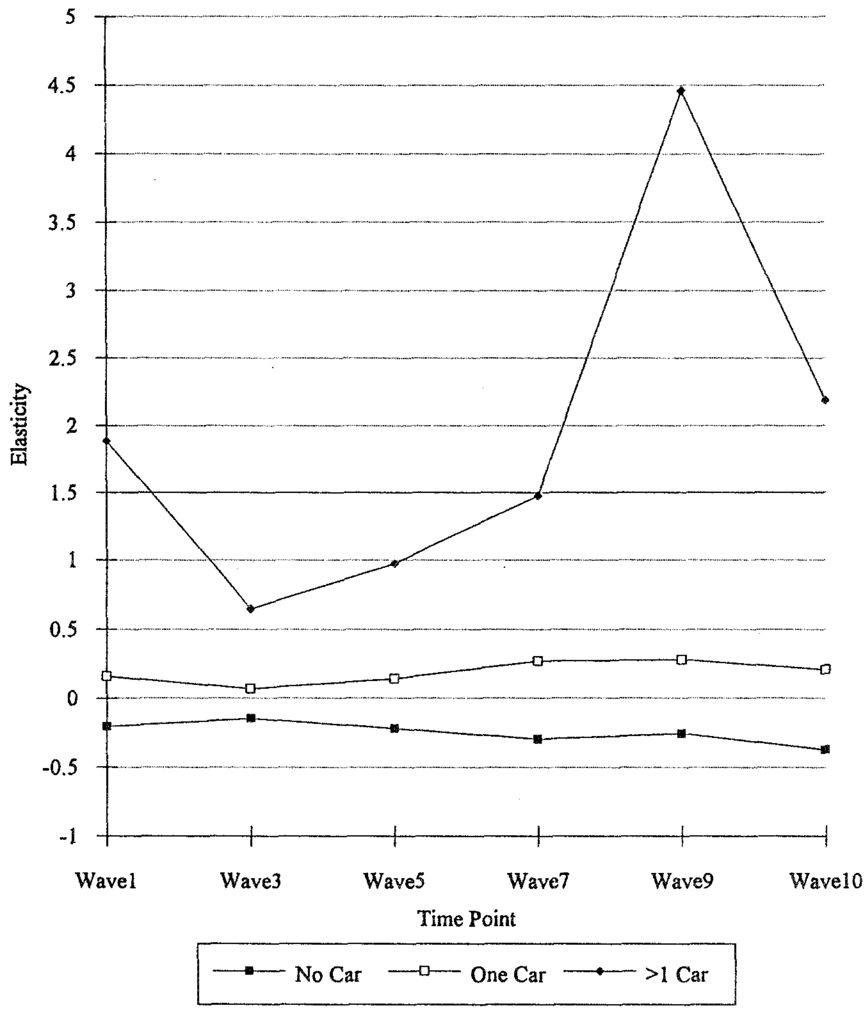


*Fig. 4.* Evolution of elasticities for single parents.

holds to couples, couples to families, etc. The composition of the various household categories was shown earlier in Table 1.

The elasticities of households that did not change their structure during the six year period ("stable" households) and those that underwent a household structure transition ("changer" households) are shown in Table 6 at waves 1 and 10.

Not surprisingly, the "changer" households show different elasticities of car ownership between waves 1 and 10. Considering that the relationship between car-ownership and income for a particular household category is believed to be constant, households that undergo a transition between categories are

*Table 5.* Market income elasticities of car ownership (1% increase in income).

| Household type | Alternative | Wave 1 | Wave 3 | Wave 5 | Wave 7 | Wave 9 | Wave 10 |
|---|---|---|---|---|---|---|---|
| Single person households | No car | –0.218 | –0.138 | –0.167 | –0.260 | –0.238 | –0.342 |
| | One car | 0.284 | 0.149 | 0.233 | 0.317 | 0.255 | 0.396 |
| | > 1 car | 2.102 | 0.911 | 1.728 | 2.256 | 1.789 | 2.129 |
| Couple | No car | –0.438 | –0.238 | –0.338 | –0.496 | –0.476 | –0.815 |
| | One car | –0.010 | –0.003 | –0.021 | 0.000 | –0.038 | –0.117 |
| | > 1 car | 1.350 | 0.611 | 0.986 | 1.430 | 1.305 | 1.757 |
| Families | No car | –0.704 | –0.337 | –0.494 | –0.759 | –0.732 | –1.189 |
| | One car | –0.063 | –0.030 | –0.049 | –0.078 | –0.139 | –0.230 |
| | > 1 car | 0.979 | 0.513 | 0.753 | 1.017 | 0.945 | 1.595 |
| Single parent households | No car | –0.208 | –0.148 | –0.222 | –0.297 | –0.256 | –0.375 |
| | One car | 0.160 | 0.070 | 0.142 | 0.272 | 0.282 | 0.207 |
| | > 1 car | 1.887 | 0.647 | 0.973 | 1.477 | 4.460 | 2.183 |
| Total sample | No car | –0.438 | –0.240 | –0.331 | –0.482 | –0.456 | –0.744 |
| | One car | –0.018 | –0.006 | –0.009 | –0.019 | –0.068 | –0.138 |
| | > 1 car | 1.068 | 0.539 | 0.801 | 1.102 | 1.020 | 1.649 |

*Table 6.* Elasticities for stable and changer households at end points (1% increase in income).

| Household type | Alternative | Wave 1 | Wave 10 |
|---|---|---|---|
| Stable (375) | No car | –0.419 | –0.696 |
| | One car | –0.006 | –0.157 |
| | > 1 car | 1.076 | 1.630 |
| Changer (110) | No car | –0.460 | –0.920 |
| | One car | –0.053 | –0.082 |
| | > 1 car | 1.051 | 1.721 |

expected to exhibit different elasticities at the two time points. However, the "stable" households also exhibit changes in elasticities over the six year time period. This means that a change in household structure is not the sole contributor to changes in car ownership-income relationships exhibited by the sample.

Table 6 further shows that "changers" exhibit greater differences in elasticities at the zero and two or more car ownership levels. This means that, if we were trying to forecast car ownership based on elasticities computed at wave 1, we would be more inaccurate for the "changers" than for the "stable" households. This further shows the importance of incorporating transitions among household structures and lifecycle stages in travel demand forecasting.

The question of symmetry in car ownership with respect to increases and decreases in income is explored next. Table 7 shows the elasticities in car

*Table 7.* Market income elasticities of car ownership (1% decrease in income).

| Household type | Alternative | Wave 1 | Wave 3 | Wave 5 | Wave 7 | Wave 9 | Wave 10 |
|---|---|---|---|---|---|---|---|
| Single person households | No car | 0.222 | 0.140 | 0.169 | 0.265 | 0.241 | 0.346 |
| | One car | –0.292 | –0.152 | –0.237 | –0.326 | –0.260 | –0.410 |
| | > 1 car | –1.695 | –0.839 | –1.466 | –1.838 | –1.525 | –1.815 |
| Couple | No car | 0.461 | 0.243 | 0.348 | 0.522 | 0.498 | 0.890 |
| | One car | –0.011 | –0.002 | –0.053 | –0.023 | 0.017 | 0.063 |
| | > 1 car | –1.239 | –0.587 | –0.923 | –1.318 | –1.217 | –1.601 |
| Families | No car | 0.756 | 0.350 | 0.518 | 0.820 | 0.794 | 1.352 |
| | One car | 0.045 | 0.025 | 0.040 | 0.057 | 0.118 | 0.175 |
| | > 1 car | –0.922 | –0.495 | –0.717 | –0.952 | –0.893 | –1.465 |
| Single parent households | No car | 0.215 | 0.150 | 0.224 | 0.300 | 0.259 | 0.393 |
| | One car | –0.176 | –0.073 | –0.146 | –0.280 | –0.287 | –0.238 |
| | > 1 car | –1.608 | –0.614 | –0.897 | –1.355 | –1.511 | –1.843 |
| Total sample | No car | 0.440 | 0.247 | 0.342 | 0.510 | 0.481 | 0.818 |
| | One car | 0.000 | 0.001 | 0.000 | –0.001 | 0.050 | 0.087 |
| | > 1 car | –0.997 | –0.519 | –0.760 | –1.028 | –0.959 | –1.508 |

ownership calculated using equation (6) with a unit percent decrease in income. Note that the values for the elasticities calculated from the model are virtually the same as those in Table 5, except for the sign, i.e., the estimated elasticities are symmetrical.

Table 8 shows the car ownership patterns for samples of individuals that experience different configurations of increases and decreases in income between timepoints 1, 5, and 9. The time span between the first and fifth waves and that between the fifth and ninth waves are both equal to 2 years. The sub-samples are identified by abbreviations which depict the pattern of change in income they exhibit. They are as follows:

*Table 8.* Patterns of change in car ownership by patterns of change in income for all households in each sample category.

| Sample category | | Wave 1 | Wave 5 | Wave 9 |
|---|---|---|---|---|
| *In-De* (128) | Income | 25778 | 33511 | 28155 |
| | Car ownership | 0.82 | 0.79 | 0.86 |
| *De-In* (152) | Income | 39107 | 31463 | 37387 |
| | Car ownership | 0.99 | 0.98 | 1.05 |
| *In-In* (120) | Income | 28711 | 35001 | 41849 |
| | Car ownership | 0.85 | 0.98 | 1.09 |
| *De-De* (85) | Income | 33074 | 27340 | 24436 |
| | Car ownership | 0.84 | 0.78 | 0.76 |

- *In-De*: Increase in income followed by a decrease.
- *De-In*: Decrease in income followed by an increase.
- *In-In*: Increase in income in both time spans.
- *De-De*: Decrease in income in both time spans.

Samples *In-In* and *De-De*, which experience consistent increases and decreases in income respectively, showed correspondingly consistent increases and decreases in car ownership. For example, the percentage increase in income between waves 1 and 5 for the In-In sample is 22% . At the same time car ownership increased by 15%. Between waves 5 and 9, there was a 20% increase in income and 11% increase in car ownership. For the *De-De* sample, income first decreased by 17% and then by 11%. The corresponding percentage decreases in average car ownership were 7% and 2.5% respectively. In general, the ratio of percentage change in income to percentage change in car ownership for the *In-In* sample is smaller than the corresponding ratio for the *De-De* sample. This suggests that households are more elastic to increases in income than to decreases in income, i.e., their behavior is asymmetric.

Sample *In-De* shows a lagged response to an increase in income. Their income increased between waves 1 and 5, but their car ownership showed an increase only between waves 5 and 9. However, the sample *De-In* does not show any lagged response. They show asymmetry. The decrease in income between waves 1 and 5 does not see any change in car ownership. But, the 19% increase in income between waves 5 and 9 met with a 7% increase in car ownership. So, they were more responsive to the increase in income than the decrease.

Again, one can argue that the changes in car ownership relative to changes in income may be due to changes in household structure. Therefore, the households that did not change their category are separated out from the sample and their patterns of car ownership with increases and decreases in income at waves 1, 5, and 9 are examined.

Table 9 shows the car ownership by pattern of change in income for the stable households that did not change household type categories during the 6 year period. The sample of stable households with consistent increases in income (*In-In*) shows a consistent increase in car ownership. However, asymmetry is very clear once we examine the sample of households who experienced a consistent decrease in income (*De-De*). For example, the *In-In* sample had a 16% increase in income and a 14% increase in car ownership between waves 1 and 5. The *De-De* sample had the same percentage decrease in income, but only a 6% decrease in car ownership. It is interesting that even though their income decreased by 9% between waves 5 and 9, their car ownership increased. This was not seen in Table 8 where changes in household structure were not accounted for. This shows that household structure changes play an integral role in determining car ownership-income relationships.

*Table 9.* Patterns of change in car ownership by patterns of change in income for stable households.

| Sample category | | Wave 1 | Wave 5 | Wave 9 |
|---|---|---|---|---|
| *In-De* (94) | Income | 26161 | 32748 | 28510 |
| | Car ownership | 0.77 | 0.74 | 0.84 |
| *De-In* (116) | Income | 38414 | 30497 | 38086 |
| | Car ownership | 0.94 | 0.99 | 1.07 |
| *In-In* (96) | Income | 30377 | 35351 | 41615 |
| | Car ownership | 0.88 | 1.00 | 1.13 |
| *De-De* (69) | Income | 31282 | 26274 | 23900 |
| | Car ownership | 0.77 | 0.72 | 0.75 |

The *De-In* sample of stable households shows a consistent increase in car ownership, even though it experiences a decrease in income between waves 1 and 5. Again, this is an indication of resistance to reduce car ownership. The *In-De* sample of stable households shows a lagged response to an increase in income, similar to that seen in Table 8.

In summary, Tables 8 and 9 have shown that asymmetry and lagged responses are the norm rather than the exception. Asymmetry in car ownership-income relationships is more clearly discernable in this analysis. Lagged responses were clear only in the case of the first sample (*In-De*). Probably, more time points are needed to study lagged dependent nature of car ownership on income. Also, the inability to isolate the effects of natural aging may have masked some of the lagged responses to income changes.

It is important to note that our car ownership models did not capture these asymmetric behavioral patterns. In that respect they are similar to most models of car ownership. Based on the models, one would expect symmetrical increases and decreases in car ownership concomitant with increases and decreases in income. However, the observed tendencies do not show this symmetry at all.

## Conclusions

In this study the car ownership of a sample of 485 households was followed over 6 years at yearly intervals. A demand model for car ownership was estimated at each of 6 timepoints and the elasticities with respect to income for each household category were determined.

There was an overall increase in car ownership in the 6 year period, supporting the concept of motorization. The elasticities of car ownership with respect to income were found to change over time and the changes differed by the type of household structure. To control the effect of transitions between household structures, the elasticities of households that did not change structure in the study period were examined. These also showed changes over time. This indicates that the relationships between car ownership and income are not constant over time and that assuming a single equilibrium is not warranted. The changes in car ownership elasticities of households that did not change household structure may well be attributable to the motorization effect. It is very likely that the underlying relationship between car ownership and household characteristics changes as a society moves towards a greater reliance on automobiles.

At each time point, single person households had the most elastic relationship between car ownership and income while families had the least elastic relationship. Single-parent households were similar to the single person households, in this respect, although somewhat less elastic. Couples were similar to families, but a little more elastic. These are most likely the effects of the extent of household constraints within different household structures. This also points to the importance of including the non-traditional households in the demand forecasting process, since their car ownership characteristics are different from that of traditional households and their proportions in the general population are growing. An understanding and quantification of the transitions between household types would be most useful in this process.

The analysis also showed that there is asymmetry in behavior with respect to an increase and decrease in income which our typical cross-sectional models do not capture. A decrease in income was not accompanied by an equivalent decrease in car ownership, showing a greater resistance (smaller elasticity) to decreases than to increases. Thus, care should be exercised when such models are used to predict car ownership, especially in conditions such as those occurring during times of economic recessions.

The general overall conclusion that can be drawn from this inquiry is that the relationship between car ownership and income for a particular household category is not a constant, but is changing over time. Capturing the relationship at one time point and using it to predict for another time point is risky if the time-points are not close together. It is in this context that longitudinal approaches are appealing and should see wider application.

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## Note

1. Motorization refers to the degree to which a society has converted to a totally automobile transportation system. At early stages of motorization only the very affluent and adventuresome own automobiles. At the last stages of motorization, almost anyone who can legally drive and is not destitute has a car available (Kitamura & Kostyniuk 1986).

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