Anne Brendemoen

Car Ownership Decisions in Norwegian Households

Discussion Papers no. 116 • Statistics Norway, Mai 1994

Anne Brendemoen

Car ownership decisions in Norwegian Households

Abstract:
In this paper, household's decisions regarding how many private cars to own are analyzed. The analysis is based on a particular multinominal logit type formulation that is consistent with a Stone-Geary utility function. The model is estimated on data from the Norwegian Expenditure Survey.

Keywords: Car ownership, car costs, multinominal logit model.

JEL classification: D12, R41

Acknowledgement: I would like to thank John K. Dagsvik for supervision, Leif Andreassen and Margaret Simpson for valuable comments and discussions and Tom Wennemo for research assistance.

Correspondence: Anne Brendemoen, Statistics Norway, Research Department,
P.O.Box 8131 Dep., 0033 Oslo. **E-mail:** acb@ssb.no

1 Introduction

As in all other industrialized countries, the stock of private cars has been increasing rapidly in Norway during recent decades. In 1960, when automobiles became generally available to consumers, there were only 225,000 private cars registered in Norway, corresponding to 16 persons per car. In 1987, there were somewhat more than 1.6 million cars, or 2.5 persons per car. The increase was largely due to growth in income and the demand for the flexibility provided by car ownership, increased leisure time and increased labour participation among women. The stock of cars has remained approximately constant since 1987, mainly because of a general economic slowdown. However, the per capita stock of cars in Norway is fairly small compared to other western industrialized countries. For instance, the number of persons per car in the U.S. was 1.8 in 1987; this difference suggests a considerable potential for growth in the Norwegian stock of cars.

A number of studies analyze private car ownership. Examples from the U.S. include Johnson (1978), who applies a multinominal logit model to analyze the demand for new and used cars. Train (1980) applies a nested logit model to estimate car ownership and work-trip mode choices in San Francisco. Berkovec and Rust (1985) use a nested logit model to analyze choices between individual makes, models and vintages of passenger vehicles. Mannering and Winston (1985) develop a dynamic model of automobile demand that accounts for choice of car quality, type and utilization. Their model enables them to quantify the importance of brand preference and brand loyalty in U.S. households. In Norway, the Institute for Transport Economics (TØI) has analyzed car use and ownership, for use in transportation planning and analyses of environmental policy. TØI (1990), presents a model to predict fuel use and emissions from private travel that is based on a joint model of car ownership and car use developed by de Jong (1990). The model is used to simulate household's responses to changes in fixed and variable car costs. Wetterwald (1994) has applied de Jong's econometric framework of ownership and car use to a different data set than the one used by TØI.

The present study springs from our interest in the consequences of car ownership decisions for the environment. In particular, we are interested in how costs affect ownership decisions. While private cars undoubtedly provide large benefits to the individual, they also cause considerable negative external effects. Traffic congestion, accidents, noise, damage to roads and pollution impose substantial costs on society. Apart from the production of cars, which is quite energy-intensive and, as a result, quite polluting, both the benefits to the individual and the costs to society are due to the use, rather than the stock, of cars. Certainly, the two are closely related. The growth in car use, measured in passenger kilometers, was on average 7.1 percent annually in Norway from 1960-1991; the annual growth in the number of cars was 6.8 percent. This correspondence suggests that car ownership decisions are relevant to environmental outcomes.

The point of departure of the present study is the neoclassical theory of consumer behaviour. We assume that households have utility functions that are consistent with a Stone-Geary specification. The household's stock of private cars and car use enter as arguments, as do all other commodities. Although this framework permits the analysis of both the discrete choice of how many cars to own and the continuous choice of how much to drive, we restrict our study to the former, deriving a multinominal logit-type formulation of the ownership decision. Our empirical findings enable us to study how demographic variables, car costs and income affect household's decisions regarding how many private cars to own, and how policy measures like the annual tax on motor vehicles affects the stock of private cars in general as well as within different groups of households.

Our model is static, in that we only consider the household's stock and not the flow of private cars. Possible lags in the adjustment of stocks, prices and income expectations, which may be important in car ownership decisions, are ignored. No distinction is made between new demand and replacement demand.

Our model specification differs from the one developed by de Jong and applied by Wetterwald, but our data set is the same as that used by Wetterwald. Consequently, we are able to examine to some extent whether the results obtained by Wetterwald and de Jong depend on their empirical specification. Furthermore, our model allows for the option of owning two and three cars, whereas the de Jong and Wetterwald studies only consider the binary choice of owning a single car or not owning a car.

The paper is organised as follows: the car ownership model is outlined in chapter 2; chapter 3 gives details of the econometric specification; data and results are presented in chapter 4.

2 The car ownership model

We rely on the neoclassical theory of consumer behaviour, in which households maximize utility subject to a given budget constraint; this approach allows for a consistent analysis of household's allocation of expenditure between private cars and other consumption goods. We assume private cars to be one homogeneous good, so as to effectively ignore the great variety that exists in makes and vintages of cars, displayed by variables such as price, size, and quality.

More precisely, we assume utility to be a function of two types of goods; private cars and an aggregate of car use and all other commodities. Both goods yield positive marginal utility. The household utility function is assumed to have the structure

$$U(X,j) = B_j^* + \beta \Sigma_i \delta_{ij} \ln(x_i - \gamma_i), \tag{1}$$

where j is the number of private cars, (j=0,1,2,3); $X = (x_1,x_2,....,x_m)$, is a vector of quantities of all other commodities; $B_j^* > 0$ is utility of owning j cars; β, δ_{ij}, γ_i are parameters and $\Sigma_i\delta_{ij}=1$. One of the components of X is annual car use. This specification of household utility implies that households derive utility from having a private car available even if they use it very little. This is represented by $\{B_j^*\}$. Even if the car is driven very little, we assume that car ownership yields some utility and that households will pay just to keep a car available. The assumption that the utility function depends on ownership is made in the models applied in the U.S. studies mentioned above but not in de Jong's model in which utility is obtained from car use only, measured by the annual distance driven.

The budget constraint is

$$\Sigma_i\, p_i x_i = Y - jc, \tag{2}$$

where x_i is the quantity and p_i the price of commodity i and Y is net income. c is the annual fixed costs per car, and includes annual taxes, insurance, depreciation and interest payments. Since private cars are assumed to be a single homogenous good, the fixed annual costs of car ownership are equal for the first, second and third car. The right-hand side of (2) is thus the income that remains to be spent on car use and commodities other than cars.

The household's utility maximization problem can be decomposed as if it takes place in two stages. In stage one, the households maximize utility with respect to $x_1,..x_i$, given the number of cars. Maximizing (1) subject to (2), while keeping j fixed, gives the (conditional on j) linear expenditure system

$$p_m x_m(j) = p_m \gamma_m + \delta_{mj}(Y - jc - \Sigma p_i \gamma_i) \ , \quad \textbf{(3)}$$

where $x_m(j)$ is the demand for good m conditional on the choice of j cars. When positive, the γ-parameters are commonly interpreted as minimum-required quantities. In general, $\Sigma_k \gamma_k p_k$ is the part of income dedicated to fixed expenditure with which no substitution is possible. Large values of $\Sigma_k \gamma_k p_k$ suggest that a small part of the income can be freely allocated between goods, while small or negative values suggest large possibilities for substitution. The δ_{mj}-parameters sum to unity and thus may be interpreted as constant budget shares, after minimum expenditure, $\Sigma_k \gamma_k p_k$, and the expenditure on private cars have been deducted. Note that these budget shares are dependent on the number of cars in the household.

Substituting (3) into (1) gives the conditional indirect utility function given j cars

$$G(Y - jc, p, j) = B_j + \beta \ln(Y - jc - \Sigma p_i \gamma_i), \quad \textbf{(4)}$$

where

$$B_j = B_j^* + \beta \Sigma_i \delta_{ij} \ln \delta_{ij} - \beta \Sigma_i \delta_{ij} \ln p_i \quad \textbf{(5)}$$

The term $\beta \Sigma_i \delta_{ij} \ln \delta_{ij}$ is a constant. The last term of (5) is a weighted mean of the logarithm of prices of all goods other than cars, and may be interpreted as a price index representing the marginal cost of living (cf. Deaton and Muellbauer,1987). In our case this marginal cost of living is dependent on the number of cars owned by the household, reflected by the δ_j-parameters.

In stage two the household chooses the number of cars that maximizes G(Y-jc,p,j), yielding the greatest overall utility.

3 Econometric specification

In the following we will introduce some further assumptions for the purpose of estimation. To this point the analysis has referred to an unspecified household; we will now introduce the subscript n to denote household number n.

The model is estimated on a cross-sectional data set in which all prices are constant. Accordingly, we cannot identify the budget shares δ_j in the last term of (5). We assume that the net utility from car ownership, B_{jn}, has the structure

$$B_{jn}=\alpha_{j0}+\alpha_j Z_n+\epsilon_{jn} \tag{6}$$

where Z_n is a vector of household characteristics consisting of the number of adults, children and employed persons in the household, the age of the head of the household, whether the household has access to a business car or not, and whether they live in a large city or not. The terms $\{\varepsilon_{jn}\}$ are unobservable, stochastic variables representing all factors and aspects of utility known to household n, but unknown to the observer. These unobservables are assumed to be identically and independently extreme-value distributed:

$$P(\epsilon_{jn}\leq y)=\exp(-e^{-y}). \tag{7}$$

We further assume that γ_{ni} has the structure

$$\gamma_{ni}=\gamma_{0i}^{*}+\gamma_i^{*}Q_n\ , \tag{8}$$

where Q_n is a vector consisting of the number of children and the number of adults in the household, and γ_0^* and γ^* are parameters. The minimum expenditure may then be expressed as

$$\sum p_i\gamma_{ni}=\sum p_i\gamma_{0i}^{*}+Q_n\sum p_i\gamma_i^{*}=\gamma_0+Q_n\gamma\ , \tag{9}$$

where γ_0 and γ are parameters that can be estimated. Note that the components of Q are also components of Z. The γ-parameters measure the effect of size and the composition of the household on the minimum expenditure.

The conditional indirect utility function can now be expressed as

$$G_n(Y_n - jc, p, j_n) = V_{jn} + \epsilon_{jn} \ , \tag{10}$$

where

$$V_{jn} = \alpha_{j0} + \alpha_j Z_n + \beta \ln(Y_n - j_n c - \gamma_0 - \gamma Q_n). \tag{11}$$

Choosing the number of cars that yields the greatest overall utility implies that household n chooses to own j cars if

$$V_{jn} + \epsilon_{jn} = \max_k (V_{kn} + \epsilon_{kn}) \ . \tag{12}$$

Let P_{jn} denote the probability of choosing j cars. The assumptions above imply that

$$P_{jn} = P(V_{jn} + \epsilon_{jn} = \max_k (V_{kn} + \epsilon_{kn})) = \frac{e^{V_{jn}}}{\sum_k e^{V_{kn}}} \ . \tag{13}$$

The distributional assumptions about the unobservables imply that the independence from irrelevant alternatives property holds. This property implies that the ratio of the probabilities of choosing any two alternatives is independent of the availability or attributes of other alternatives.

The change in the probability of choosing alternative j, given a change in any of the regressors, r, is given by

$$\frac{\partial P_{jn}}{\partial r_n} = P_{jn}\left(\frac{\partial V_{jn}}{\partial r_n} - \sum_k \frac{\partial V_{kn}}{\partial r_n} P_{kn}\right). \tag{14}$$

The elasticity of P_{jn} with respect to income is therefore equal to

$$EL_Y P_{jn} = \beta Y_n \left[\frac{1}{(Y_n - jc - \gamma_0 - \gamma Q_n)} - \Sigma_k \frac{P_{kn}}{(Y_n - kc - \gamma_0 - \gamma Q_n)} \right], \tag{15}$$

and the elasticity of P_{jn} with respect to fixed car ownership costs equals

$$EL_c P_{jn} = -\beta c \left[\frac{j}{(Y_n - jc - \gamma_0 - \gamma Q_n)} - \Sigma_k \frac{kP_{kn}}{(Y_n - kc - \gamma_0 - \gamma Q_n)} \right]. \tag{16}$$

We define the aggregate elasticity of $P_{j.} = \Sigma_n P_{jn}$ with respect to variable r as

$$\frac{\Sigma_n \frac{\partial P_{jn}}{\partial r_n} r_n}{\Sigma_n P_{jn}} = \frac{\Sigma_n P_{jn} \left(\frac{\partial V_{jn}}{\partial r_n} - \Sigma_k \frac{\partial V_{kn}}{\partial r_n} P_{kn} \right) r_n}{\Sigma_n P_{jn}}. \tag{17}$$

The aggregate elasticity of $P_{j.}$ with respect to income is equal to

$$EL_Y P_{j.} = \frac{\beta \Sigma_n P_{jn} Y_n \left[\frac{1}{(Y_n - jc - \gamma_0 - \gamma Q_n)} - \Sigma_k \frac{P_{kn}}{(Y_n - kc - \gamma_0 - \gamma Q_n)} \right]}{\Sigma_n P_{jn}}, \tag{18}$$

and the aggregate elasticity of $P_{j.}$ with respect to fixed car ownership costs is equal to

$$EL_c P_{j.} = \frac{-\beta \Sigma_n P_{jn} c \left[\frac{j}{(Y_n - jc - \gamma_0 - \gamma Q_n)} - \Sigma_k \frac{kP_{kn}}{(Y_n - kc - \gamma_0 - \gamma Q_n)} \right]}{\Sigma_n P_{jn}}. \tag{19}$$

The elasticities defined in (15) and (16) measure the percentage change in household n's probability of choosing j cars, brought about by a one percent change in household n's income, or in the average fixed costs associated with car ownership. The elasticities given by (18) and (19) measure the percentage change in the total number of households having j cars from one percent change in each household's income.

Finally, let A denote the total number of private cars owned by the households. The elasticity of the expected total number of cars with respect to variable r is equal to

$$El_r E(A) = \frac{\sum_{j=1}^{3} j \Sigma_n \frac{\partial P_{jn}}{\partial r_n} r_n}{\sum_{j=1}^{3} j \Sigma_n P_{jn}}. \qquad \textbf{(20)}$$

4 Data and empirical results

The data used are from the Norwegian Expenditure Survey 1985 (Statistics Norway, 1987), which was a typical year regarding the stock (if not the flow) of Norwegian private cars. The data set includes 1555 representative Norwegian households. The number of cars owned and several household characteristics are included. In our study, the households with net incomes less than 30000 NOK (8 households only) were excluded from the sample. The remaining data set consists of 1547 households, of which 361 (23 percent) did not own a car, 926 (60 percent) owned one car, 227 (15 percent) owned two cars, and 33 (2 percent) owned three cars. We also estimate all models on the restricted sample that remains after the three car households are dropped from the sample; one of the models is also estimated on the restricted sample of households that either own a single car or do not own a car.

The explanatory variables entering the utility function are:
- Net household income measured in Norwegian kroner;
- Average annual fixed costs of private cars, equal to 9204 NOK. This equals fixed costs in one car owning households, as used in TØI (1990) and Wetterwald (1994). Fixed costs is calculated using Budget Survey data, with some exogenous data, and includes for instance insurance, annual taxes on cars, depreciation and interest payments;
- The number of adult persons in the household;
- The number of children less than eighteen years of age in the household;
- The age of the head of the household;
- The number of employed persons in the household;
- A dummy taking the value one if the household has access to a business car;
- A dummy taking the value one if the household lives in Oslo, Bergen or Trondheim; the

three largest cities in Norway. This variable may be interpreted as a proxy for the availability of public transportation, which is far better in large cities than in rural and sparsely populated areas.

Table 1 displays summary statistics for the variables used.

Table 1. Descriptive Statistics.

					Subsample of households with less than three cars			
	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max
No. of cars	0.956	0.681	0	3	0.911	0.617	0	2
Net income (1000 NOK)	141	68	30	588	139	66	30	588
No. of adults	2.050	0.764	1	7	2.025	0.742	1	7
No. of children	0.769	1.048	0	8	0.768	1.051	0	8
No. of employed	1.267	0.933	0	5	1.234	0.904	0	5
Age of head	47.840	17.003	18	89	47.886	17.108	18	89
Dummy for business car	0.038	0.192	0	1	0.030	0.194	0	1
Dummy for big city	0.167	0.373	0	1	0.170	0.376	0	1

Empirical results

The model given by (11) and (13), (model A), was estimated by the maximum likelihood method. In addition, alternative specifications of the utility function were also estimated. In model B, the fixed element $\Sigma_k\gamma_k p_k$ is assumed to be independent of the size and composition of the household, γ=0, $\gamma_0 \neq 0$. In model C, all γ-parameters are assumed to be zero. The last model, D, is equivalent with C with the exception that the effect of the remaining income on utility is allowed to vary between the alternatives. The β-parameter is accordingly alternative-specific. The models A, B and C are nested, as are C and D. The nested models are tested by likelihood ratio tests to check which one is best.

As a measure of goodness of fit we will use the "pseudo-R^2" (cf. Maddala, 1983, pp 37-41), given by

$$pseudo\text{-}R^2 = \frac{1-\left(\frac{L_0}{L}\right)^{\frac{2}{N}}}{1-L_0^{\frac{2}{N}}}, \qquad (21)$$

where L_0 is the value of the likelihood function when all parameters except the constant term are set equal to zero, L is the value obtained when the estimated parameters are inserted and N is the number of households in the sample.

The "remaining income" variable (Y-jc) is the only explanatory variable that is alternative-specific. The other variables are household-specific only, and normalization is thus required. Without any loss of generality we set all alternative-specific parameters for the "no-car" alternative to zero: $\alpha_{00}=\alpha_0=0$.

Estimated coefficients, t-statistics, the value of the log-likelihood functions and "pseudo-R^2" are shown in Tables 2-5. If the unobserved heterogeneity in the population is not too large, we should obtain approximately the same estimates when we apply the conditional likelihood function given that the households have no more than two cars, and given that the households have no more than one car. The right hand side of Tables 2-4, and the middle column of Table 5 display the results from the corresponding conditional maximum likelihood procedure, given that households have no more than two cars. The right column of Table 5 displays the results when the sample is restricted to households owning one car or not owning a car. We see that the parameters estimated from these sub-samples are close to the ones obtained by the full maximum likelihood procedure. This suggests that the independence from irrelevant alternatives assumption holds for our sample.

The likelihood-ratio test statistics of model A versus model B, and A versus C imply that model A is significantly better than both B and C. Model B is no better than C. Furthermore, the hypothesis that the β-parameters are equal cannot be rejected, as model D is no better than model C. Also, according to the pseudo-R^2, all these models explain car ownership decisions about equally well.

Table 2. Coefficients, t-values, log-likelihood values and pseudo-R^2, model A.

Model A: $V_j = \alpha_{j0} + \alpha_j Z + \beta \ln(Y\text{-}jc\text{-}\gamma_0\text{-}\gamma Q)$

	Full Sample 1 car	Full Sample 2 cars	Full Sample 3 cars	Restricted sample*) 1 car	Restricted sample*) 2 cars
α_0	7.5316	8.900	7.9892	7.4712	8.2749
t	(6.9138)	(2.2844)	(2.8195)	(6.5206)	(4.0034)
α adults	-0.9173	-0.8177	-0.7606	-0.9005	-0.7921
t	(-4.1312)	(-2.4990)	(-1.6604)	(-3.9683)	(-2.3685)
α children	0.2212	0.0674	-0.0973	0.2067	0.0446
t	(1.4269)	(0.3079)	(-0.2934)	(1.2850)	(0.1945)
α age	-0.0329	-0.0411	-0.0702	-0.0326	-0.0408
t	(-6.0730)	(-5.3171)	(-3.5322)	(-6.0037)	(-5.2397)
α city	-0.5936	-1.1255	-1.9075	-0.5921	-1.1572
t	(-3.0820)	(-3.8728)	(-2.3943)	(-3.0742)	(-3.9664)
α business	-1.6425	-2.8789	-31.9913	-1.6424	-2.8867
t	(-4.9481)	(-4.7941)	-	(-4.9513)	(-4.8011)
α employed persons	0.2770	0.6943	1.4105	0.2797	0.6585
t	(2.2903)	(4.0780)	(5.0452)	(2.2978)	(4.1201)
β	73.5797			72.7493	
t	(2.5200)			(2.3877)	
γ_0	5884.			5744.	
t	(0.2565)			(0.2359)	
γ adults	-69980.			-69052.	
t	(-3.9897)			(-3.8563)	
γ children	7939.			6837.	
t	(0.9701)			(0.7608)	
$\partial V/\partial r$					
r=adults	18.6189	19.4254	20.2425	18.3843	19.1991
r=children	0.0364	-0.0247	-0.0007	-1.7027	-1.9348
Log L_0	-1563			-1404	
Log L	-1171			-1064	
Pseudo R^2	0.46			0.43	

*) Sample of households that own no more than two cars.

To conclude, model A is preferred. However, as we will see below, model A has some rather peculiar features, as do B and D. Accordingly, we will only give a brief discussion of these models before we turn to model C, as model C is more intuitive than A and is preferred to B and D according to the likelihood-ratio tests.

Consider first model A, and the estimated parameters reported in Table 2. Note that in models B, C and D, the effects of changes in the number of children or adults on utility are

Table 3. Coefficients, t-values, log-likelihood values and pseudo R^2, model B.

Model B: $V_j = \alpha_{j0} + \alpha_j Z + \beta \ln(Y\text{-}jc\text{-}\gamma_0)$

	Full Sample			Restricted sample*)	
	1 car	2 cars	3 cars	1 car	2 cars
α_0	4.0249	3.0776	1.3719	4.0606	3.1411
t	(7.0193)	(3.0831)	(0.8687)	(6.7940)	(3.0033)
α adults	0.1094	0.5902	0.8442	0.1016	0.5664
t	(0.8047)	(3.2794)	(2.7682)	(0.7435)	(3.1216)
α children	0.2105	0.0056	-0.2148	0.2095	0.0043
t	(1.9615)	(0.0427)	(-0.8549)	(1.9420)	(0.0326)
α age	-0.0293	-0.0382	-0.0682	-0.0292	-0.0380
t	(-5.6666)	(-4.9627)	(-3.3832)	(-5.6286)	(-4.9054)
α city	-0.5696	-1.1110	-1.9345	-0.5737	-1.1517
t	(-3.0079)	(-3.8424)	(-2.4176)	(-3.0248)	(-3.9608)
α business car	-1.5741	-2.8109	-23.4131	-1.5735	-2.8177
t	(-4.7896)	(-4.6389)	-	(-4.7841)	(-4.6452)
α employed persons	0.2455	0.6053	1.3924	0.2428	0.6150
t	(2.0039)	(3.7285)	(4.9247)	(1.9682)	(3.7451)
β	23.3866			23.5702	
t	(3.5016)			(3.3843)	
γ_0	-17123			-16800	
t	(-1.3059)			(-1.2749)	
Log L	-1191			-1082	
Pseudo R^2	0.44			0.41	

*) Sample of households that own no more than two cars.

given by the corresponding α-parameters. In model A, by contrast, the number of children and adults enters the utility function both in the minimum-expenditure term and in the term representing the net utility from car ownership. The combined effect on utility from a change in these variables is reported in the lower part of Table 2.

Although a formal test has not been conducted, the values of the α-parameters do not seem significantly different across alternatives.

The results of estimating model A suggests that the net utility of car ownership decreases with the number of adults; this may be because the parameter measures the effect of the marginal cost of living as well as the utility of car ownership. A more puzzling result is that

Table 4. Coefficients, t-values. log-likelihood values and pseudo R^2, model D.

Model D: $V_j = \alpha_{j0} + \alpha_j Z + \beta_j \ln(Y\text{-}jc)$

	Full Sample				Restricted Sample*)		
	No car	1 car	2 cars	3 cars	No car	1 car	2 cars
α_0		-5.2251	-9.1443	-16.6729		-4.1122	-7.5197
t		0.7551	0.8592	1.1393		-0.5867	-0.6991
α adults		0.0652	0.5968	0.8350		0.0654	0.5822
t		0.4551	3.2882	2.6854		0.4567	3.2031
α children		0.1989	0.0222	-0.2011		0.2011	0.0235
t		1.8240	0.1705	-0.7990		1.8377	0.1795
α age		-0.0298	-0.0372	-0.0667		-0.0295	-0.0368
t		-5.6925	-4.8304	-3.2643		-5.6345	-4.7661
α city		-0.5855	-1.0998	-1.9286		-0.5872	-1.1375
t		-3.0678	-3.8055	-2.4029		-3.0757	-3.9177
α business cars		-1.5788	-2.7918	-31.6657		-1.5758	-2.7933
t		-4.7697	-4.5949	-		-4.7643	-4.5975
α employed persons		0.2058	0.6223	1.3960		0.2117	0.6398
t		1.5755	3.7696	4.8413		1.6169	3.8685
β	9.7486	10.4855	10.6534	11.0948	10.6096	11.2556	11.3859
t	1.9681	2.3672	2.5613	2.7553	2.1040	2.4949	2.6853
Log L	-1190.91				-1082.51		
Pseudo R^2	0.44				0.41		

*) Sample of households that own no more than two cars.

the number of adults in the household reduces the size of the minimum expenditure γQ. The total effect on utility is positive. The estimate of the constant term γ_0 is not significant. The number of children in the household does not significantly affect either the net utility of car ownership or the fixed element γQ.

In model B, shown in Table 3, the constant term α is significant only for the one and two car choices. In contrast to the results of model A, net utility of car ownership increases with the number of adults in the household, but the parameter related to the one-car choice is not significantly different from zero. As in model A, the number of children increases the net utility of one or two cars, and reduces the net utility of owning three cars. The parameter intended to measure the minimum expenditure is negative, making a meaningful interpretation of this term no longer possible. The estimate is, however, not significantly different from zero.

In model D, shown in Table 4, the alternative-specific β-parameters are, as was pointed out earlier, not significantly different. Allowing for alternative-specific β-parameters does alter the sign of the constant terms α_{0j}, j=1,2,3.

Model A's counterintuitive finding that the minimum expenditure declines when there are more adults in the household makes model C preferred to A. Model C is preferred to both B and D based on the likelihood ratio test statistic. Thus we choose model C as our final model. Table 5 displays the estimated parameters of model C. Table 6 shows the marginal effects for model C, calculated at the mean of the regressors, and Table 7 shows the model's estimated probabilities and elasticities.

In model C, the number of adults in the household significantly increases the net utility of having two and three cars but has no significant impact on the net utility of having one car. An increase in the number of adults will increase the probability of owning two or more cars and decrease the probability of owning one car or being without a car, with the probability of choosing one car decreasing the most and the probability of choosing two cars increasing the most.

The net utility of one car increases with the number of children in the household. The effect of the number of children on the net utility of two and three cars is not significantly different from zero.[1]

The older is the head of the household, the less net utility is obtained from car ownership. The probability of preferring not to own a private car increases with the age of the head of the household. Accordingly, the probability of owning one or more cars decreases. The result is as expected and is in accordance with the low frequency of drivers licenses among older people, and women in particular. The result may not be appropriate for forecasting purposes; the frequency of drivers licenses will be larger in the future, and one may expect a different attitude towards cars among future "older" generations. Living in one of Norway's three largest cities reduces the net utility of car ownership. The probability of choosing two or more cars would decrease if an average household moved from a rural area to a large city. The probability of choosing a single car or not to own a car would accordingly increase.

---

[1] In earlier versions of the models, the number-of-children variable was split into children younger and older than twelve years of age, without yielding any significant changes to the results.

Table 5. Coefficients, t-values, log-likelihood values and pseudo R^2, model C.

Model C: $V_j = \alpha_{j0} + \alpha_j Z + \beta \ln(Y\text{-}jc)$

	Full sample	Restricted sample*)		Restricted sample**)		
	1 car	2 cars	3 cars	1 car	2 cars	1 car
α_0	3.5837	2.1161	-0.0469	3.5883	2.1326	3.6589
t	(7.4005)	(2.8815)	(-0.0385)	(7.3039)	(2.8598)	(6.8150)
α adults	0.1167	0.6236	0.8955	0.1143	0.6077	0.1011
t	(0.8586)	(3.4968)	(2.9638)	(0.8384)	(3.3941)	(0.7195)
α children	0.2218	0.0310	-0.1835	0.2218	0.0309	0.2085
t	(2.0692)	(0.2407)	(-0.7348)	(2.0612)	(0.2392)	(1.8926)
α age	-0.0288	-0.0366	-0.0651	-0.0287	-0.0363	-0.0279
t	(-5.5628)	(-4.8138)	(-3.2758)	(-5.5252)	(-4.7618)	(-5.2545)
α city	-0.5732	-1.0966	-1.8981	-0.5747	-1.1329	-0.5650
t	(-3.0300)	(-3.8072)	(-2.3783)	(-3.0350)	(-3.9163)	(-2.9413)
α business cars	-1.5583	-2.7637	-23.3958	-1.5587	-2.7711	-1.5663
t	(-4.7641)	(-4.5904)	-	(-4.7639)	(-4.5987)	(-4.7425)
α employed persons	0.2662	0.6564	1.4593	0.2674	0.6709	0.2315
t	(2.1831)	(4.1306)	(5.2326)	(2.1836)	(4.1980)	(1.8379)
β	15.3532			15.4221		16.2290
t	(9.1658)			(8.9485)		(7.8387)
Log L	-1192			-1083		-553
Pseudo R^2	0.44			0.41		0.39

*) Sample of households that own no more than two cars.
**) Sample of households that either own a single car or do not own a car.

Table 6. Marginal effects in model C, calculated at the sample mean.

	Full sample				Restricted sample*)			Restricted sample**)
	No car	1 car	2 cars	3 cars	No car	1 car	2 cars	1 car
$\partial P_j/\partial z$								
adults	-0.0217	-0.0407	0.0610	0.0014	-0.0214	-0.0361	0.0575	0.0147
children	-0.0211	0.0402	-0.0184	-0.0007	-0.0220	0.0397	-0.0177	0.0303
age	0.0033	-0.0019	-0.0014	-0.0001	0.0034	-0.0021	-0.0013	-0.0041
city	0.0725	0.0006	-0.0705	-0.0026	0.0748	-0.0023	-0.0726	-0.0822
business cars	0.1980	0.0064	-0.1616	-0.0428	0.1979	-0.0350	-0.1628	-0.2279
employed persons	-0.0363	-0.0157	0.0498	0.0023	-0.0373	-0.0127	0.0499	0.0337

*) Sample of households owning no more than two cars
**) Sample of households owning one single car or not owning a car. In this case, the marginal effects on the choice of not owning a car equals the negative of the effect of the one car choice.

Again the result is as expected. Public transportation is far more available in the large cities than in rural areas and distances are smaller.

As expected, access to business cars reduces the net utility of private cars. Increased access to business cars will increase the probability of preferring not to own a car and to own one car. The probability of choosing not to own a car increases the most. The probability of choosing two or more cars more decreases[2].

The number of employed persons in the household increases the net utility of car ownership. When the number of employed persons increases, the probability of choosing not to own a car or to own one car decreases, and the probability of choosing two or more cars increases. The probability of choosing two cars increases the most[3].

In general, the probability of choosing one car is less sensitive to changes in the number of employed persons in the household, access to business cars or whether the household lives in the cities or not, than are the other choices.

Table 7 displays estimated probabilities and elasticities of the choice probabilities with respect to income as given by (15), calculated at the sample mean, and estimated probabilities and aggregate elasticities as given by (18) for the whole population and for different groups of households. The households are grouped according to level of income. Income group one containe households with incomes less than the 25 percent income quantile, group two containe households with incomes between the 25 percent quantile and the median, group three containe households with incomes between the median and the 75 percent quantile, and group four containe households with incomes above the 75 percent income quantile. Note that in this particular model, elasticity of costs equals the negative of the elasticity of income. Only the latter is reported.

[2]None of the households in the sample that owned three cars had access to a business car. The standard error of the corresponding parameter is, accordingly, infinitely large, and it is not obvious whether the parameter should be included or not.

[3]Because of the fairly high correlation between the number of adults and the number of employed persons in a household, the models were estimated without the latter variable. This caused only minor changes in the results.

The estimated choice probabilities for the whole sample equal the observed frequencies in the sample. This is a property that follows from the model and the ML-method (cf. Maddala, 1983). As the model is estimated on the full sample, the estimated choice probabilities within each income group differ slightly from the actual frequencies within the same group. The difference between the observed frequencies and estimated probabilities is quite marginal, and Table 7 displays the latter only.

As the table shows, the aggregate mean income elasticities are in line with those calculated at the sample mean. The elasticities calculated at the sample mean, for the population as a whole and for households with income above the median, shows that the probability of choosing two cars or more will increase when income increases or costs are reduced. The income elasticities of second and third cars are all increasing with income. What may be more puzzling is that an income increase would, according to this model, cause the probability of choosing one car to be reduced in the households with income above the median. However, one likely outcome of an income increase is that households without a car become one car households, one car households become two car households and two car households add a third car. If the last two effects are greater than the first, the mean probability of choosing one car will decrease; as is the case in the richest two groups of households in our study. The effect is particularly strong among the households with the highest income. As the upper part of Table 7 shows, the effect of an income increase on the (total) mean probability of choosing one car is positive. Furthermore, the one-car-elasticities are quite small. In the aggregate, the mean probability of choosing one car will increase by 1.2 percent if income increases by 10 percent. The mean probability within the two richest groups of households would fall by less than two percent. According to these estimates, ownership of one car in households with incomes above the 25 percent income quantile, is fairly inelastic with respect to income and costs, suggesting that these households consider the first car as a necessity. The second and third car may be classified as luxury goods, in particular among households with low incomes. This effect is less striking for high income households, and for the populationas a whole.

Table 8 shows the elasticity for different groups of households, of the expected number of cars with respect to incomes and fixed annual car costs as given by equation (20). The elasticity of the expected total number of cars is 0.41. Assuming that this elasticity is also valid for a larger interval of costs, the effect of the currently debated abolition of annual

Table 7. Income elasticities and probabilities calculated at the sample mean, for the population as a whole and for different income groups. Model C. Full sample.

	No car	1 car	2 cars	3 cars
Sample mean elasticities				
P_{jn}	0.13	0.73	0.13	0.01
$El_Y P_{jn}$	-1.11	-0.04	1.19	2.26
Aggregate elasticities				
Total				
P_j	0.23	0.60	0.15	0.02
$El_Y P_j$	-0.94	0.12	0.82	1.17
Income group 1				
P_j	0.55	0.42	0.02	0.01
$El_Y P_j$	-0.89	1.04	3.34	6.28
Income group 2				
P_j	0.21	0.68	0.10	0.01
$El_Y P_j$	-1.12	0.09	1.51	3.04
Income group 3				
P_j	0.10	0.69	0.19	0.02
$El_Y P_j$	-0.98	-0.14	0.88	1.98
Income group 4				
P_j	0.07	0.59	0.28	0.06
$El_Y P_j$	-0.78	-0.19	0.39	0.80

taxes on cars may be calculated. At present, the annual tax on motor vehicles amounts to approximately 10 percent of fixed annual car costs. According to our model, abolishing this tax would increase the number of cars in Norway by around 4 percent. Most of this growth would occur among the low income households. The poorest 25 percent of the households would increase their stock of private cars by 12 percent, while the richest 25 percent would increase their stock of cars by 2 percent only.

According to our model, the number of cars owned by households without children would increase by 5.6 percent if the annual tax on private cars is abolished, while the corresponding figure among the households with children less than 18 years of age is 2.6 percent. Further, there is no difference between households living outside or in the largest cities. The distributional impacts of abolishing the tax, between rural and urban areas and between families with and without children, may thus be quite different than what is expected by

Table 8. Income elasticities of the expected number of cars with respect to income.

Total	0.41
Income group 1	1.21
Income group 2	0.46
Income group 3	0.29
Income group 4	0.20
Households without children	0.56
Households with children less than 18 years of age	0.26
Households living in Oslo. Bergen. Trondheim	0.41
Households living outside the cities	0.41
One person households	0.94
Two adults	0.38
More than two adults	0.27

advocates of the policy. Furthermore, the growth in the stock of cars will be largest in the one person households and lowest in the households with more than two adults.

The structure of model C is only consistent with the special case with $\gamma_i = 0$ for all i (Cobb-Douglas). However, since we do not estimate the full structure of indirect utility as a function of prices, model C is in fact also consistent with the PIGLOG class of demand functions. It is of interest that model C also has the same structure as the one obtained by Van Praag (1991), who conducted a series of individual laboratory type experiments to determine the utility of income.

As was mentioned in the introduction, Wetterwald (1994) uses the same data set to analyse car ownership and use. Wetterwald essentially applies a model developed by de Jong (1990), in which the household's ownership decision is restricted to own a single car or not to own a car. This restriction is evidently unrealistic. The result turns out not to be robust with respect to this simplification. While Wetterwald obtains an elasticity of the probability of ownership with respect to income of about 0.37, the corresponding figure in table 7 is 0.12. To check that this difference in results does not depend crucially on the difference in econometric specification, we have also computed the elasticity for the case when the choice is restricted to own a single car or not to own a car. The income elasticity that follows from this restricted model is about 0.35, which is very close to Wetterwald's result. This seems to indicate that the difference in econometric specification does not matter much for the discrepancy in results between our model and the model proposed by de Jong.

Predicted frequencies

Above we computed the pseudo-R^2 as a measure of goodness of fit. Another measure is obtained by using the model to simulate behaviour and record the fraction of correct predictions. We have carried out the following simulation experiment:

We first make predictions by simulating behaviour while ignoring the random disturbances in the utility function. Second, we simulate behaviour taking account of the disturbances in the utility function for each household. Consistent with the theory above, these disturbances are all i.i.d. draws from the extreme value distribution without error terms.

Table 9 shows actual and predicted outcomes, and predicted outcomes in percent of actual outcomes when the residuals are zero. 67 percent of all predictions are correct. The model does quite well in predicting the choice of owning one car, as 90 percent of actual outcomes are predicted. The remainder of households that own one car are predicted to choose not to own a car by the model. About 50 percent of the choices not to own a car are correctly predicted. The model does rather poorly when it comes to predicting the ownership of two or three cars.

Table 9. Actual and predicted number of cars.

	Predicted					Per cent
Actual	0	1	2	3	Total	correct
0	184	171	5	1	361	51
1	76	830	19	1	926	90
2	1	202	21	3	227	9
3	0	14	14	5	33	15
Total	261	1217	59	10	1547	67

Table 10. Actual and predicted number of cars with error term drawn from the extreme value distribution.

Actual	Predicted 0	1	2	3	Total	Per cent correct
0	174	163	22	2	361	48
1	160	621	132	13	926	67
2	22	128	64	13	227	28
3	1	13	16	3	33	9
Total	357	925	234	31	1547	56

Actual	Predicted 0	1	2	3	Total	Per cent correct
0	172	165	21	3	361	48
1	149	627	135	15	926	68
2	19	132	64	12	227	28
3	1	16	11	5	33	15
Total	341	940	231	35	1547	56

Actual	Predicted 0	1	2	3	Total	Per cent correct
0	191	141	26	3	361	53
1	150	631	137	8	926	68
2	21	131	66	9	227	29
3	1	18	6	8	33	24
Total	363	921	235	28	1547	58

Actual	Predicted 0	1	2	3	Total	Per cent correct
0	182	155	22	2	361	40
1	174	596	143	13	926	64
2	25	141	51	10	227	22
3	0	16	9	8	33	24
Total	381	908	225	33	1547	54

Table 10 displays the predictions that result when the random disturbances are taken into account. This method corresponds to the theory in section 3, in which we made the assumption that there is a stochastic term, known only to the households, that affects household utility and thus ownership decisions. We implement the simulation by making, for each household, four independent draws from the extreme value distribution for each alternative.

As Table 10 shows, the fraction of outcomes correctly predicted is somewhat reduced when the random disturbances are accounted for. Between 54 and 58 percent of total predictions are correct. Predictions of single car outcomes are still most successful; between 64 and 68 percent of these outcomes are correct. The differences in the ability to predict the different choices are smaller than in our first simulation. Predictions of the choice of not owning a car are slightly improved when the random residuals are included, and predictions of the two and three cars choices are substantially improved. The tendency to over-predict single-car ownership is reduced when the residuals are included.

As expected (cf. Maddala, 1983) the sum of predictions of each alternative is very close to the number of observations in the sample of the same outcome. On average, the predicted frequency of each choice is equal to the actual frequency. Comparing predictions to actual choices indicates that the effects of unobserved aspects of utility are substantial.

5 Conclusions

We have developed and estimated a model of household's car ownership decisions based on microeconomic theory. The main conclusions from our estimations are as follows:

Income and cost elasticities are very small for the choice of owning one car in households with average income. The elasticities decrease with income levels, and increase with the number of cars.

Second, reduced fixed annual car costs or increases in income will give rise to an increase in the number of private cars in Norway. If the fixed costs of car ownership are reduced by 10 percent, the number of cars will grow by approximately 4 percent.

The model's performance in predicting the sample outcomes is quite good. The model predicts fairly well the ownership of one car and the choice of not owning a car well; its performance in predicting ownership of two or three cars is worse.

There are some important shortcomings in our approach. For example, cars are treated as a homogeneous good, which is obviously not realistic. Both fixed and variable car costs are clearly endogenous variables, a complication which is ignored in this paper. Accordingly, data on costs should not enter the utility function in the simple way adopted by the models above. To develop a model where cars are treated as a heterogenous good is an important challenge for future research. Finally, the model should be extended to a intertemporal setting.

References

Berkovec, J. and J. Rust (1985): "A nested logit model of automobile holdings for one vehicle households", *Transportation Research Record 19b, 4,* 275-285.

Deaton, A. and J. Muellbauer (1987): *Economics and consumer behavior.* Cambridge University Press, Cambridge.

de Jong, G.C. (1990): "An indirect utility model of car ownership and private car use", *European Economic Review 34,* 971-985.

Johnson, T: (1978): "A Cross-Section Analysis of the Demand for New and Used Automobiles in the United States", *Economic Inquiry 16, 4,* 531-548.

Maddala, G. S. (1983): *Limited-Dependent and Qualitative Variables in Econometrics.* Cambridge University Press, Cambridge.

Mannering, F. and C. Winston (1985): "A dynamic empirical analysis of household vehicle ownership and utilization", *Rand Journal of Economics, 16, 2,* 215-236.

Train, K. (1980): "A Structural Logit Model of Auto Ownership and Mode Choice", *Review of Economic Studies, XLVII,* 357-370.

Statistics Norway (1987): Forbruksundersøkelsen 1983-1985 (Survey of Consumer Expenditure). NOS B; 674.

TØI (1990): "A Model System to Predict Fuel Use and Emissions from Private Travel in Norway", A joint report by Hague Consulting Group and Institute of Transport Economics.

Van Praag (1991): "Ordinal and Cardinal Utility", *Journal of Econometrics, 50,* 64-89.

Wetterwald, Dag (1994): "Car Ownership and Private Car Use. A Microeconometric Analysis Based on Norwegian Data", Discussion Papers No 112, Statistics Norway.

Statistics Norway
Research Departme
P.O.B. 8131 Dep.
N-0033 Oslo

Tel.: +47-22 86 45 00
Fax: +47-22 11 12 38

Statistics Norway
Research Department