The Influence of the Price of Gasoline on Vehicle Use in Multivehicle Households

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ABSTRACT

Two-thirds of the households in the United States that own motor vehicles own two or more. Multiple vehicle ownership permits households to substitute travel by fuel-efficient vehicles for travel by inefficient vehicles in response to higher fuel prices. Travel demand equations were estimated for one-, two-, and three-vehicle households by using disaggregate data from a monthly diary of vehicle use from April 1978 to March 1981. Three individual equations and a combined equation for small cars, large cars, and trucks were estimated. Price and fuel efficiency elasticities were allowed to vary according to the type of other vehicle owned by the household. In response to a 25 percent increase in gasoline price, the model predicts a 5 percent decline in vehicle use, but only a 0.2 percent increase in overall fuel efficiency is due to shifts to smaller vehicles.

Consumer demand for gasoline and automobile use has been extensively studied, especially since the Arab oil embargo of 1973-1974. [A review of the literature on this subject through 1978 has been compiled by Greene (1).] Many of these studies have dealt with gasoline demand in the aggregate by using either single equation, dynamic adjustment models (2,3), or systems of equations representing the demand for vehicle travel and fuel efficiency (4-8). Mellman (9) has reviewed many of the significant studies of aggregate automobile travel demand. There is considerable literature on modeling travel demand by using disaggregate household data; however, it is primarily concerned with tripmaking and choice of travel mode rather than vehicle use and total vehicle travel (e.g., 10,11). Adequate survey data for disaggregate econometric analyses of household vehicle use have been collected only recently (12,13), and as a result a few disaggregate studies of household use of highway vehicles have been published (14-16).

Both Mannering (16) and Train and Lohrer (15) specifically consider the determination of vehicle use in households owning more than one vehicle. Mannering's model, estimated for two-vehicle households, includes use of the other vehicle as an endogenous right-hand side variable in each vehicle-use equation. This structure clearly requires simultaneous equation estimation techniques. Train employs the more traditional econometric approach of expressing quantities of travel consumed as a function of prices and income (and demographic variables). Although Mannering's equation system consists of two linear simultaneous equations for two unknowns, it could have been estimated in reduced form by nonsimultaneous techniques. From the perspective of the classical economic theory of consumer demand, demands for commodities such as travel are temporally simultaneous; yet equilibrium demand equations, as functions of prices and income alone, always exist (e.g., 17). This is the approach adopted in this paper.

Both Mannering and Train include the price of gasoline in their models as a component of a cost-per-mile variable. In the context of the household production theory of consumer demand, discussed below, this results in a commodity demand equation that is a function of commodity prices. As Pollack and Wachter (18) have demonstrated, it cannot be proven that such demand equations exist. The problem is the joint determination of commodity demand and commodity prices. Recognizing this, Train used an instrumental variable to represent cost per mile. Although this solution addresses the econometric problem of joint determination, it does not address the question of existence. Finally, both studies estimate a single equation for all vehicles owned by a household. That is, estimates of parameters are not allowed to vary across number of vehicles. In this study, miles traveled by different vehicles are considered to be different from, but closely related to, commodities and parameters; in particular the responses to gasoline price changes are allowed to vary.

The focus of this paper is on changes in household vehicle use in response to changes in the price of gasoline. Disaggregate data permit quantification of the substitution of travel in fuel-efficient vehicles for travel in larger, inefficient ones and the variation of the sensitivity of travel to cost as a function of the number and types of vehicles owned. Recent panel survey data collected from April 1978 to March 1981 afford an opportunity to explore the tendencies for U.S. households that own more than one vehicle to shift vehicle-use patterns as well as reduce total travel in response to higher fuel costs (13). The data used are almost ideally suited to this purpose because each fuel purchase is recorded for every vehicle owned by a household including the price paid, gallons purchased, and the odometer reading. This permits the estimation of miles traveled for each vehicle as well as actual, realized fuel economy.

The demand for travel is modeled in the context of household production theory as a produced commodity. For one-vehicle households it is possible to investigate the hypothesis that consumers respond to the commodity price (gasoline cost per mile) instead of the goods price (the price of gasoline, which controls fuel economy). For two-vehicle households a demand equation is estimated that allows the travel response to fuel costs to vary according to the nine possible household combinations of small cars, large cars, and trucks. Because of the small sample size, it was not possible to estimate a similar equation for a three-vehicle household; however, a reasonable, simplified version was developed.

The remainder of the paper contains sections on the household production approach and functional forms of the vehicle-use models; the results of ordinary least squares estimation of the model; and shifts in vehicle use and improvements in fuel economy in response to price changes.

THEORY

Michael and Becker (19) viewed households as deriving utility from commodities produced by them using purchased market goods (durable and nondurable) and labor. Their concept is used in this analysis. Households are assumed to maximize utility (u), which is a function of the commodity vector (z), subject to a constraint that full income (s) be spent. This can be represented by the Lagrangian

$$L = u(z) - \lambda[\sum_i (wt_i + \underline{p}_i'\underline{x}_i) - s] \quad (1)$$

where w is the wage rate, $\underline{p}_i$ the price vector, $\underline{x}_i$ the vector of market goods quantities, and t_i the labor time used in producing commodity i. First order conditions require that the ratio of the marginal utilities (MU) of two commodities (i and j) equal the ratio of their marginal costs (MC) in both time and money as shown by Equation 2.

$$\begin{aligned} MU_i/MU_j &= (\partial u/\partial z_i)/(\partial u/\partial z_j) \\ &= [w(\partial t_i/\partial z_i) + p_i (\partial x_i/\partial z_i)]/ \\ &\quad [w(\partial t_j/\partial z_j) + p_j (\partial x_j/\partial z_j)] \\ &= MC_i/MC_j \end{aligned} \quad (2)$$

The marginal costs are shadow prices of the commodities (which depend on the prices of market goods), the value of time, and the productivity of each in producing z_i.

Consider a household that produces travel using two different vehicles. If both vehicles travel at the same speed, then (hedonic aspects of travel aside) the time cost component of marginal cost will be the same for both. Assume that vehicle 1 is more fuel efficient than vehicle 2 and that all other things are equal. Then

$$p(\partial x/\partial z_1) < p(\partial x/\partial z_2) \quad (3)$$

where z_i (i = 1 or 2) represents travel by the respective vehicle, x is fuel consumed, and p is the price of fuel. From Equations 2 and 3 it is clear that if the price of fuel increases between time periods, $p_{t+1} > p_t$, then

$$(MC_{1,t+1})/MC_{2,t+1}) < (MC_{1,t})/(MC_{2,t}) \quad (4)$$

and the relative use of vehicle 1 should increase (assuming declining marginal utilities or increasing marginal costs of travel for each vehicle).

In one-car households options are more limited. Vehicle use can be reduced or another mode of travel (e.g., walking or mass transit) can be substituted for personal vehicle travel. The ability to substitute may depend on location more than any other factor.

In three-vehicle households the opportunities for vehicle substitution are more complex. The sample size, which is only one-fifth of that for two-vehicle households, proved to be a serious limitation to exploring vehicle-use patterns in three-vehicle households. However, a model with a simplified characterization of vehicle holdings was reasonably successful.

Variables included in the models were gasoline price, own and other vehicle fuel economies in miles per gallon (MPG), household income, number of drivers, age of the vehicle (years), location (within city limits of city of 50,000 or more, outside city limits of city of 50,000 or more, or rural), quarter of the year, and region (the nine Bureau of the Census regions were used). The fuel economy assigned to a vehicle was average MPG over the entire survey period. Thus simultaneity between MPG and vehicle use was not a problem. No information was available on the division of income into wage and nonwage sources.

All models were estimated using the logarithms of all variables except age of vehicle. This formulation implies constant elasticities but exponentially declining use over time. For all vehicle ownership levels, separate equations were estimated by vehicle type (small, large, or truck) to facilitate analysis of response of vehicle use to higher fuel prices. An alternative model, which uses the translog utility function, has been applied by Aigner and Hausman (20) to disaggregate data on the use of electricity. Their formulation would require expressing gasoline price in terms of cost per mile for each vehicle. Three vehicle classes were formed by aggregating the Environmental Protection Agency (EPA) classes of vehicle size. Compact and smaller cars were considered small; larger than compact, large. Standard-sized pickup trucks, vans, and recreational vehicles were combined in the truck category, but minipickups were considered to be small cars.

RESULTS

All equations were estimated by calculating ordinary least squares regressions. The GLM procedure of the 1979 SAS User's Guide (21) was used throughout except in testing the price and MPG coefficients restriction, for which the SYSREG procedure was used. The fuel purchase data were aggregated to monthly average, and each month for each household was treated as a single observation (a description of the data and data processing is available from the authors). The dependent variable was average daily travel for the month. The large number of households prevented the use of generalized least squares techniques and at the same time tended to make them unnecessary. Results for the one-, two-, and three-vehicle household models are described in turn. In the interest of conserving space, quarterly and regional dummy variable estimates have been omitted from tables. These are available from the authors on request.

Most of the single-vehicle households in the sample owned a large car. About half as many owned a small car and relatively few owned only a truck. As the data in Table 1 indicate, the estimates for most parameters are similar for the three vehicle types. The elasticity of gasoline price for large cars and trucks is 75 percent or more higher than for small cars. Households with large cars appear to respond to the cost of gasoline per mile of travel as evidenced by the equal and oppositely signed elasticities of gasoline price and MPG. If this condition were imposed as a constraint on each equation it would be rejected in all except the large car equation.

It appears that truck owners are overly sensitive to the price of gasoline. There does not appear to be an obvious explanation for this, although there is also no requirement that household travel depend on cost per mile. In the context of household production theory, cost per mile is the commodity price of travel (or at least part of it). As Pollack and Wachter (18) have shown, commodity demand equations in terms of commodity prices do not exist, in general. Essentially this is because the commodity price depends on exactly how the household chooses to produce the commodity and how much it produces. In the case of multiple-vehicle households, it is evident that the overall gasoline cost per mile of

TABLE 1 Coefficients for Travel Demand Equations: One-Vehicle Households

Vehicle Type	Intercept	Price	MPG	Income	No. of Drivers	Age	Urban	Suburban	R^2	N
Small car	6.540	−0.184	0.302	0.288	0.081*	−0.047	−0.167	−0.121	0.107	14,916
Large car	6.078	−0.328	0.316	0.250	0.267	−0.051	−0.162	−0.050	0.124	29,281
Truck	5.743	−0.435	0.301	(−0.080)	(0.062)	−0.068	−0.163	0.226	0.135	2,020
Combined	6.400	−0.294	0.307	0.251	0.198	−0.051	−0.165	−0.059	0.119	46,217

Note: Coefficients in parentheses are not statistically significant at the 0.05 confidence level for a two-tailed test. All other estimates are significant at at least the 0.01 confidence level except one, which is indicated by an asterisk.

travel depends on which vehicle the household uses to produce the travel. For single-vehicle households it may be that truck owners are more likely to car-pool or shift to other modes of travel. Unfortunately the survey data are insufficient to test this conjecture.

The estimates for MPG elasticity are remarkably consistent across vehicle types. They suggest that, within a size class, a 25 percent more efficient vehicle would receive 7 percent more use, other things being equal. Travel appears to be inelastic with respect to income; in fact, income elasticity is not significantly different from zero in the truck equation. The number of licensed drivers in a household has little effect in the truck and small car equations but substantially more in the large car equation. The effect of vehicle age is quite consistent across vehicle types, indicating approximately a 5 percent decrease in vehicle use per year for cars and almost 7 percent for trucks. Finally, the use of vehicles of all types inside the city limits of a city of 50,000 or greater is 15 percent less than of vehicles in rural areas. The effect of a suburban location varies much more across vehicle types. Caution should be used in interpreting the truck estimate because of the relatively small number of households (as opposed to monthly observations) in the sample.

A pooled estimation, using dummy variables to represent the effects of vehicle size, looks similar to an average of the three individual equations. The combined equation indicates strongly that one-vehicle households respond to gasoline cost per mile in making vehicle use decisions. An F-test for equality of slope coefficients across the three vehicle types rejects the hypothesis of equality. This same result recurs in the two- and three-vehicle models.

The two-vehicle household model recognizes the ability of households to make relative changes in vehicle use in response to higher fuel prices by allowing the price and MPG elasticities to vary according to the type of the other vehicle. Once again separate small car, large car, and truck equations were estimated. Although the MPG elasticities are relatively constant across vehicle combinations, the price elasticities vary a great deal, and generally in an interpretable pattern (Table 2). In the one-vehicle household equations the price elasticity was lowest for small cars and higher for large cars and trucks. This result tends to hold for two-car households as well. Furthermore, the elasticity of gasoline price should be expected to increase as the size of the alternative car decreases (its efficiency increases). This also appears to be reflected in the results. With the exception of trucks, price elasticity is highest when a second small car is owned. Beyond that, it appears to make little difference whether the other vehicle is a large car or a truck. The truck equation is unusual in not following these patterns. The reason may be that in most cases when a household owns a truck, the other vehicle is a large car. Note that the other two price elasticity estimates are nonsignificant. Another possibility is that these results partially reflect real differences in the way households use trucks and cars.

Another distinctive aspect of these equations is the pattern of increasing household income elastic-

TABLE 2 Coefficients for Travel Demand Equations: Two-Vehicle Households

	Small Car	Large Car	Truck	Combined
Intercept[a]	5.756	5.784	5.663	5.617[b] 5.716[c] 5.722[d]
Gasoline price if other vehicle is				
Small	−0.161	−0.301	(−0.119)	−0.225
Large	(−0.058	−0.148	−0.228	−0.137
Truck	(−0.061)	−0.144	(−0.091)	−0.118
Own MPG if other vehicle is				
Small	0.284	0.417	0.356	0.343
Large	0.354	0.346	0.286	0.328
Truck	0.328	0.354	0.479	0.372
MPG of other vehicle	(−0.012)	−0.015	0.077	(0.004)
Income	0.050	0.130	0.230	0.114
Age	−0.062	−0.053	−0.063	−0.057
Number of drivers	0.223	0.277	0.251	0.255
Urban	(−0.032)	−0.111	0.082	−0.048
Suburban	0.088	(−0.009)	0.118	0.056
R^2	0.102	0.112	0.117	0.106
N	21,814	30,354	10,394	62,562

Note: Estimated values in parentheses are not significantly different from zero at the 0.05 confidence level using a two-tailed test.

[a]Quarterly estimates and estimates of eight regional dummy variable parameters have been excluded to conserve space (available from authors on request).

[b]Small.

[c]Large.

[d]Truck.

ity from small cars to large cars to trucks. Still, motor vehicle travel is decidedly income inelastic given vehicle holdings. Unlike the one-vehicle equation set, all equations appear equally responsive to an increase in the number of drivers in the household. Going from two to three drivers would increase the use of a typical vehicle by about 10 percent. Again, unlike the one-vehicle household equations, use appears to bear no simple or consistent relationship to location. Finally, the fuel economy of the other vehicle (MPG other) does not appear to be an important factor in determining vehicle use.

For three-vehicle households, twice as many price and MPG slopes would have been required to cover all possible vehicle combinations. Because only one-fifth as many observations are available and especially because the distribution of households among vehicle combinations is not uniform, this could not be done. Instead, the two other vehicles available to the household were classified according to whether one of the other vehicles was a small car. This is believed to be reasonable because most of the differences in coefficient estimates for the two-car equation appear to be based on a small car or other distinction.

The relatively large number of insignificant coefficients (Table 3) hinders interpretation of the individual vehicle type equations. The combined equation has only one insignificant coefficient, income, and is thus easier to analyze. Although it may appear that there are more than enough observations, actually most are monthly replicates from a much smaller set of households. The panel data cover 36 months. If the average household remained in the panel only one-half that time, then the 2,487 observations used to estimate the three-vehicle household truck equation may represent only a few more than 100 households. For these reasons only the combined equation results are discussed.

The three-vehicle model continues a trend evident in the one- and two-vehicle model results. As the number of cars per household increases, the importance of household income in determining use declines and the importance of the number of drivers increases. Indeed, income is statistically insignificant in the three-vehicle model. The importance of location is also diminished. The factors that appear to matter are number of drivers, vehicle age, fuel economy, price of fuel, and household fleet composition. Use of cars in households owning at least one alternative small car is almost twice as sensitive to fuel price changes as in households that do not. Thus, the results indicate substantial willingness to substitute cheap miles for expensive ones when the choice is available.

EFFECT OF GASOLINE PRICE ON VEHICLE USE

It is clear that higher gasoline prices would cause these models to predict reduced vehicle use overall and a shift away from larger cars and trucks toward smaller cars. The effect on gasoline demand would be twofold: (a) a direct reduction through less travel and (b) a reduction proportional to the improvement in fleet fuel economy brought about by the shift in use. The quantity of vehicle travel for each category for which there is a distinct price elasticity is needed to quantify these effects. Given this, the new total travel (T_t) can be computed as follows:

$$T_t = \sum_i T_{oi} \, (P_t/P_o)^{\alpha_i} \quad (5)$$

where (P_t/P_o) is the new-to-old price ratio, T_{oi} is the initial period traveled by category i vehicles, and α_i is the appropriate price elasticities. An average price elasticity for the given price change can be computed as follows:

$$\bar{\alpha} = \ln(T_t/T_o)/\ln(P_t/P_o) \quad (6)$$

where $T_o = \sum_i T_{oi}$. Note that $\bar{\alpha}$ is not constant but depends on the price ratio.

For vehicle miles the total vehicle miles of all vehicles in each ownership level is used--vehicle type category for the entire sample period. The corresponding total fuel use is used to compute efficiencies (these data are available from the authors on request). To give the reader a rough idea of proportions, 35 percent of the total vehicle miles is by small cars, 53 percent by large cars, and about 13 percent by light trucks. By ownership level, 37 percent of vehicle miles is by one-vehicle, 49 percent by two-vehicle, and 14 percent by three-vehicle households.

A 25 percent real price increase would cause a

TABLE 3 Coefficients for Travel Demand Equations: Three-Vehicle Households

	Small Car	Large Car	Truck	Combined
Intercept[a]	5.575	4.889	5.615	5.404[b] 5.302[c]
Gasoline price if at least one other vehicle is				
Small	(-0.242)[d]	-0.517	(-0.044)	-0.343
Otherwise	(0.001)	-0.316	(-0.095)	-0.185
Own MPG if at least one other vehicle is				
Small	0.445	0.311	0.119	0.319
Otherwise	0.420	0.441	0.404	0.413
MPG of second vehicle	(0.009)	(0.046)[d]	(0.026)	0.037
MPG of third vehicle	-0.066	(-0.037)	-0.167	-0.090
Income	(0.059)	(0.025)	(0.066)	(0.027)
Age	-0.061	-0.057	-0.074	-0.062
Number of drivers	0.327	0.341	0.352	0.321
Urban	-0.100	-0.078	0.167	(-0.028)
Suburban	(-0.058)	(-0.037)	0.122	(-0.005)
R^2	0.142	0.131	0.139	0.130
N	4,424	6,437	2,487	13,348

Note: Estimates in parentheses are not significantly different from zero at the 0.05 confidence level using a two-tailed test.

[a]Quarterly estimates and estimates for eight regional dummy variable parameters have been omitted to conserve space (available from authors on request).

[b]Small vehicle.

[c]No small vehicle.

[d]Significant at the 0.1 confidence level using a two-tailed test.

4.7 percent overall decline in travel for an average elasticity for that size increase of -0.216. Such a price increase, of course, occurred in consecutive years in 1979 and 1980. One-car households are most responsive to the 25 percent increase ($\bar{\alpha}$ = -0.284), whereas two-car households are the least responsive ($\bar{\alpha}$ = -0.158). Elasticity increases again for three-car households ($\bar{\alpha}$ = -0.246).

By vehicle type, large cars have the highest price elasticity ($\bar{\alpha}$ = -0.2786); small car use is only half as high ($\bar{\alpha}$ = -0.1314); and trucks fall in between ($\bar{\alpha}$ = -0.1931). Thus a price increase will have the effect of shifting travel away from large cars toward smaller ones. This will have subtle but estimable effect on the overall vehicle fleet fuel economy. The 25 percent price increase has the effect of increasing fleet fuel economy a mere 0.2 percent. This would be less than 5 percent of the total decline in gasoline consumption caused by the price change. Of course, the possibility that households may take other actions (e.g., greater tire inflation pressures and slower speeds) to improve vehicle fuel economies has not been discussed here. Apart from these, however, reduction in travel totally dominates shifts in fuel economy in terms of the amount of gasoline used.

SUMMARY

The household production theory of consumer demand has been used to specify estimable disaggregate equations for household vehicle use. Separate sets of small car, large car, and truck equations were estimated for one-vehicle, two-vehicle, and three-vehicle households by using panel survey data from April 1978 to March 1981. The results indicate a rough consistency between gasoline price and vehicle fuel efficiency elasticities for one-vehicle households. This result suggests that one-vehicle households may base decisions about use on the cost of gasoline per mile. For multiple-vehicle households this result breaks down as households indicate an inclination to substitute more efficient for less efficient travel. Although this practice may significantly improve fuel economy for some households, the overall effect is negligible. In response to a 25 percent price increase the model predicts a 4.7 percent decline in vehicle use and a 0.2 percent improvement in fleet fuel economy induced by a shift in use. The average price elasticity of all vehicle travel associated with a 25 percent price increase was calculated to be -0.216.

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Fuel Crises, Economic Uncertainty, and Outdoor Recreational Travel

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ABSTRACT

An assessment was made of the effects of fuel availability, fuel price, and general economic conditions on attendance at national parks. The findings indicate that American propensity for outdoor recreational travel is strong enough to withstand the challenge of fuel shortage or economic uncertainty. This study demonstrates the resilience of outdoor recreational travel patterns in the decade 1973 to 1982. The challenges of two severe fuel shortages in 1974 and 1979 and periodic recessions, most notably in 1981-1982, caused only momentary and inconsistent variations in the outdoor recreational travel patterns of the American traveling public.

The focus of this study was a sample of 35 national parks selected from the list of national parks included in "The Statistical History of the National Park System" and a parallel sample of state parks selected from nine states in different regions of the country. First, a procedure is presented for considering the potential associations between attendance figures and fuel availability, fuel price, and the economy. Second, an assessment is made of the findings of a series of regression analyses, pertaining to both the national and the state samples. Third, available origin and destination information is reviewed so that the possibility of substituting closer trips to state parks for longer trips to national parks can be considered. The findings are then summarized and assessments presented.

PROCEDURE

Attendance patterns at national parks are frequently regarded as a barometer of outdoor recreational travel (1). This is in part because of the availability of a relatively consistent source of comparable data. For energy-related studies national park attendance has the additional merit of representing the choice of long-distance travel. Because travel to national parks generally requires advance planning, such travel could be deferred in response to concerns about fuel availability, fuel price, or the economy. The existing body of literature on national parks is substantial. Most of it is concerned with predicting demand for particular attractors or particular parks; for example, Cesario (2) cites and assesses numerous studies that have constructed models that use measures of park attendance as dependent variables and a variety of influencing factors as independent variables. Burton (3) reviews recreational forecasting studies in both the United States and England, and Cheung (4) assesses outdoor recreation participation models. Cheung's model incorporated population size, accessibility, alternative opportunities, and attractiveness into a regression model. No attempt is made in this study to add to this body of literature. Instead this study seeks to provide an aggregate longitudinal analysis of the impact of fuel availability, fuel price, or the economy on park attendance (5) and examine the potential for state parks as alternative attractors. [McAllister and Klett (6) introduced the effects of alternative recreational opportunities into a gravity model which would predict demand, but does not assess such impacts in a broadly based analysis of travel patterns.]

The 35 national parks in the study sample were selected from the list of national parks included in "The Statistical History of the National Park System" provided by the U.S. Department of the Interior. All facilities designated as national parks, as distinguished from national monuments, national forests, or national recreational areas, were included. An attempt was made to update and amplify the data supplied by the Interior Department through direct contact with each of the parks. Aggregate figures for 1981 and 1982 were requested as was information on the state of origin of the visitors. About 15 parks were able to provide updated aggregate attendance figures, but only 5 supplied