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AN ECONOMETRIC ANALYSIS OF VEHICLE USE IN MULTIVEHICLE HOUSEHOLDS

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Abstract—The significance of the multivehicle household in the U.S. has increased substantially in recent years to the point where over 80% of household vehicles holdings are owned by multivehicle households. Despite this fact, traditional travel demand models have not explored the determinants of individual vehicle use in such households, even though knowledge of vehicle usage allocations within household fleets is critical to subsequent fuel consumption forecasts. This paper presents a discussion of vehicle use in multivehicle households and then develops an appropriate modeling specification. The specification consists of a simultaneous equation system which is estimated using a sample of two-vehicle households from a recently conducted national survey. The estimation results proved to be quite satisfactory and the model was applied to forecast policy impacts. The results underscore the importance of income and vehicle fuel efficiency in the allocation of use to household vehicles, and suggests that the ability of multivehicle households to substitute the use of more fuel efficient vehicles for less efficient ones (thereby maintaining higher usage levels) can have potentially significant consequences for traditional vehicle miles traveled (VMT)—price elasticity estimates.

INTRODUCTION

Recent concerns relating to energy availability and fuel consumption behavior have underscored the need for explicit models of household vehicle utilization. Traditional aggregate and disaggregate modeling approaches have simply not addressed the individual vehicle utilization issue, which is critical to the understanding of fuel consumption behavior since both the extent of individual vehicle use and corresponding vehicle fuel efficiency determine the demand for fuel.

In the aggregate case, models of vehicle miles traveled (VMT) are generally used in conjunction with some gross estimate of fleet fuel efficiency to estimate the demand for fuel (see Verleger and Osten (1976), Schink and Loxley (1977), Reza and Spiro (1979)). However, since the fleet fuel efficiency is in itself a function of the extent of individual vehicle use (a fact that is seldom adequately accounted for) the fleet fuel efficiency estimate is often questionable at best. Moreover, the conventional problems associated with aggregate models of VMT (e.g. multicollinearity, lack of behavioral motivation, and so on) further limit the effectiveness of the approach. Conversely, dissaggregate models of VMT (usually at the household level) including regression and discrete choice trip approaches (see Charles River Associates (1978), Cambridge Systematics (1976), and Cambridge Systematics (1979)) overcome many of the shortcomings of aggregate methods by being behaviorally motivated and explaining a greater amount of variance. Unfortunately, existing disaggregate research works have a critical deficiency in that they do not assign VMT to specific vehicles within multivehicle households (which account for 80% of the household vehicle holdings in the U.S. Mannering 1981). Therefore, the basic issue of individual vehicle utilization and ultimately fuel consumption is not accounted for.

The objective of the current research is to overcome the weaknesses of previous research efforts by presenting a discussion and corresponding model of individual vehicle utilization in multivehicle households. The focus on the multivehicle household will permit the exploration of many interesting phenomena, such as the ability of such households to substitute the use of one vehicle with other vehicles in response to fuel price changes. Such a substitution effect can have interesting implications for traditional notions of fuel price elasticities and fuel related policies in general.

The paper first presents a general discussion of multivehicle household usage. On the basis of this discussion, an econometric model of individual vehicle use in multivehicle households is presented, having been estimated with recently collected national disaggregate data of two-vehicle households. This is followed by a presentation of a number of simulation runs performed with the model. The paper concludes by summarizing the major findings of the research along with their implications.

1. VEHICLE USE IN MULTIVEHICLE HOUSEHOLDS

In principle, the household vehicle ownership problem consists of the joint choices of: vehicle ownership level (number of vehicles to own), vehicle type (make, model and vintage), and the assignment of usage (VMT) to individual vehicles (see Train and Lohrer (1982) and Mannering, Winston and Friedlaender (1982)). For the purposes of this paper, the choices of ownership level and vehicle type are viewed as exogenous (the econometric consequences of this assumption are discussed in a later section). With this in mind, a qualitative discussion of vehicle use in multivehicle households is in order.

As Fig. 1 implies, the problem faced by the household is one of selecting both activities and a vehicle allocation process that appropriately matches vehicles with activities and resolves possible temporal conflicts resulting from the vehicular demands

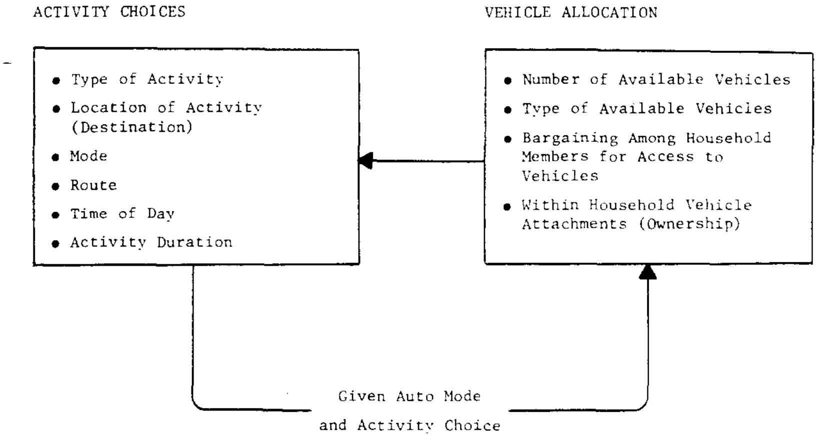

Fig. 1. Factors determining household vehicle use.

of individual households members. In this context, it is clear that the determination of vehicle use emanates from the household's selection of activities (including type, frequency and location), since activity choices translate into vehicular trips and VMT (given that competing modes of travel are not selected). In the multivehicle household the allocation of vehicle services to selected activities may be viewed from three perspectives: (1) individual vehicles are assigned to the activity choices that are most compatible with vehicle attributes (e.g. fuel efficiency, seating capacity and reliability in terms of possible breakdowns), (2) vehicle assignment is determined by a process in which household members bargain to obtain access to available vehicles for activities of a specified time duration, and (3) allocation is based on individual members consistently using a specific vehicle, perhaps out of some notion of vehicle ownership within the household. These three perspectives and their obvious interrelationships give some idea as to the scope of the allocation process. Also implicit in the allocation process is extent to which vehicles can be used as substitutes, as potential incompatibilities between vehicle attributes and activity choices, temporal conflicts, and notions of vehicle ownership within the household, act as constraints on substitutability.

As the above discussion suggests, an empirical model of multivehicle household vehicle use should be of a structure that appropriately accounts for the allocation process (individual vehicle use) and substitution across vehicles as well as the vehicular trip generating potential of the household. The current research is distinguished from previous work in this area by virtue of the fact that explicit account is given to the allocation of VMT to individual vehicles and substitution effects.

2. AN EMPIRICAL MODEL OF VEHICLE USE IN MULTIVEHICLE HOUSEHOLDS

Based on the discussion in Section 1 consider a model of household individual vehicle utilization that is in the form of a simultaneous equation system in which substitution across vehicles is explicitly incorporated:

$$\begin{aligned}
\mu_1 &= \alpha_1 + \delta_1\phi_1 + \lambda_1\bar{U}_1 + \beta_1\psi_1 + \epsilon_1 \\
\mu_2 &= \alpha_2 + \delta_2\phi_2 + \lambda_2\bar{U}_2 + \beta_2\psi_2 + \epsilon_2 \\
&\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
&\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
\mu_n &= \alpha_n + \delta_n\phi_n + \lambda_n\bar{U}_n + \beta_n\psi_n + \epsilon_n
\end{aligned} \tag{1}$$

where μ_n is the total extent of usage of vehicle n in some time period (VMT); α_n is an estimation constant; ϕ_n is a vector of attributes of vehicle n; $\bar{U}_n$ is a vector of usage of all other household vehicles not including vehicle n; ψ_n is a vector of household socioeconomic conditions and the socioeconomic conditions of the principal driver of vehicle n; ϵ_n is an error term; and δ, λ and β are estimable vectors.

The reasons for including vehicle attributes in eqn (1) are fairly obvious, since such attributes can reflect the compatibility of household activity choices with vehicle attributes, probabilities of vehicle downtime, and general reliability. Also, the extent to which other household vehicles are used is an important consideration, as the simultaneity among vehicle usages reflects the "competition" among vehicles for selection in a fixed number of activity choices (i.e. substitution across vehicles). Finally, the household socioeconomic conditions will represent trip generation potential, the likely choice of activity types, frequencies, and locations and preferences towards various vehicle attributes.

The only element of eqn (1) that has not been explained is the socioeconomic conditions of the principal driver. In accordance with the discussion presented in this paper, the principal driver concept is vital to the estimation of any vehicle use model. The reason for this is twofold; (1) the attributes of the principal driver provide a clearer indication (than household characteristics) of likely activity choices in which the vehicle is to be used, and (2) the attributes of the principal driver account for the notion of individual vehicle attachments.

This second point can be critical, as it is believed *a priori* that vehicle attachments play a very important role in the extent to which household vehicles are used, since it is not uncommon for a vehicle to be used exclusively by a particular household member. However, it must be realized that even in the extreme case, when each household member exclusively uses only one vehicle, the usage simultaneity suggested by eqn (1) is still valid, since household members can satisfy the vehicular demands of other household members (e.g. shopping, and so on). Perhaps the most likely case is the virtually exclusive use of certain vehicles, and the joint use of the "family car" for activities involving a number of household members, in which case the simultaneity of eqn (1) clearly applies.

2.1 *Estimation issues*

For the purposes of estimation, only two-vehicle households are considered. Equation (1) can then be written as:

$$\begin{aligned}\mu_1 &= \alpha_1 + \delta_1\phi_1 + \lambda_1\mu_2 + \beta_1\psi_1 + \epsilon_1 \\ \mu_2 &= \alpha_2 + \delta_2\phi_2 + \lambda_2\mu_1 + \beta_2\psi_2 + \epsilon_2\end{aligned} \qquad (2)$$

where μ_1 and μ_2 are the extent of vehicle use of vehicle one and vehicle two respectively, over some time interval; and all others are as defined for eqn (1).

It is apparent from the simultaneous determination of vehicle use suggested by eqn (2) that a simultaneous equation estimation process is needed. If one were to ignore this simultaneity and estimate eqn (2) using ordinary least squares (OLS), the resulting parameters will be both biased and inconsistent, since a correlation can be expected to exist between the usage variables and the error terms. To alleviate this problem, a number of estimation procedures are available, including instrumental variables (IV), two-stage least squares (2SLS), limited information maximum likelihood (LIML), three-stage least squares (3SLS), and full information maximum likelihood (see Theil (1971), Kmenta (1971), Pindyck and Rubinfeld (1976)). It is not always clear as to which of these estimation procedures is most appropriate since the results of any approach depend on the data used for calibration. However, for this research a three-stage least squares (3SLS) estimation process was selected due to the fact that the approach accounts for cross-equation correlations and provides more efficient estimators (asymptotically) than either IV, 2SLS, or LIML.

Also note that to estimate eqn (2) by the proposed procedure, it is necessary to assume that the ϕ's and ϵ's are statistically independent (i.e. vehicle attributes are exogenous). Such an assumption clearly violates the theory, mentioned earlier, that the choice of vehicle level, type and usage are joint decisions, which implies that the ϕ's should be treated as endogenous. However, arguments for assuming vehicle attributes to be exogenous in such usage equations can be raised if the time period over which such usage is being observed is sufficiently small. The logic behind this is that; (1) vehicle type and level choices are longer term decisions, than usage decisions, and (2) the costs associated with changing vehicle types and/or levels tend to be prohibitively large in the short term (e.g. search costs, transaction costs, and other costs associated with entering the vehicle market). Therefore, if models of usage are estimated over relatively short time periods, vehicle type attributes can be assumed to be exogenous since the household option of changing vehicle holdings is not viewed as being realistic in the short term. Should usage be considered over long time periods (e.g. a year), vehicle type attributes must be viewed as endogenous, and subsequently, type and level choices must be modeled jointly with vehicle usage using discrete/continuous econometric techniques (see Heckman (1978), Hay (1979), Dubin and McFadden (1981)). Work on such estimation has been undertaken by Train and Loher (1982) and Mannering, Winston and Friedlaender (1982). Also, it must be pointed out that the assumption of exogeniety made above is not completely valid since unobservables affecting type and level choices may persist to usages accumulated over small time periods. However, the potential bias in parameter estimates resulting from this source can be expected to be quite small (Mannering 1981).

Another issue relating to the estimable model parameters can be mentioned. In principle, the parameters of the two-vehicle usage equations should be generic (i.e., constrained to be equal; $\alpha_1 = \alpha_2$, $\delta_1 = \delta_2$, $\lambda_1 = \lambda_2$, and $\beta_1 = \beta_2$) unless a distinction between the two vehicles can be drawn. Possible vehicle distinctions include defining primary and secondary vehicles, or determining the vehicle of the primary worker. After considerable exploration of this subject, it was concluded that the definitions used to distinguish vehicles tended to be rather arbitrary and a possible source of considerable model error (see Mannering 1981). Subsequently, the generic parameter approach is used in this paper.

2.2 *Data description*

The primary data source used for model estimation was the 1979–80 Household Transportation Panel collected by the Energy Information Administration of the U.S. Department of Energy. This data source contains a wealth of information relating to vehicle use including: vehicle principal driver identification with age, employment status and sex, household socioeconomic data, vehicle make and model information in coded form, vehicle vintage, and monthly vehicle usage determined from actual odometer readings. Data was available for the months of June 1979 to May 1980. For model estimation, two-vehicle households were taken only from September–November 1979. These months were selected to minimize seasonal variation in vehicle usage and to avoid the fuel supply problems that occurred in the early summer of 1979. This selection led to a sample of 272 households (544 vehicles). A summary of sample household characteristics is presented in Table 1.

To supplement this household data, the Cambridge

Table. 1. Summary of the household estimation data (averages unless otherwise noted)

Income (dollars)	22432
Household Location (Urban/Rural)	71%/29%
Number of Household Members	3.13
Number of Household Licensed Drivers	2.08
Age of Principal Driver (Years)	42.44
Sex of Principal Driver (Male/Female)	54%/46%
Monthly Usage (Miles per Vehicle)	761.58

Systematics Vehicle Attribute File was used, thereby expanding vehicle information from make, model, and vintage to include; vehicle weight, fuel efficiency, seating capacity, vehicle value, and horsepower (Cambridge Systematics (1978)).The combination of these two data sources results in a sample sufficiently detailed to explore the concepts set forth in this paper.

2.3 *Model estimation*

The discussion of multivehicle household vehicle use presented in this paper allows for considerable flexibility relating to the actual independent variables used for estimation. However, on the basis of the discussions presented earlier and the inherent limitations of the data, a model of monthly vehicle usage (VMT) was estimated of the following form:

$$\begin{aligned} \mathrm{USE}_1 &= \sigma_0 + \sigma_1\mathrm{SCRAPROB}_1 + \sigma_2\mathrm{COST}_1 + \sigma_3\mathrm{PDAGE}_1 \\ &\quad + \sigma_4\mathrm{PDSEX}_1 + \sigma_5\mathrm{URBRUR} + \sigma_6\mathrm{USE}_2 \\ \mathrm{USE}_2 &= \sigma_0 + \sigma_1\mathrm{SCRAPROB}_2 + \sigma_2\mathrm{COST}_2 + \sigma_3\mathrm{PDAGE}_2 \\ &\quad + \sigma_4\mathrm{PDSEX}_2 + \sigma_5\mathrm{URBRUR} + \sigma_6\mathrm{USE}_1. \end{aligned} \tag{3}$$

The dependent variables in this system, USE_1 and USE_2 are defined as the extent of monthly usage (in miles) for vehicles 1 and 2 respectively. A description of the independent and endogenous variables along with expalnations for their inclusion is presented below.

SCRAPROB. This variable is defined as the probability of the vehicle being scrapped in a year time period. These probabilities were derived from the relatively simple scrappage model presented by Manski and Sherman (1980). This model is based on the theory that a vehicle will be scrapped if its market value drops below its scrappage value. Hence the model is simply:

$$\mathrm{PROB}\{P_j < R_j\} = \frac{\tau R_j}{V_j} \tag{4}$$

where: P_j is the market value of vehicle j and is dependent on mechanical condition, body quality, optional equipment, and so on; R_j is the scrap value of vehicle j; V_j is the make, model, and vintage red book value of vehicle j; and τ is an estimated parameter. Manski and Sherman assume that all R_j's are equal, and define $\pi = \tau R$. The point estimate of $\pi = 250$ was then obtained by ordinary least squares. Therefore,

$$\mathrm{SCRAPROB} = \frac{250}{\text{Vehicle Value (in dollars)}} \tag{5}$$

The inclusion of this variable is intended to account for expected vehicle downtime and reliability, an important concern in vehicle availability and in the allocation process. It would be expected that the higher the scrappage probability, the less the vehicle will be used.

COST. The cost variable is defined as the vehicle fuel cost per mile; fuel price per gallon (in cents) divided by fuel efficiency (in MPG), divided by income (in thousands of dollars). The division by income supports the belief that operating costs are less important to wealthier households. This variable captures household activity generation in response to the operating cost characteristics of its vehicle fleet. Naturally, as operating costs increase vehicle use should decline.

PDAGE. This is a dummy variable defined as 1 if the principal driver of the vehicle is less than 50 yr old and zero otherwise. This variable reflects the frequency and types of activities that the principal driver is likely to be engaged in. Since it is known that older people tend to select frequencies and types of activities that require less vehicular travel, this variable should be positively correlated with vehicle use.

It should be noted that a number of age dummy variables were considered for inclusion, but it was found that the single age dummy provided the most significant results. Apparently, the 50 yr mark reflects the period when two factors tend to cause substantial changes in driving patterns; 1) children are generally in the process of leaving home, and 2) retirement preparations are being made.

PDSEX. This is a dummy variable defined as 1 if the principal driver is a female and zero otherwise. Again this variable accounts for the frequency and types of activities that the principal driver is likely to be engaged in. Since it is believed *a priori* that women select frequencies and types of activities that require less vehicular travel than do men, this variable is expected to have a negative effect on vehicle use.

URBRUR. Is a dummy variable defined as 1 if the household resides in an urban area and zero otherwise. This variable is intended to represent frequency and type of household activity involvement, along with availability of modal alternatives and transport infrastructure. It is expected that urban locations will generate less vehicle use, and hence the variable will have a negative effect on usage.

USE. Is defined as the extent of monthly vehicle use (in miles) of the vehicle not being modeled. This variable accounts for competition among vehicles competing for use in selected activities. This variable can be expected to have a negative impact on vehicle usage. In other words, the more use one vehicle is given the less use the remaining one will be given. Obviously, this variable then reflects the vehicle substitution effect mentioned earlier.

Table 2. Three-stage least squares estimation results (Monthly usages of household vehicles in two-vehicle households); standard errors in parentheses

VARIABLE	COEFFICIENT	t-STATISTIC
σ_0 CONSTANT	1205.14 (117.17)	10.28
σ_1 SCRAPROB	-1150.63 (197.67)	-5.82
σ_2 COST	-102.23 (46.24)	-2.21
σ_3 PDAGE	123.51 (76.24)	1.62
σ_4 PDSEX	-130.93 (70.02)	-1.87
σ_5 URBRUR	-154.44 (53.44)	-2.89
σ_6 USE	-.172 (.146)	-1.18

With the variables defined and a linear functional form selected, the reduced form of the equation system was solved to make certain that parameter identification problems did not exist, and in fact the system was found to be over-identified. Model estimation was then performed using three-stage least squares (3SLS) with a Davidon–Fletcher–Powell optimization algorithm. The parameters were constrained across equations and the resulting estimates are presented in Table 2. The table indicates that all of the variables are properly signed as suggested by prior expectations. Moreover, all of the coefficients were found to be significant at well over the 90% confidence level (using a one-tailed t-test) with the exception of σ_6 which is significant at the 85% confidence level. The magnitudes of the estimated coefficients also seem to be quite reasonable. For example, all other factors equal: (1) principal drivers under 50 yr of age drive their vehicles 123.51 miles more per month than those over 50, (2) urban households drive 154.44 miles less than rural ones, (3) female principal drivers operate their vehicles 130.93 miles less than males, and (4) for every 100 miles driven on a "competing" vehicle, the modeled vehicle will be driven 17.2 miles less.

The estimation produced single equation R-squared's of 0.2395 and 0.2611, which are quite satisfactory considering the amount of variance inherent in disaggregate data of the type used in this study. As a final note, it is believed that the model fit could be enhanced by data that is more detailed than that available for this study. Specifically, information relating to the type of activities the principal driver actually undertakes, such as type of work, types of leisure activities, and so on, would be of considerable value.

3. MODEL APPLICATION

To illustrate the potential usefulness of the model, the impacts of a doubling of fuel prices are considered. Since the model was calibrated using 1979, September–November data, when fuel prices were near the one dollar per gallon mark, this increase translates into a price of nearly two dollars per gallon. The impact of the price change was evaluated in the equation system by sample enumeration (i.e. evaluating the changes for each of the 272 households used in the estimation process). The aggregated results of this procedure are presented in Table 3.

The implied price elasticity in the two-vehicle household population is -0.113 with respect to VMT, and this value is consistent with the estimates from previous research efforts. In addition, Table 3 indicates that the differential impacts of the fuel price increase on both income and vehicle fuel efficiency groups can be rather substantial, a fact that must be considered in forecasting fuel consumption in general.

With these figures in mind, it is interesting to direct attention toward the substitution effect discussed earlier. Again, substitution occurs since the two-vehicle household can substitute the use of their more efficient vehicle for the use of their less efficient one. All of the numbers presented in Table 3 include both substitution effects and price effects (i.e. the phenomenon of less efficient vehicles being more sensitive to changes in fuel prices). If no substitution were to occur, it would be expected that total household VMT would be less than the case when substitution does occur, if one assumes that the household operates on a relatively fixed transportation time and monetary budget. In this sense the two-vehicle

Table 3. Projected impacts of a doubling of fuel price (percent change in VMT in two-vehicle households)

	Vehicle Fuel Efficiency Grouped by MPG					
Income Group	≤12	12-14	14-20	20-25	25+	TOTAL
Less Than $20,000	-22.6	-18.7	-15.7	-10.4	- 7.0	-16.7
$20,000 - $30,000	-13.1	-11.0	- 8.3	- 5.6	- 3.9	- 8.5
$30,000 +	- 7.4	- 5.7	- 4.7	- 3.2	- 2.0	- 4.8
TOTAL	-16.2	-14.4	-10.9	- 6.3	- 4.4	-11.3

household can be viewed as the recipient of a VMT bonus resulting from the substitution effect. Determining the exact magnitude of this bonus is not possible with the simultaneous framework presented in this paper, however some approximations can be made to provide insight into this subject.

The estimated model structure indicates that price increases alone will cause the use of a less efficient vehicle (denoted U_1) to decrease at greater rates than the use of a more efficient one (denoted U_2), as a result of the differences in the absolute increases in costs per mile. Note that this price effect tends to decrease the fuel consumed per mile driven since average household fleet fuel efficiency will increase in accordance to the harmonic mean (see Sherman and Manski (1979)). Moreover, the simultaneous equation system implies that the larger rate of decrease in U_1 will tend to increase U_2 with respect to the U_2 resulting from the price effects alone. This constitutes the substitution effect. Since it is not possible to isolate the price and substitution effects with the equation system developed in this paper, as noted above, the following approximation was made to capture the magnitude of the combined impact of both price and substitution effects:

(1) Assume that the proportion of vehicle usage (U_1/U_2) is the same after the policy implementation as it was before the implementation (i.e. not permitted to vary).

(2) Assume that the household consumes the same amount of fuel with the fixed U_1/U_2 as it did with the variable (or true) U_1/U_2.

(3) Translate this second assumption into an equivalent VMT decrease (over the variable U_1/U_2 case) resulting from declines in average household vehicle fleet fuel efficiency (again, as determined by the harmonic mean).

The application of this approximation makes the implicit assumption of a constant household vehicle transportation budget. Nevertheless, the above procedure should provide a reasonably accurate approximation of the true price and substitution effects. With this point considered, the resulting estimates of the combined price and substitution effects are presented in Table 4.

This table indicates that the approximated price and substitution effect accounts for a 12.4% reduction in the estimated VMT-price elasticity (from -0.129 to -0.113), for the two-vehicle household sample. This figure tends to be rather low for a number of reasons including; (1) the notion of the principal driver implies a limit of the use of specific vehicles by other household members (i.e. limiting substitution), (2) vehicle attribute and activity compatibility also limit substitution, and (3) differences in the efficiencies of the two vehicles may be small, in which case both price and substitution effect will be negligible. This third point deserves some elaboration. In the 272 household sample used for model estimation and policy testing, the mean difference in vehicle efficiencies within households was 4.87 m.p.g. with 14 households owning vehicles of identical efficiency. Therefore, although few households own vehicles of identical efficiency, for those that do not, differences in the efficiencies of the two vehicles are generally not large enough to produce dramatic price and substitution effects.

Despite the fact that the approximated effects dis-

Table 4. Combined price and substitution effect approximations in two-vehicle households; percent change in VMT resulting from a doubling of fuel prices

Income Group	True VMT Impact	Estimated VMT Impact Assuming no Price and Substitution Effects
Less Than $20,000	-16.7	-18.9
$20,000 - $30,000	- 8.5	- 9.7
$30,000 +	- 4.8	- 5.7
TOTAL	-11.3	-12.9

played in Table 4 are rather small, they reveal the dependence of traditional VMT estimates on the number of multivehicle households in the population and their fleet composition. Since traditional elasticity estimates implicitly include price and substitution effects, any shift in household vehicle ownership levels and/or household fleet compositions (such as the substantial shifts that occured in the U.S. during the 1970's, see Sherman (1980)), will cause such estimates to produce erroneous forecasts. Moreover, theory suggests that substitution effects in higher level-of-ownership households (e.g. three and four vehicle households) will be substantially larger than those observed in the two vehicle case, thereby stressing the need for an explicit model of individual vehicle use in multivehicle households such as the one proposed in this paper.

A final note on Table 4 can be made with regard to income effects and price and substitution behavior. Essentially, two forces are at work that tend to negate income effects. First, lower income households are more sensitive to fuel price increases which implies an increase in price and substitution effects. However, countering this is the fact that lower income households generally own older inefficent vehicles that have approximately the same efficiency, hence tending to decrease both price and substitution effects. The result of these two factors produce minimal income effects, as virtually the same percentage drop in VMT-price elasticity occurs across income groups.

CONCLUSIONS

This paper has provided a number of insights into the determinants of vehicle use in the multivehicle household. These insights result from the estimation of an appropriate econometric model of vehicle use in two-vehicle households, and from the subsequent policy testing of the estimated model. On the basis of the results presented in this paper the following statements can be made:

(1) Traditional aggregate and disaggregate models of VMT have virtually ignored individual vehicle use in multivehicle households, and hence their forecasting capabilities are necessarily limited.

(2) Estimation of an appropriate model of individual vehicle use in multivehicle households can be achieved using a simultaneous equation approach.

(3) The impacts of fuel price increases on individual vehicle use vary significantly across income groups and vehicle fuel efficiency categories, thereby underscoring the importance of household socioeconomic conditions and household fleet composition.

(4) The ability of multivehicle households to substitute the use of more efficient vehicles for the use of less efficient ones should be considered in VMT-price elasticity estimates.

In summary, the explicit modeling of individual vehicle use is still in its infancy, as appropriate data sources and modeling methodology are just now becoming available. It is felt, however, that the concepts and model proposed in this paper contribute an important basis from which future work in this area can proceed.

REFERENCES

Cambridge Systematics Inc. (1976) Carpool Incentives: Analysis of Transportation and Energy Impacts, Submitted to the Federal Energy Administration, Washington, D.C.

Cambridge Systematics Inc. (1978) Description of the Vehicle Attribute File, Cambridge, Massachusetts.

Cambridge Systematics Inc. (1979) Analytic Procedure for Estimating Changes in Travel Demand and Fuel Consumption, Vol. II DOE/PE8628-1, Washington, D.C.

Charles River Associates (1978) Auto Fuel Efficiency and Auto Usage, Interim Report prepared for the National Highway Traffic Safety Administration, Washington, D.C.

Dubin J. and McFadden D. (1981) An Econometric Analysis of Residential Electric Appliance Holdings and Consumption, Department of Economics, M.I.T.

Hay J. (1979) An Analysis of Occupational Choice and Income, Ph.D. Dissertation, Yale University.

Heckman J. (1978) Dummy endogenous variables in a simultaneous equation system, *Econometrica*, **46**, (6).

Kmenta J. (1971) *Elements of Econometrics.* MacMillan, New York.

Mannering F. (1981) Household Vehicle Usage and Type Choice Decisions, Working Paper, Department of Civil Engineering, M.I.T.

Mannering F., Winston C. and Friedlaender A. (1982) Dynamic Models of Household Vehicle Ownership and Utilization, presented at the winter meeting of the Econometric Society, New York.

Manski C. and Sherman L. (1980) An empirical analysis of household choice among motor vehicles, *Trans. Res.* **14A**; 349-366

Pindyck R. and Rubinfeld, D. (1976), *Econometric Models and Econometric Forecasts.* McGraw-Hill, New York.

Reza A. and Spiro, M. (1979), Demand for passenger car transport services and gasoline, *J. Transport Economics and Policy.* 13, 304-319.

Schink G. and Loxley C. (1977) An Analysis of the Automobile Market: Modeling the Long-Run Determinants of the Demand for Automobiles, Wharton Econometric Forecasting Associates Inc.

Sherman L. (1980) Implications of current household vehicle ownership and use patterns on the feasibility of electric cars, *Transportation.* 9, 209-227.

Sherman L. and Manski C. (1979), Analysis of the Effects of Gasoline Prices and Vehicle Design Attributes on Consumer Choice of Vehicle Type, Cambridge Systematics, Inc. Cambridge, MA.

Theil H. (1971) *Principles of Econometrics*, Wiley, New York.

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

Verleger P. and Osten J. (1976) Econometric Model of Consumer Demand for New and Replacement Automobiles, Data Resources, Inc., Lexington, Massachusetts.