DYNAMIC ECONOMETRIC MODELS OF HOUSEHOLD VEHICLE OWNERSHIP AND UTILIZATION

by

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ABSTRACT

This thesis presents a theoretical and empirical assessment of the demand for motor vehicles in the U.S. The analysis was undertaken at the household level, and full explicit consideration was given to the interrelationships between the household's choices of quantity of vehicles to own, types of vehicles to own (defined by make, model and vintage), and the extent to which these vehicle types are utilized. Moreover, the dynamic aspects of the household's vehicle ownership and utilization decision were accounted for by viewing dynamics as the evolution of household tastes. Based on fundamentally different economic theories relating to the manner in which households address the intertemporal nature of their vehicle ownership problem, two dynamic econometric models of vehicle ownership and utilization were derived.

The derived models were estimated with a national household sample in which all relevant vehicle ownership information was available for the same households for a two-and-one-half year period, December 1977 to June 1980. The resulting model estimations suggest that vehicle demand conditions favor the survival of the domestic automobile industry. This is reflected by the finding that households have an inherent preference toward GM and Ford products, and to a lesser extent, Chrysler and AMC products, as opposed to foreign-made vehicles. However, to exploit this preference, domestic manufacturers must be able to offer reasonably competitive models, both in terms of performance and capital costs.

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CHAPTER 1. INTRODUCTION

Historically, automobile sales in the U.S. have been characterized by a cyclical pattern that has had a strong effect on the profitability and viability of automobile manufacturers. In more recent years, since the energy shock of 1979, there has been concern that a fundamental shift in the demand for new automobiles has occurred. This concern has its basis in the fact that automobile sales have been depressed for the three years following the 1979 energy shock, an unusually long time for a typical downward sales cycle. The implication of a fundamental downward shift in the demand for new automobiles is that some domestic manufacturers may not survive, and it will be necessary for the industrial base of the U.S. economy to adjust accordingly.

The current state of the U.S. automobile market can be presented in relatively short order. Essentially, sales of domestic new cars reached a respectable 9.3 million units during the 1978 calendar year with import sales accounting for less than 18 percent of total sales. At the time, it appeared as though the domestic industry had successfully rebounded from the 1975 recession and was offering a competitive product line. However, with the energy shock of June 1979 and the corresponding increases in fuel prices, domestic new car sales began a steady decline with 8.3, 6.6, 6.2 and 5.7 million units being sold in the 1979, 1980, 1891, and 1982 calendar years respectively. Also, the proportion of total sales attributable to foreign manufacturers increased steadily to nearly 29 percent in calendar year 1982, despite the voluntary import restrictions assumed by the Japanese manufacturers in April 1981.

Largely as a result of changing consumer demand during this period, Chrysler has been flirting with bankruptcy and both Ford and GM have recorded record losses. To date, there does not appear to be any strong indications that the recent plight of the domestic automobile industry is improving.

The objective of the current work is to assess the consumer's demand for automobiles and the manner in which this demand has changed over time. Three aspects of consumer demand are critical to the analysis. First, the determination of whether or not consumer's valuations of vehicle attributes, such as fuel efficiency and capital costs, have changed over time will provide valuable insight into the underlying determinants of the current state of the vehicle market. Second, the estimation of existing consumer valuations of vehicle attributes will be useful in determining the financial viability of domestic automobile manufacturers. Finally, establishing the inherent preferences of consumers for specific makes of automobiles (e.g. Ford, GM, and so on) will be an important concern in assessing the recovery potential of specific automobile manufacturers.

To achieve these objectives, the current work derives and estimates, at the household level, dynamic econometric models of automobile demand that account for the household choices of vehicle quantity (number of vehicles to own), vehicle type (by make, model, and vintage), and vehicle utilization (vehicle miles of travel). These models are estimated with national data covering the time before, during, and after the June 1979 energy shock. Therefore, the empirical estimations will provide valuable information relating to the determinants of the current state of the U.S. automobile market. Moreover, the results will be useful in analyzing the future financial prospects of demestic manufacturers.

This thesis is organized in the following manner. Chapter 2 presents a critical review of previous automobile demand research. The objective of the chapter is to emphasize the inadequacies of previous work in addressing the household vehicle ownership decision-making process. In Chapter 3, two plausible theories of household vehicle ownership behavior are discussed and used as a basis to derive econometrically estimable models. Chapter 4 summarizes a number of data sources that are suitable for estimating the models derived in Chapter 3, and provides reasons for selecting and a description of the data actually used for model estimation. The empirical work is presented in Chapter 5 along with interpretations of the results. Finally, Chapter 6 summarizes the major findings of the work and provides insight into the future of the domestic automobile industry.

CHAPTER 2. CRITICAL REVIEW OF PREVIOUS RESEARCH

In recent years, a large number of vehicle related research efforts have been undertaken in an attempt to analyze particular issues relating to market behavior and to provide projections of future market conditions. The factors motivating past research efforts have varied considerably over the years, apparently in response to prevailing economic or regulatory conditions. The traditional motivation has been to provide information to the vehicle industry and government that relates to the demand for new vehicles and the effect of vehicle pricing policies on demand (see Richardson et al. (1979)). More recently, the motivating forces have expanded from new vehicle demand pricing issues to include concerns relating to air pollution and energy consumption (see Richardson et al. (1980, 1982)). The air pollution concerns evolved out of the government regulations of the late Sixties and early Seventies. Energy consumption became a relevant issue after the petroleum supply disruptions of 1973 and 1979 and the new vehicle fuel efficiency standards established by the government in the mid-Seventies.

Although the motivations of research efforts have varied noticeably, two underlying concerns have served as a focus for all vehicle market research: 1) vehicle demand and 2) vehicle usage. In this context, vehicle demand may be viewed as the types (make, model and vintage) and quantitities of vehicles entering and surviving in the national vehicle fleet, while vehicle usage relates to both the type (e.g. city, highway) and extent of vehicle use. Once vehicle demand

and usage concerns are determined, the issues discussed above can be readily addressed. In comparing various vehicle related research efforts, a distinction can be identified by considering the manner and extent to which the underlying concerns of vehicle demand and usage have been addressed.

At the household level (viewed here as the primary vehicle consumption unit) three aspects of vehicle demand and usage are vital to vehicle related research work. First, the level of household vehicle ownership (i.e., number of vehicles owned) is critical not only due to the shear quantity of vehicles owned, but also because vehicle replacement behavior, extent of vehicle specialization by type, and vehicle utilization behavior vary greatly with respect to ownership level. Second, there is strong theoretical evidence to suggest that households select vehicle types and extent of vehicle usage jointly. In this sense a household can be viewed as selecting vehicle types with some expectation of the extent of their future use. The jointness of the type and usage decisions is a vital aspect of vehicle demand and usage modeling. Finally, the dynamic behavior of household vehicle type and usage decisions is an important concern, since by their nature, household vehicle tastes (preferences for vehicle attributes) evolve over time as past decisions and future expectations affect current vehicle related choices.

In the following review, previous research will be categorized by modeling approach, and critiqued within the vehicle demand and usage framework described above.

2.1 Aggregate Models

Aggregate models have been the primary vehicle market modeling research approach for many years. Such models generally use time series data of aggregate vehicle sales, prices, and prevailing socio-economic conditions in the model calibration process; they do not explicitly address the household as the decision making unit, but instead consider the aggregate behavior of households.

The initial motivation, to provide new vehicle demand/pricing information to benefit industrial and governmental policy development, served as a catalyst for a number of pioneering aggregate research efforts. These pioneering works, which include Roos and Von Sozliski (1939), Farrell (1954), and Boulding (1955) led to the development of the classic stock adjustment model, which has served as a basis for much of the aggregate modeling work since the 1950's.

2.1.1 Stock Adjustment Models

Stock adjustment models represent an attempt to capture the dynamic aspects of vehicle choice at an aggregate level. The principle underlying the stock adjustment model is that at any given time some desired stock of vehicles exists; however, due to the transactions costs associated with entering the vehicle market, this desired stock is realized only gradually over time. This theory implies that due to transactions costs, households may not change their vehicle stocks at once even if they differ from desired stocks. In general stock adjustment models assume the following form:

$$X_t = k(S_t^* - S_{t-1}) + \delta S_{t-1}$$

where: X_t is the new vehicle demand in a specified period of time; S_{t-1} is the stock in the preceding time period; S_t^* is the desired stock and is a function of vehicle prices, socioeconomic conditions, and so on; δ is the rate of depreciation of old stock (i.e., δS_{t-1} represents replacement demand); and k is the adjustment coefficient representing the fraction of the desired change in ownership taking place in one time period.

Stock adjustment models were first applied to vehicle demand by Chow (1957), Nerlove (1957), and Brems (1957). These early works led to a series of research efforts that applied the same basic approach, such as the work of Suits (1958), Houthakker and Taylor (1970), Hamburger (1967), Evans (1969), Schaessler and Smith (1974), Westin (1975), and Eastwood and Anderson (1976).

Although classic stock adjustment models can be easily developed from reaily available data, they have a number of critical deficiencies. First, they do not account for the jointness of vehicle choice and utilization. Next, the behavioral difference associated with household ownership levels is not adequately addressed. Finally, their treatment of the dynamic aspects of household vehicle ownership (the evolution of vehicle related tastes) is restricted by the use of aggregate data and the limited time period over which such data were obtained.

2.1.2 Comprehensive Aggregate Models

As the factors motivating vehicle market research expanded to include issues related to energy consumption and air pollution, more elaborate models than the classic stock adjustment models were developed. Such comprehensive aggregate models generally had their theoretical foundation based on the stock adjustment approach, but were expanded to include vehicle demand by size class (aggregates of makes, models, and vintages), vehicle utilization, and vehicle scrappage rates by model year. Again aggregate time series data were used for estimation. Examples of comprehensive aggregate models include the works of Burright and Evans (1975), Whorf (1975), Kulash (1975), Schine and Loxley (1977), Wharton (1977), Cassella (1978), Luckey (1978) and Kendall (1978).

The basic deficiencies of the classic stock adjustment models translate directly to comprehensive aggregate models; inadequate consideration of behavioral differences by household vehicle ownership levels, non-existent or superficial treatment of the interrelationship between vehicle choice and utilization, and limited treatment of the dynamic aspects of changing consumer tastes.

2.2 Disaggregate Models

Disaggregate models of vehicle ownership, which are generally estimated with household level data, were developed to correct deficiencies observed in traditional stock adjustment based aggregate models. The use of disaggregate approaches corresponded roughly to the development of discrete choice modeling methods, which are the primary econometric techniques of disaggregate vehicle ownership modeling.

Existing disaggregate analyses are classified here into four categories; 1) household level of ownership models (i.e., number of vehicles owned), 2) household vehicle type choice models (i.e., make, model, and vintage), 3) vehicle utilization models, and 4) joint disaggregate models, that attempt to account for the interrelationships between level, type, and utilization. The major research works in each of these categories are reviewed below.

2.2.1 Household Level of Ownership Models

Level of ownership models were motivated, to a large extent by urban transportation modeling requirements imposed by federal mandates in the mid-1970's, and by energy consumption concerns. The major thrust of such modeling efforts has been to account for the different travel behavior exhibited by households at different vehicle ownership levels. Pioneering vehicle level choice models were concerned with estimating the probability of a household owning a specific number of vehicles. This was achieved by estimating the utility associated with various ownership levels. Such works generally utilized a discrete choice model of the multinomial logit form in which vehicle ownership level utilities were a function of such factors as automobile price, household income, and household travel accessibility. Examples of models of this type include those of Burns, Golob, and Nicolaidis (1976), and Golob and Burns (1978).

Subsequent vehicle ownership level models viewed the household decision of vehicle ownership to be determined jointly with other transportation related decisions. Examples of this include the joint work trip mode choice and vehicle ownership level model of Lerman and

Ben-Akiva (1976), and the joint location and type of residence, work trip mode choice and vehicle ownership level model of Lerman (1976). Both of these models were of the multinomial logit form. In later work, Train (1980) estimated a work trip mode choice and vehicle ownership level model along the same lines as the Lerman and Ben-Akiva work, but used a sequential logit model to alleviate possible "independence of irrelevant alternatives" (IIA) violations.

Unfortunately, the ownership level models, while overcoming the inability of traditional aggregate models to account for behavioral differences by household ownership level, still suffer from a number of major shortcomings. First, the models do not incorporate vehicle type (make, model, and vintage) information. Therefore, issues relating to vehicle type specialization by household level and subsequent energy and air pollution information that can be derived only from the characteristics of individual vehicle types (e.g., fuel efficiency, engine emissions), can not be assessed. Second, the lack of vehicle type consideration precludes evaluation of the joint relationship between vehicle type and utilization. Finally, the models are static, estimated with cross sectional data, and completely ignore the effect of changing tastes on household vehicle choice and usage decisions.

2.2.2 Household Vehicle Type Choice Models

Disaggregate type choice models were motivated by the need to determine specific components of vehicle demand so that the propagation of new vehicle technologies, such as high fuel efficiency vehicles, could be determined in the national vehicle fleet. In this regard, type choice models were developed to overcome some of the deficiencies of both aggregate stock adjustment models and disaggregate ownership level models by explicitly accounting for the vehicle type choice aspect of the household decision making process.

The earliest disaggregate type choice work was that of Lave and Train (1976, 1979), in which they estimate a multinomial logit model and provide for household choice among ten new vehicle classes (i.e. aggregates of make and model), conditioned on the fact that the purchase of a new vehicle is to be made. In subsequent work, Manski and Sherman (1980) estimate true type choice models in which households select specific makes, models, and vintages from both new and used vehicle market offerings. The model is of the multinomial logit form, and different type choice models were estimated for different ownership levels, in recognition of the behavioral differences among household ownership levels, as discussed earlier. Moreover, the Manski/Sherman model made an attempt to capture the dynamic behavior of household vehicle ownership by including a lagged dummy variable in the utility function of the vehicle types owned in the preceding time period. The model was estimated with cross sectional data that included information on household vehicle holdings and socioeconomic conditions. The attempt to capture dynamic behavior by inclusion of the lagged dummy variable has no theoretical justification and is not an appropriate method of addressing the evolution of household vehicle tastes. To assert that household tastes are determined only from the ownership of specific vehicle types is clearly a simplification of the process, as current and expected fuel costs and the characteristics of vehicles owned by the household can also be expected to influence tastes. Therefore, although the use of such dummy variables has been found to have substantial statistical significance, they are an imprecise measure of dynamic behavior.

Aside from this point, the Manski/Sherman model suffers from two additional weaknesses. First, the interaction between vehicle type choice and utilization is not taken into account. Since the choice of vehicle types is made jointly with use, the absence of a type choice/usage interaction is a serious limitation. Second, the manner in which multivehicle households are addressed is inadequate, as they deploy the concept of a composite vehicle (i.e., a fictitious vehicle comprised of the best attributes of the true household vehicle types), which has no theoretical justification. Moreover, the fact that multivehicle households account for over 80% of total household vehicle holdings in the United States (Mannering (1981)) makes the importance of proper theoretical treatment of the multivehicle household obvious.

In an attempt to overcome some of the deficiencies of the Manski and Sherman work, Berkovec and Rust (1981) estimate a nested logit model in which households are assumed to first select a class of vehicle type, and then a specific vehicle type within the class chosen. The work presents a theoretical framework for properly addressing vehicle type and usage interactions, but the empirical work does not consider this interaction. Moreover, Berkovec and Rust used the same theoretically questionable lagged dummy variable, as did Manski and Sherman, to account for the dynamics of household behavior. (Again, they had only cross sectional data with information on vehicle holdings in the preceding year). In summary, the Berkovec and Rust work, by its use of a sequential logit model as opposed to a single-level multinomial logit model, can be considered a statistical improvement over the Manski/Sherman models (as it alleviates some of the possible IIA violations), but not a theoretical improvement. Moreover, Berkovec and Rust only consider single vehicle households in their analysis, thereby providing no insight into the behavior of multivehicle households, which are the dominant sector in the U.S. market.

Whereas the Manski/Sherman and Berkovec/Rust models were structured such that the decision to acquire a car and the type of car acquired were considered jointly, the work of Hocherman, Prashker, and Ben-Akiva (1982) separate the two decisions with a nested logit structure. The Hocherman models were estimated with a 1978 cross-sectional sample of Israeli households. Due to the small percentage of multivehicle households in Israel, only single vehicle households were considered in the analysis. Statistically, the nested structure proposed by Hocherman appears to be an improvement over the Manski/Sherman structure, as a greater number of vehicle attributes were found to significantly influence the choice of vehicle type (make, model, and vintage). The shortcomings of the Hocherman model include the non-consideration of vehicle type and usage interactions and the theoretically questionable treatment of the dynamics of household vehicle ownership. Again, the treatment of dynamics in the Hocherman work is based on the lagged dummy variable approach used by Manski and Sherman, with the result being the same imprecise measure of changing tastes.

With a structure similar to that developed by Hocherman, Prashker, and Ben-Akiva, Hensher and Mansfield (1982) estimated a nested logit acquisition choice/type choice model using Australian data. Only three classes (aggregates of type) of vehicles were considered, and these were classified by vehicle fuel efficiency (i.e. low, medium, and high). Aside from this very limited choice of vehicle type, the treatment of dynamics was virtually non-existent as was the effect of: 1) the vehicle type and usage interactions and 2) the choice of ownership level.

2.2.3 Household Vehicle Utilization Models

Vehicle utilization models were motivated largely by the need to forecast energy consumption. Utilization models can be categorized into those based on the discrete choice of individual trips and those that view vehicle miles of travel as a continuous variable.

Classic examples of the discrete choice approach to vehicle utilization include the modeling systems developed by Cambridge Systematics (1976, 1979). These modeling systems were estimated with regional data samples (e.g. Washington, San Francisco). The determination of vehicle utilization (VMT) was derived from work trip and non-work trip modal choice models (e.g. choice of drive alone, shared ride, or transit) and non-work trip generation and destination choice models. Unfortunately, such a modeling approach is deficient in a number of important ways. First, the treatment of the interactions between vehicle ownership level, vehicle type, and vehicle utilization are virtually ignored. Next, the dynamic aspects influencing vehicle ownership and their impact on vehicle utilization are not addressed. Finally, such an approach does not assign utilization (VMT) to specific vehicles within multivehicle households. This last point is a potentially serious flaw since fuel consumption is a function of the extent to which specific vehicle types (make, model, and vintage) are used.

The modeling of vehicle miles of travel as a continuous variable at the household level has been undertaken by only a few researchers. An example of typical work in this area is the household VMT model estimated by Charles River Associates (1978). Unfortunately, the Charles River work suffers from the same weaknesses as the discrete choice approaches discussed above. In an effort to overcome some of the weaknesses of previous household vehicle utilization models, Mannering (1983) estimated a model of vehicle use in multivehicle households in which utilization was assigned to specific household vehicles. The model was estimated with national U.S. data collected during the months of September, October, and November, 1979, and an equation system was estimated to model the allocation of vehicle use to individual household vehicles. Although the model provides potentially useful insight into vehicle use in multivehicle households, the treatment of the interrelationships between level, type, and utilization are limited, and the dynamic aspects of vehicle ownership are not addressed.

2.2.4 Joint Disaggregate Models

In recognition of the fact that the household vehicle choices of level, type, and utilization are interrelated, a number of research efforts have attempted to explicitly account for these interrelationships. Perhaps the earliest work in this direction is the simultaneous number of cars, new or used car choice model of Johnson (1978). The Johnson specification was of the multinomial logit form and, although his definition of vehicle type was rather crude (new or used), the fact that the relationship between vehicle level and type was accounted for is significant. Johnson made no attempt to account for dynamic behavior.

In more recent work, Booz, Allen & Hamilton (1983) estimate a nested logit structure with choice of level and choice of type (make, model, and vintage). The type choice model follows that of Manski and Sherman (1980) and the level choices of zero, one, or two vehicles are considered. The Booz, Allen, & Hamilton specification indicated that the effect of type choice on level choice is minimal. This somewhat counterintuitive finding may be explained by a number of deficiencies in the model structure. First, vehicle utilization was incorrectly viewed as an exogenous variable in the type choice specifications. This of course should be treated as an endogenous variable and be explicitly modeled as such. Perhaps more importantly, the dynamic aspects of the vehicle ownership problem were virtually ignored in Booz, Allen & Hamilton work.

The only known work that attempts to account for all of the interactions between vehicle level, type, and utilization, is that of Train and Lohrer (1982). Their modeling system includes household choices of: 1) vehicle level for zero, one, and two vehicles, 2) vehicle type defined by classes (aggregates of make, model, and vintage), and 3) vehicle utilization (over a one-year period) of the chosen vehicle class in miles. Although the Train and Lohrer effort represents an advance in that the interrelationships between the critical aspects of household vehicle ownership are explicitly accounted for, the work suffers from two critical deficiencies. First, by considering only aggregates of vehicle makes, models, and vintages (classes), potentially rich information on vehicle attributes and vehicle brand preferences is ignored. Second, Train and Lohrer use the same dummy variable to capture the dynamics of vehicle ownership as did Manski and Sherman (1980) (i.e. in this case, one if the vehicle class was not owned in the preceding time period and zero otherwise). The faults of this approach to dynamics in a true type choice model (i.e. choice among makes, models, and vintages) have been discussed at length earlier. In a class choice model of the Train and Lohrer variety, this dummy variable approach to dynamics is even less valid since changes in the type (make, model, or vintage) of a vehicle owned within the same class is simply not accounted for in the model structure.

2.2.5 Summary of the Current Work

The objective of the research presented herein is to overcome what are thought to be the critical deficiencies of previous work undertaken in the automobile demand area. To achieve this, a disaggregate, household level modeling approach is used. It should be clear from the preceding literature review that a disaggregate approach offers many advantages, as opposed to traditional aggregate approaches, in terms of explaining underlying behavior. Also, the current research views the dynamic aspects of household vehicle ownership as the evolution of household tastes. From this view, estimable models are derived using appropriate economic theory relating to taste changes. Finally, explicit account is given to the interrelationships between the household choices of quantity of vehicles, vehicle type (make, model, and vintage), and vehicle utilization.

It is asserted that the current work, by addressing the weaknesses of previous automobile demand research, will provide valuable insight into household vehicle ownership behavior and to the financial viability of domestic automobile manufacturers.

CHAPTER 3. THEORETICAL MODELS OF HOUSEHOLD VEHICLE OWNERSHIP AND UTILIZATION

This chapter is comprised of four primary sections. In the first section, a general discussion of the household's vehicle ownership problem is given. The objective here is to present the reader with an intuitive sense of the dimensions of the household vehicle ownership decision. The following two sections are devoted to the development of alternate theories of household vehicle ownership behavior. Based on these theories, econometrically estimable models are derived. The final section describes econometric procedures that are used in the eventual estimation of the derived models.

3.1 The Household's Vehicle Ownership Problem

In general, household choices of vehicle quantity, vehicle type and vehicle utilization are made with the intent of achieving some optimal pattern of trip generating activities given three areas of concern: 1) socioeconomic factors, 2) exogenous economic conditions and 3) dynamic considerations. Socioeconomic factors comprise a broad range of characteristics, such as household income and household composition, that affect household activities and vehicle ownership needs. Exogenous economic conditions include the cost of petroleum products and vehicle prices in new and used car markets. The dynamic considerations of the household's vehicle ownership problem arise from the evolution of household tastes over time. This concept of changing household tastes, which has been virtually overlooked in previous automobile demand literature, forms the basis for the model derivations presented in this work.

Intuitively, taste changes can be expected to arise from a number of sources. In particular, households can be viewed as learning and collecting information from past experiences with a specific vehicle or make of vehicle, thereby forming a basis for taste changes. Other sources of taste changes include those resulting from advertising and the information collected from contact with other vehicle owners.

Although there is an abundance of economic literature that addresses the issue of accounting for taste changes in utility functions (see, for example, Peston (1967), Gorman (1967), Fisher and Shell (1969), Pollak and Wales (1969), Pollak (1970), Phlips (1972) and Lluch (1974)), essentially, two basic approaches have been used. The first approach was that used by both Peston (1967) and Gorman (1967). Their work considers utility functions of the form

$$U_t = A\, x_{1t}^{\beta_1}\, x_{2t}^{\beta_2} \tag{1}$$

where the x's represent quantities of the commodities that are consumed, and the A and β's are parameters. To introduce taste changes, the exponents in Equation (1) are permitted to be functions of time such that

$$U_t = A\, x_{1t}^{\beta_{it}}\, x_{2t}^{\beta_{2t}} \tag{2}$$

Under the assumption that the consumer is learning from past experiences, this approach adopts the following learning functions (see Peston (1967)):

$$\beta_{1t} = f\left(\frac{x_{1t-1}}{x_{2t-1}}\right)$$
$$\beta_{2t} = g\left(\frac{x_{1t-1}}{x_{2t-1}}\right) \tag{3}$$

where the subscripts t-1 denote consumption in the preceding time period. Although this approach has the advantage of explicitly accounting for taste changes, it suffers from the fact that the functional form used makes the derivation of estimable commodity demand equations exceedingly difficult, if not impossible.

With limitations of the Peston type taste change formulation in mind, a more fruitful approach was developed and applied by Fisher and Shell (1969), Pollak and Wales (1969), and Pollak (1970). The starting point for this approach is to consider utility functions of the following form

$$U_t = \sum_{i=1}^{n} a_i \log (x_{it} - b_{it}), \tag{4}$$

where the x_i's represent quantities of the commodities that are consumed and a_i and b_{it} denote parameters, with the latter controlling for taste changes over time. In this regard, the taste change parameter b_{it} can be any function of time or past consumption. Unlike the Peston type taste change formulation, accounting for taste changes in the manner implied by Equation (4) permits the derivation of dynamic commodity demand equations with relative ease (see Pollak and Wales (1969) and Pollak (1970)). For this reason, the analysis of vehicle ownership in this study follows from the idea expressed in Equation (4).

To incorporate taste changes in the case of household vehicle ownership, the current analysis assumes that such changes are determined solely by past decisions. Specifically, it is assumed that taste changes are determined by the past utilization of specific vehicles operated by the household. This implies that the household can be viewed as developing "habits" of vehicle ownership based on its past experiences with specific vehicles (i.e. extent of utilization). If a state variable is defined, S_{it}, that summarizes past utilization relevant to vehicle i at time t, then taste changes can be introduced into the functional form of Equation (4) by the simple linear expression

$$b_{it} = \theta_i + \alpha_i S_{it}. \tag{5}$$

where θ_i and α_i are parameters. The precise definition of the state variable, along with the development of alternative dynamic vehicle ownership models that account for taste changes, is given in the next section.

3.2 The Restricted Dynamic Model

The restricted dynamic model permits households to consider the effects of past behavior on current tastes but assumes that they do not consider the effect that current consumption will have on future utility. This somewhat unrealistic assumption will be relaxed later with the intertemporal dynamic model, but the cost of this relaxation in terms of additional limitations that must be imposed on the decision making process will be shown to be high.

In the development of the restricted dynamic model, a four-step procedure is used in which the household's choices of vehicle quantity, vehicle type, and vehicle utilization are viewed as contemporaneous. The procedure begins by specifying a dynamic utilization equation which is then transformed to be measurable in all variables. Using the derived dynamic utilization equation, Roy's Identity is applied to recover the corresponding indirect utility function. Finally, a dynamic discrete choice model of vehicle quantity and vehicle type is obtained from the indirect utility function

3.2.1. The Dynamic Utilization Equation

To develop appropriate household vehicle ownership models, taste changes are incorporated directly into the demand equation (in this case the utilization equation) as opposed to the more traditional method described earlier of first incorporating taste changes in the direct utility function and then deriving the corresponding demand equations. The advantages of addressing taste changes in this manner will become apparent as the model derivations are presented.

To begin, consider a household selecting only one vehicle from the set of available vehicle types (make, model, and vintage). The multivehicle ownership case will be addressed later. If it is assumed that taste changes are determined by previous choices only, then the dynamic utilization equation can be written as

$$x_{it} = \tau_i + \beta_i (I_t - C_{it}) + \alpha_i S_{it}, \tag{6}$$

where x_{it} is the rate of utilization of vehicle i, I_t is the rate of income, C_{it} is the rate of vehicle operating cost, S_{it} is the state variable at time t, and τ_i, β_i, and α_i are parameters. Recall that the state variable is intended to "summarize" past utilization relevant to vehicle i. Consequently, it is not measurable in the traditional sense and therefore must be eliminated from the utilization equation in order for this equation to be estimable.

To eliminate the state variable from Equation (6), consider the accounting relationship (at any time t) for variable i

$$\frac{\partial S_i}{\partial t} = \dot{S}_{it} = J_{it} - \delta_i S_{it}, \tag{7}$$

where J_{it} is the gross addition of utilization from vehicle choices, and δ_i is a constant rate of depreciation of S_{it} (i.e. the depreciation of past experiences with the vehicle i). In this analysis, J_{it} is defined to be a linear function of the utilization of vehicle i, and the utilization of vehicles of the same make as vehicle i. These latter variables capture the notion of transference of ownership experience between vehicles of the same make (i.e. brand loyalty). Thus, J_{it} can be defined as

$$J_{it} = ax_{it} + cx'_{it} , \tag{8}$$

where x_{it} is the utilization of vehicle i, x'_{it} is the utilization of a vehicle (not including vehicle i) that is the same make as vehicle i.

Given this definition, note that the general solution to Equation (7) is

$$S_{it} = \int_{-\infty}^{t} J_{it}(u)\, e^{\delta_i (u-t)}\, du. \tag{9}$$

This indicates that the state variable at any time t is equal to the sum of the discounted experiences (as defined by Equation (8)) of vehicle i.

Given the above relationships, it is desirable for estimation purposes to transform Equation (6) into a discrete time framework. Thus, Equation (6) is redefined for vehicle i as

$$x_{it} = \tau_i + \beta_i (I_t - C_{it}) + \alpha_i \bar{S}_{it}, \tag{10}$$

where x_{it} is the accumulated utilization of vehicle i over the discrete time interval, I_t is the interval household income, C_{it} is the interval cost of operating vehicle i, τ_i, β_i, and α_i are parameters, and $\bar{S}_{it}$ is defined as the mean value of the state variable over the time interval.

Attention can now be given to removing $\bar{S}_{it}$, which is not measurable, from Equation (10). The procedure that is used to do this is somewhat tedious, and therefore is presented in Appendix A. As shown in this appendix, the transformed equation can be written as

$$x_{it} = A_{io} + A_{i1} x_{it-1} + A_{i2} \lambda_{it} + A_{i3} \lambda_{it-1} + A_{i4} x'_{it-1}, \tag{11}$$

where the A_i's are parameters, $\lambda_{it} = I_t - C_{it}$, and all other variables are as defined previously. Note that this equation is a dynamic equation of vehicle utilization that is measurable in all variables, since the unmeasurable state variable has been removed.

3.2.2. Derivation of the Indirect Utility Function

Given the dynamic utilization equation specified above, it is possible to derive the corresponding dynamic indirect utility function implied by Roy's Identity. That is

$$\frac{\partial V_{it}}{\partial I_t} x_{it} + \frac{\partial V_{it}}{\partial p_{it}} = 0, \tag{12}$$

where V_{it} is the dynamic indirect utility function and p_{it} is the unit price of vehicle utilization. Now, define the operating cost of vehicle ownership as

$$C_{it} = \pi r_{it} p_{it}, \tag{13}$$

where r_{it} is the typical vehicle utilization of vehicle i in period t, and π is a parameter. Thus, using Equations (11), (12), and (13), it can be shown (see, for example, Hausman (1981)) that the indirect utility function is of the form

$$\begin{aligned} V_{it} = \quad & [A_{io} - \pi r_{it} + A_{i1} x_{it-1} + A_{i2}(I_t - C_{it}) \\ & + A_{i3}(I_{t-1} - C_{it-1}) + A_{i4}\, x'_{it-1}]\, e^{-A_{i2} p_{it}}. \end{aligned} \tag{14}$$

3.2.3 Dynamic Discrete Choice Model of Vehicle Quantity and Vehicle Type

The derivation provided above is valid for households that choose to own one vehicle. The analysis is now extended to include multi-vehicle ownership choice.

It is assumed that households choose the quantity of vehicles to own, n, and the type of vehicle to own, i, such that their indirect utility functions are maximized. That is, a household will select n' vehicles of type i'_n (i.e. make, model, and vintage of each of the n' vehicles)

$$\text{iff} \quad V_{n'i'_n} \geq V_{ni_n} \; \forall \; n, i_n . \tag{15}$$

The probability of selecting n' and i'_n is

$$P_{n'i'_n} = \text{Prob}[V_{n'i'_n} \geq V_{ni_n} \; \forall \; n, i_n]. \tag{16}$$

Decomposing the indrect utility function into a systematic component, $\bar{V}_{ni_n}$, and a random component, ε_{ni_n}, such that

$$V_{ni_n} = \bar{V}_{ni_n} + \varepsilon_{ni_n} , \tag{17}$$

and assuming that $\varepsilon_{ni_n} \; \forall \; n, i_n$ are jointly distributed with a generalized extreme value distribution, we can obtain a nested or sequential logit model such that

$$P_{n'i'_n} = P_{n'} \cdot P_{i'_n|n'} , \quad (18)$$

where $P_{n'}$ is the marginal probability of n' vehicles being selected, and $P_{i'_n|n'}$ is the probability of a vehicle type being selected conditional on n'. As shown by McFadden (1979) these probabilities can be written as

$$P_{n'} = \frac{e^{\left[\bar{V}_{n'} + \zeta L_{n'}\right]}}{\sum_n e^{\left[\bar{V}_n + \zeta L_n\right]}} , \quad (19)$$

$$P_{i'_n|n} = \frac{e^{\bar{V}_{i'_n|n}}}{\sum_n e^{\bar{V}_{i_n|n}}} , \quad (20)$$

where $\bar{V}_{n'}$, the mean indirect utility, varies only over n, and $\bar{V}_{i'_n|n}$ varies over n and i_n, ζ is a parameter, and L_n is the inclusive value.

Given the above relationships, all that remains is to specify the functional form of the indirect utility function. In this study, we are forced for empirical reasons to consider only one and two vehicle households. The appropriate indirect utility function for the one vehicle household is given by Equation (14). In the case of a two-vehicle household, the operating costs of its vehicle portfolio i are defined as:

$$C''_{it} = r_{it}\, \pi_i\, p^1_{it} + r_{it} \pi_i\, p^2_{it}, \quad (21)$$

where p^1_{it} and p^2_{it} are the operating costs of vehicle 1 and 2 respectively, in vehicle portfolio i, r_{it} is the typical utilization of each vehicle in the portfolio, and π_i is a parameter. Thus, it can be shown that the indirect utility function for portfolio i is:

$$V_{it} = [A_{io} - \pi_i r_{it} + A_{i1}x^T_{it-1} + A_{i2}(I_t - C''_{it}) + A_{i3}(I_{t-1} - C''_{it-1}) + A_{i4} x^{T'}_{it-1}] e^{-A_{i2}(p^1_{it}+p^2_{it})}, \quad (22)$$

where the superscript T represents the combination of vehicles comprising portfolio i. The dynamic utilization equations corresponding to this indirect utility function (i.e. Equation (22)) are of the form

$$x^m_t = A_{io} + A_{i1}x^T_{it-1} + A_{i2}(I_t - C''_{it}) + A_{i3}(I_{t-1} - C''_{it-1}) + A_{i4} x^{T'}_{it-1}, \; m=1,2. \quad (23)$$

For the restricted dynamic case, the complete system of equations describing the household's choice of vehicle quantity, vehicle type, and vehicle utilization are now defined. The structure of the actual estimable forms of these equations will be given in a later section.

3.3 The Intertemporal Dynamic Model

The intertemporal approach differs from the restricted dynamic approach in that households are now assumed to consider the effects of current consumption on future utility. This implies that households take into account the effect that current consumption will have on future taste changes. Hence, the intertemporal model is based on a substantially different and somewhat more realistic decision making process than that upon which the restricted dynamic model is based. The unfortunate disadvantage of the intertemporal model is that a number of strong assumptions must be made to arrive at tractable results. These assumptions and the complete derivation of the intertemporal dynamic model are presented below.

3.3.1 The Utility Functional

The objective here is to derive models that can be empirically evaluated. To achieve this, it is necessary to define an intertemporal utility function that is the sum of present and future instantaneous utilities (i.e. utilities at any point in time). In reducing the intertemporal utility to a sum of instantaneous utilities, it is imperative that the postulates set forth by Koopmans (1960) be discussed. To begin, Koopmans' notation is adopted by defining a sequence of commodity purchases over time as a program and denoting it.

$$ {}_1x = (x_1, x_2, x_3 \ldots x_4 \ldots) = (x_1, {}_2x) = \ldots \qquad (24) $$

where x's are consumption vectors and the subscripts 1, 2, 3, ... refer to discrete time periods. Note that Equation (24) implies that each program is assumed to extend over an infinite future. In the case of household vehicle ownership, the infinite future assumption may not be entirely unrealistic since households tend to survive from generation to generation.

Using the above notation, the previously stated objective is to define a utility function for all possible programs (i.e. for all ${}_1x$), such that this utility, $U({}_1x)$ is a simple function of the instantaneous utilities $u_1(x_1)$, $u_2(x_2)$, ..., $u_t(x_t)$. To achieve this, the following four postulates must be accepted (see Koopmans (1960) and Koopmans, Diamond, and Williamson (1964)),

P1 (Existence and Continuity): There exists a continuous utility function $U({}_1x)$, which is defined for all ${}_1x = (x_1, x_2, \ldots)$ such that, for all t, x_t is a point of a bounded convex X of the n dimensional commodity space.

A detailed discssion on the existence and continuity postulate is presented in Koopmans (1960).

P2 (Sensitivity): There exist first period consumption vectors x_1, x_1' and a program ${}_2x$ from the second period on, such that

$$U(x_1, {}_2x) > U(x_1', {}_2x).$$

This postulate requires utility to be changed when consumption is changed in some specified time period. This postulate excludes the possibility that a consumer attaches utility only to a consumption level exceeding some minimum value. Thus, both postulates P1 and P2 are not very restrictive or unrealistic.

P3 (Limited Noncomplementarity) for all x_1, x_1', ${}_2x$, ${}_2x'$

(P3a) $U(x_1, {}_2x) \geqq U(x_1', {}_2x)$ implies $U(x_1, {}_2x') \geq U(x_1', {}_2x')$

(P3b) $U(x_1, {}_2x) \geq U(x_1, {}_2x')$ implies $U(x_1', {}_2x) \geq U(x_1', {}_2x')$

P3a states that different consumption programs undertaken after the first period do not affect consumption preferences in the first period. P3b states that different consumption patterns in the first period do not affect the preference orderings comsumption programs considered from the second period onward. Postulate P3 is not terribly relaistic since there is no reason to believe that the complementarity of goods does not extend over more than one time period. In the case of vehicle ownership modeling, with notions of brand loyalty considered, it is clear that this postulate does not have a high degree of realism. Nevertheless, acceptance of P3 is critical since the intertemporal utility function can be written as

$$U({}_1x) = V(u_1(x_1), U_2({}_2x)) \tag{25}$$

where $V(u_1, U_2)$ is a continuous and increasing function of the instantaneous utility function at time t=1 (u_1), and the intertemporal utility function associated with all consumption sequences starting from period t=2 ($U_2({}_2x)$). In order for Equation (25) to become useful in the derivation of the intertemporal model, it is necessary to drop the time subscripts from the instantaneous and intertemporal utility functions thereby writing Equation (25) as

$$U({}_1x) = V(u(x_1), U({}_2x)) \tag{26}$$

To achieve the transformation from Equation (25) to Equation (26), the following postulate must be accepted.

P4 (Stationarity): For a given x_1 and all ${}_2x$, ${}_2x'$,
$U(x_1, {}_2x) \geqq U(x_1, {}_2x')$ iff $U({}_2x) \geqq U({}_2x')$

The implication of this postulate is that the passage of time is not permitted to have an effect on preferences. Koopmans, Diamond and Williamson (1964) provide the following clarifications of this postulate. P4 states that for some x_1 and all ${}_2x$, ${}_2x'$, program A (see below) is at least as good as program B if and only if program C is at least as good as program D where:

Program	Period 1	2	3	4
A	x_1	x_2	x_3	x_4 ...
B	x_1	x_2'	x_3'	x_4' ...
C	x_2	x_3	x_4	......
D	x_2'	x_3'	x_4'	......

In words, the orderings of programs differing only from the second period onward will not be affected by advancing the timing of such programs by one period. Similarly, the postponement of programs will not affect existing ordering providing common consumption vectors are used to fill interim time periods. The proof of how P4 permits Equations (25) to be transformed into Equation (26) is given elsewhere (see Phlips (1974)).

The reader is referred to Koopmans (1960) and Koopmans, Diamond, and Williamson (1964) for additional technical details regarding the postulates described above. What is important to this study is that the acceptance of the Koopmans postulates permits the recursive intertemporal utility function, Equation (26), to be written. As an additional point, note that the iterative application of Equation (26) gives

$$U({}_1x) = V(u(x_1), u(x_2), \ldots, u(x_t), U({}_{t+1}x)) \qquad (27)$$

where the functions $u(x_1)$ $u(x_2)$, ... represent instantaneous utility levels associated with a program, ${}_1x$.

Ultimately, to derive an intertemporal model of household vehicle ownership, it is desirable to have an intertemporal utility functional, in continuous time, of the form,

$$U({}_1x) = \int_0^\infty e^{-\gamma t} u_t(x(t))\, dt \qquad (28)$$

This equation implies that the intertemporal utility function is defined as a discounted sum of all future one-period instantaneous utilities. To arrive at Equation (28), the major restriction of "additivity" over time must be added to the four postulates described earlier. This restriction, of course, implies that the marginal rate of substitution between two adjacent periods is independent of future period decisions. It is clear that additivity is a very strong restriction.

Finally, the discount function appearing in Equation (28) captures the notion of "impatience", which is the preference for advanced timing of consumption. The fact that the discount function assumes the form $e^{-\gamma t}$ where γ is constant over time, is tied to the work of Strotz (1956). Strotz has shown that a consistent planner must substitute for his true discount function (which may assume any form), a discount function whose rate of change over time is constant, before maximizing his intertemporal utility. Although the Strotz result is powerful in that it provides a utility functional that lends itself to the development of tractable models, there are reasons to suspect that the strategy of consistent planning is never entirely achieved.

The primary reason is that Strotz's derivations assume that future events are known with certainty. If in fact the planner's expectations of future satisfactions are not realized, the use of a constant discount function will not be valid. Moreover, even if all expectations were realized, the possibility that impatience may change over time will result in a γ that varies.

As the postulates and other assumptions discussed in this section indicate, the price of obtaining a utility functional of the form indicated in Equation (28) is high in terms of the restrictions that must be imposed. However, with these restrictions accepted, it will be shown in the following section that an intertemporal model of vehicle quantity, type, and utilization choice can be readily derived.

3.3.2 The Intertemporal Model and the Maximum Principle

The intertemporal nature of the household's vehicle ownership problem lends itself to dynamic optimization techniques and in particular the Maximum Principle. To illustrate this, the household's optimization problem can be viewed as consisting of the maximization of its present discounted value of utility

$$\text{Max } U = \int_0^\infty u(S,x)e^{-\gamma t}\, dt, \tag{29}$$

where $u(S,x)$ is the time invariant instantaneous utility function, x denotes vehicle utilization, S is a state variable as defined in the restricted dynamic model, and γ is the discount rate. This equation follows from Equation (28), with all the restrictions necessary to write that equation, applying. In determining an optimal vehicle ownership program for the household, the Maximum Principle will provide the necessary conditions. Specifically, the household's vehicle ownership problem can be formulated in terms of a Hamiltonian as

$$\max H(S, x, \psi, y, z) = u(S,x) + \psi\dot{S} + yf(x,z), \qquad (30)$$

where ψ is a costate variable, $\dot{S}$ is the time rate of change in the state variable, f denotes a vector of equations of motion, y denotes a vector of costate variables that correspond to f, and z is a vector of other state variables that relate to the vehicle ownership decision (for example, household wealth). The economic interpretation of the Hamiltonian is simply the current flow of utility from all sources, including those realized immediately, $u(S,x)$, and those anticipated, $\psi\dot{S} + yf(x,z)$.

Unfortunately, solving the household's intertemporal vehicle ownership problem by direct maximization of the Hamiltonian is exceedingly difficult if not impossible. Therefore, an indirect procedure that parallels the procedure used in the derivation of the restricted dynamic model, is followed. That is, an intertemporal dynamic utilization equation is specified and then transformed so that all independent variables are measurable. The resulting equation is used with Roy's Identity to derive a corresponding intertemporal indirect utility function. Finally, the indirect utility function is used to derive a dynamic intertemporal discrete choice model of vehicle quantity and vehicle type.

To begin, the intertemporal dynamic utilization equation is specified as

$$x_{it} = \tau_i + \beta_i(I_t - C_{it}) + \alpha_i S_{it} + \omega_i \psi_{it}, \tag{31}$$

where ψ_{it} is the Hamiltonian costate variable as defined in Equation (30), ω_i is a parameter, and all other variables are as defined for the restricted dynamic model. The economic interpretation of ψ_{it} is that it is the implicit value attached to a marginal unit of the state variable S_{it}. The inclusion of ψ_{it} distinguishes the intertemporal from the restricted dynamic utilization equation in that now, in the intertemporal case, the effect that current consumption has on future utility is entered into the household's optimization problem. This point will become clearer below.

It should be noted that Equation (31) has two unmeasurable variables, ψ_{it} and S_{it}. The state variable, S_{it}, can be eliminated from the equation by the method used in the restricted dynamic model derivation, while an analogous procedure can be used to eliminate ψ_{it}. Specifically, elimination of ψ_{it} can be achieved by beginning with the canonical equation for maximization of the Hamiltonian (for each t),

$$\dot{\psi}_i = \gamma\psi_i - \frac{\partial H}{\partial S_i}, \tag{32}$$

or (from Equation (30))

$$\dot{\psi}_i = \gamma\psi_i - \frac{\partial u}{\partial S_i} + \psi_i \frac{\partial \dot{S}_i}{\partial S_i} \quad . \tag{33}$$

Differentiating Equation (7) with respect to S_i and substituting the result into Equation (33) yields

$$\dot{\psi}_i = (\gamma + \delta_i)\psi_i - \frac{\partial u}{\partial S_i} \quad . \tag{34}$$

To proceed further, it is necessary to specify a functional form for the time invariant instantaneous utility function, u. A convenient functional form in this regard, due to its linear first order derivatives, is a quadratic specification. Therefore, if the instantaneous utility function is defined as

$$u(x,s) = \tilde{a}'x + \tilde{b}'S + \frac{1}{2}x'\tilde{A}x + x'BS + \frac{1}{2}S'\tilde{c}S \tag{35}$$

then Equation (34) can be written as

$$\dot{\psi}_{it} = (\gamma + \delta_i)\psi_{it} - (\tilde{b} + \tilde{c}S_{it} + Bx_{it}), \tag{36}$$

where $\tilde{b}$, $\tilde{c}$, and $\tilde{B}$ are parameters and the time subscript has been reintroduced. Using Equations (7), (31), and (36), a dynamic intertemporal utilization equation can be derived without the state and associated Hamiltonian costate variables. As shown in Appendix B, the resulting intertemporal utilization equation is

$$\begin{aligned} x_{it} = {} & A_{io} + A_{i1}x_{it-2} + A_{i2}x_{it-1} + A_{i3}\lambda_{it-2} \\ & + A_{i4}\lambda_{it-1} + A_{i5}\lambda_{it} + A_{i6}x'_{it-2} + A_{i7}x'_{it-1} , \end{aligned} \tag{37}$$

where A_i's are functions of the structural parameters, and all other terms are as previously defined. In comparing this utilization equation with the restricted dynamic utilization equation, the major empirical distinction is that this equation contains variables that are lagged over both one and two time periods. This is true despite the fact that the initial behavioral postulates set forth to derive these equations were quite different.

Given Equation (37), the derivation of the intertemporal indirect utility function and the complete model of vehicle quantity type, and utilization consists of a straightforward application of the procedures used to derive the restricted dynamic system.

3.4 Estimable Models and Econometric Procedures

In this section, estimable forms of the equations derived in Sections 3.2 and 3.3 are presented along with a description of appropriate econometric estimation procedures. To begin, consider the following stochastic indirect utility function which is based on the restricted dynamic model Equations (14) and (22). For one vehicle:

$$V_{1i_1} = [A_{1io} - \pi_{1i} r_{1it} + A_{1i1} x_{it-1} + A_{1i2}(I_t - C_{it})$$

$$+ A_{1i3}(I_{t-1} - C_{it-1}) + A_{1i4} x'_{it-1} + Z'\theta_1 + \nu_{1t}] e^{-A_{1i2} P_{it}} + Y'_{1i_I} \Omega_{i1} + \varepsilon_{1i_1 t},$$

for two vehicles: (38)

$$V_{2i_2} = [A_{2io} - \pi_{2i} r_{2it} + A_{2i1} x^{T}_{it-1} + A_{2i2}(I_t - C''_{it}) + A_{2i3}(I_{t-1} - C''_{it-1}) + A_{2i4} x^{T'}_{it-1} + Z'\theta_2 + \nu_{2t}]\, e^{-A_{2i2}(p^1_{it} + p^2_{it})} + Y'_{2i_2}\Omega_{i2} + \varepsilon_{2i_2 t} ,$$

where Z is a vector of household characteristics believed to influence vehicle ownership decisions; θ is a vector of estimable parameters; ν's are unobserved household characteristics; Y_{1i_1} and Y_{2i_2} are vectors of observable household and vehicle characteristics influencing vehicle ownership decisions; Ω_{i1} and Ω_{i2} are parameter vectors; ε_{1i_1t} and ε_{2i_2t} are unobserved vehicle attributes; and all other variables are as previously defined.

Under the assumption that the ε_{1i_1}'s and ε_{2i_2}'s are jointly distributed with a generalized extreme value distribution, it can be shown that the models of level choice and type choice given in Equations (19) and (20) respectively are based on individual household maximization of the indirect utility function given above. Applying Roy's Identity to Equation (38), the stochastic utilization equations are of the form:

$$x_{it} = A_{1io} + A_{1i1} x_{it-1} + A_{1i2}(I_t - C_{it}) + A_{1i3}(I_{t-1} - C_{it-1}) + A_{1i4} x'_{it-1} + Z'\theta_1 + \nu_{1t} \quad (39)$$

for one vehicle, and

$$x_{it}^{m} = A_{2io} + A_{2i1}x_{it-1}^{T} + A_{2i2}(I_t - C''_{it})$$

$$+A_{2i3}\ (I_{t-1} - C''_{it-1}) + A_{2i4}x_{it-1}^{T'} \qquad (40)$$

$$+ Z'\theta_2 + \nu_{2t}$$

for two vehicles, m = 1,2,

where all other variables are as previously defined.

Stochastic estimable equations for the intertemporal model are achieved by the same procedure as the one outlined above.

Note that the modeling system consisting of Equations (19), (20), (39) and (40) constitute a discrete/continuous model of vehicle quantity, type, and utilization choice. The econometric consequences of a discrete/continuous model structure have been the subject of considerable research in recent years. Initial theoretical contributions in this area include those of Heckman (1976, 1978, 1979). More recent theoretical and empirical contributions include those of Hay (1980), Dubin and McFadden (1981), and McFadden and Winston (1981). In the modeling system presented above, the discrete/continuous structure is an issue in the estimation of Equations (39) and (40), since a statistical correlation between vehicle specific attributes and the additive error terms in the dynamic utilization equations will be present. Intuitively, some correlation can be expected to exist between unobservables affecting vehicle type choice and those affecting utilization. For example, the unobserved effects that tend to increase usage (e.g. pleasure of driving) will adversely affect the probability of selecting an old, decrepit vehicle from which little driving pleasure can be derived. Similarly, the unobserved effects that increase the utility of selecting a newer model vehicle (e.g. the need for vehicle reliability) may increase the extent to which is is used. Such correlation implies that ordinary least squares will lead to biased and to inconsistent estimates of the utilization equation parameters. To alleviate this problem, consider, for example, a rewritten form of the one-vehicle restricted dynamic utilization equation (Equation (39)) conditioning on the choice of vehicle type i,

$$x_t = A_{1o} + A_{11}\sum_{k=1}^{n} x_{kt-1}\phi_{kit} + A_{12}I_t - A_{12}\sum_{k=1}^{n}\pi_1 r_{kt}p_{kt}\phi_{kit}$$

$$+ A_{13}I_{t-1} - A_{13}\sum_{k=1}^{n}\pi_1 r_{kt-1}p_{kt-1}\phi_{kit} + A_{14}\sum_{k=1}^{n}x'_{kt-1}\phi_{kit} + Z'\theta + \nu_t, \qquad (41)$$

where n is the total number of vehicle types in the choice set; ϕ_{kit} is a dummy variable which is one when k=i and zero otherwise.

To obtain consistent estimates of this equation in the current study, the choice dummies (ϕ_{kit}) in Equation (41) are replaced by the estimated probabilities from the discrete choice type models, $\hat{P}_{it}$. This method of addressing the endogeneity of vehicle type attributes in the utilization equations (again, resulting from the discrete/continuous model structure) was first proposed by Dubin and McFadden (1981).

Another issue that is of concern to the econometric estimation of the proposed modeling system is the possible presence of serial correlation. Should serial correlation of error terms exist, then the $\hat{P}_{it}$ used in the estimation of the utilization equation will be correlated with the additive error term, since $\hat{P}_{it}$ is influenced by lagged utilization. Also, the lagged utilizations used as explanatory variables in the utilization equation will be correlated with the error term. A solution to this problem would be to regress $\hat{P}_{it}$ and x_{it-1} on exogenous variables thereby enabling least squares estimation of the utilization equation, which will now include $\hat{\hat{P}}_{it}$ and $\hat{x}_{it-1}$, to produce consistent parameter estimates. Unfortunately, this procedure is not feasible in the analysis undertaken in this study due to the exceptionally large number of vehicle type alternatives (i's).

As a further complication, accounting for serial correlation in the presence of lagged endogenous variables in the discrete choice model of vehicle type is exceedingly difficult. Although theoretical work in this area has been undertaken by Heckman (1981), only a simple binary probit discrete choice model has been considered. Moreover, Heckman's work indicates that the treatment of serial correlation in the presence of a lagged endogenous variable in a dynamic discrete choice context requires an approximation of initial conditions, which in the vehicle ownership case is an impossible data requirement. In any event, extensions of Heckman's work to a multinomial logit structure such as the one proposed here are likely to be extremely difficult.

As a result of the difficulties in addressing the serial correlation problem, the current study is forced to assume that disturbances are serially independent. It should be pointed out, however, that reasonable general arguments can be made to support the validity of this assumption. For example, Pollak and Wales (1969) argue that there is no reason to assume serial correlation in models which depend on consumption in previous periods. Their argument is based on the fact that serial correlation can be expected, for example, if a higher level of consumption of a good yesterday is associated with a higher level of consumption today. However, if lagged consumption is included in the model, then this relationship is captured since a higher level of yesterday's error term implies a higher level of yesterday's consumption, which in turn implies a higher value of lagged consumption is used to predict today's consumption. Consequently, the effects of serial correlation are negated.

A final point relates to the estimation of the discrete type choice model. In this analysis, the type of vehicle is defined by make (e.g. Ford), model (e.g. Mustang), and vintage (e.g. 1967). With this definition, the household theoretically has thousands of choices available, and if every one was included in the estimation, the computational burden would be excessive. Fortunately, the choice of assuming the disturbances of the discrete choice model to be jointly distributed with a generalized extreme value distribution permits consistent estimation of parameters using a sub-sample of the available choice set (see McFadden (1978)). A number of empirical tests relating to the suitability of the assumed logit type choice structure are presented in Chapter 5.

CHAPTER 4. COMPARATIVE ANALYSIS OF AVAILBLE DISAGGREGATE DATA

In the U.S. context, a number of household level data sources can be used in estimating models of the household vehicle ownership decisions of quantity, type, and utilization of vehicles. This chapter first classifies such data sources into cross-sectional and panel data, and presents an overview and qualitative discussion relating to their usefulness as a basis for household vehicle ownership modeling. Next, a discussion of vehicle type attribute files is presented. Such files are used to complement household data and they include information on different vehicle makes, models, and vintages (e.g. 1974 Ford Pinto), such as price, horsepower, luggage capacity, seating capacity, and other attributes that may influence vehicle ownership choices. Finally, the chapter concludes with a brief discussion of the data used in the empirical analysis undertaken in this work.

4.1 Cross-Sectional Household Data

A summary of the characteristics of four major cross-sectional household level data sources is presented in Table 1. The following paragraphs present a discussion of these sources.

Perhaps one of the first data sources suitable for household vehicle ownership modeling was the data collected by the Survey Research Center (SRC) during the winter of 1976. Incidently, this national random sample of 1200 households was used in the estimation of the Manski and Sherman (1980) vehicle type choice models. The data is one of the earliest known samples to include information on the model year of each vehicle currently held, along with a code indicating manufacturer (make)

Table 1. Summary of Household Level Data Sources

		Cross-Sectional		
	SRC	NPTS	NTS	NIECS
Sample Size	1200	17949	1095	4081
Collection Dates	Winter '76	Apr.'77 to Mar.'78	May/June '78	Nov/Dec '78
Sample Type	National Random	National Random	National Random	National Random
Information				
A. Socio Economic				
1. Income	X	X	X	X
2. Family Size	X	X	X	X
3. Ages of Members	X	X	X	X
4. Education of Members	X	X	X	X
5. Employment Status of Members	X	X	X	X
6. Sex of Members	X	X	X	X
7. Geographic Location	X	X	X	X
B. Vehicle Related				
a) Vehicles Owned at time of Collection				
1. Model Year	X	X	X	X
2. Make	X	X	X	X
3. Model	X*	X	X	X
4. Utilization (VMT)	X	X	X	X
5. Vehicle Options (e.g. No. of cylinders)	X	X	X	X
6. Vehicle Purchase Date		X	X	X
b) Vehicles Owned one Year Prior to Collection				
1. Model Year			X	X
2. Make			X	X
3. Model			X	X

Table continued next page

* See Text

Table 1 (Continued)

		SRC	NPTS	NTS	NIECS
4.	Utilization (VMT)			X	X
5.	Vehicle Options (e.g. No. of cylinders)			X	X
6.	Vehicle Purchase Date				X

(Table 1 continued on next page)

Table 1 (Continued)

	Panel	
	HTP	SIME/DIME
Sample Size	*	4800
Collection Dates	June '79 to Dec. '80	1970 - 78
Sample Type	National Random	Low Income Seattle/Denver
Information		
A. Socio Economic		
1. Income	X	X
2. Family Size	X	X
3. Ages of Members	X	X
4. Education of Members	X	X
5. Employment Status of Members	X	X
6. Sex of Members	X	X
7. Geographic Location	X	X
B. Vehicle Related		
a) Vehicles Owned at time of Collection		
1. Model Year	X	X
2. Make	X	
3. Model	X	
4. Utilization (VMT)	X	
5. Vehicle Options (e.g. No. of Cylinders)	X	X
6. Vehicle Purchase Date		X

and, in the case of domestic cars, the vehicle model (e.g. Pinto). There are two major faults with this data. First, as implied above, vehicle model information was not collected for foreign makes. This clearly limits the usefulness of the data in studying a number of major concerns, such as causes of import market penetration. Second, the data contains no information on the vehicles owned prior to the survey date. The absence of this information precludes any analysis of the dynamics of household vehicle ownership (i.e. the evolution of household vehicle related tastes).

Another significant cross-sectional data source is the 1977 Nationwide Personal Transportation Study (NPTS). This survey was conducted by the Bureau of the Census under the sponsorship of the Department of Transportation. Data was collected nationally from the period covering April 1977 to March 1978. Unfortunately, the NPTS data shares a critical deficiency with the SRC data in that information on the vehicles owned prior to the survey date was not collected. Despite this rather serious deficiency, the incredible size of the NPTS sample (17,949 households) makes it a desirable data source for static modeling of household vehicle ownership. To date, this source is not known to have been used in any disaggregate vehicle ownership study.

The most widely used data set appears to be the National Transportation Survey (NTS) which was collected in May and June 1978 by Cambridge Systematics Incorporated for the National Science Foundation (both the Berkovec and Rust (1981) and Train and Lohrer (1982) works use this data source). The sample consists of 1095 households which were chosen on a nationwide basis. The value of this data source lies in the fact that it was the first source to include information on vehicles owned prior to the time the survey was collected. In this case, information on all vehicles owned during the one-year period preceding the survey date was obtained. The availability of this data permits the explicit analysis of the dynamic aspects of the vehicle ownership problem.

In a more recent survey, the National Interim Energy Consumption Study (NIECS), relevant vehicle related information was collected from 4,081 households. This survey was conducted by the U.S. Department of Energy in the Fall of 1978 to obtain information on energy consumption in the residential sector. As was the case with the NTS data, information on all vehicles owned during the one-year period preceding the survey date was obtained. However, for at least two reasons, the NIECS data is superior to the NTS data in its ability to address the household vehicle ownership problem. First, the sheer size of the NIECS data is a substantial advantage. This size advantage permits exploration of vehicle ownership behavior by specific segments of the population. For example, a sufficient number of observations on households owning three and four vehicles may be available in the larger data set, thereby permitting estimation that could not have been undertaken in the smaller data sample. The second advantage is that the confidence intervals on model parameter estimates will generally be smaller for the larger data set, thereby providing more precise estimates. To date, only the Booz, Allen, & Hamilton (1983) study have used the NIECS data for vehicle ownership modeling.

4.2 Household Panel Data

At least two household panel data sources containing vehicle related information are known to exist. These are the Household Transportation Panel (HTP) and the Seattle and Denver Income Maintenance Experiments (SIME/DIME). A summary of the characteristics contained in these data sources is presented in Table 1.

The household transportation panel was initiated by the Department of Energy to provide a follow-up survey (relative to the NIECS sample) with information on vehicle utilization. This panel initially consisted of previously surveyed NIECS households who owned at least one vehicle. The survey strategy was to divide the eligible households of the NIECS sample into six groups, and to collect monthly information on vehicles owned, fuel consumed, and miles driven. The panel was initiated in June 1979, and one group was brought into the sample each month for a two-month reporting period. Starting in December 1979, these groups were returned to the sample, one each month, for a final two-month reporting period. To extend the survey beyond November 1979, another national random sample was collected (i.e. non-NIECS households) and segmented to create additional household groups which were again introduced into the survey in the same manner. Data is available from this panel to December 1980.

The HTP is an extremely rich data source for vehicle ownership modeling, as all relevant vehicle related information is included.

Moreover, when the HTP data is linked with the corresponding observations in the earlier NIECS survey, a two-and-one-half year vehicle ownership history can be constructed for each household. This is particularly valuable in the assessment of the dynamic aspects of household vehicle ownership. The HTP data has not been used in any previous vehicle ownership study.

The Seattle and Denver Income Maintenance experiments were surveys conducted to assess the feasibility of a negative income tax program that provides a minimum guaranteed income to eligible families. The surveyed families were divided into two roughly equal groups, with one group receiving various levels of guaranteed income and the other group used as the study control. The survey was conducted by the Stanford Research Institute (SRI), and in all, 2,042 families were enrolled between 1970 and 1971 in Seattle, and 2,758 families were enrolled between 1971 and 1972 in Denver. Eligibility in the survey was limited to low income families (i.e. total income less than $11,000 in 1971). Information on participating families was collected on a quarterly basis through the early months of 1978.

The primary attraction of the SIME/DIME data base is that information on specific households is available for a seven-year period. Moreover, the rate of attrition (always a concern with panel data of this type) was kept to a minimum (see Spiegleman and Yaeger (1979)). The major disadvantage associated with the SIME/DIME data is that information on the make and model of vehicles owned and the extent to which such vehicles are used is not available. It is frustrating to know that vehicle make and model information was actually collected but never coded onto data files. Recovering such information is virtually impossible since all work on the project terminated during the summer of 1982. The total absence of vehicle utilization data, and the fact that only low income households are considered, further limits the applicability of the SIME/DIME survey to vehicle ownership modeling.

4.3 Vehicle Attribute Files

As mentioned earlier, vehicle attribute files are used to complement household data. Such files contain information relating to the attributes of specific vehicle makes, models, and vintages.

One of the earliest vehicle attribute files was that assembled by Cambridge Systematics (1978) and subsequently used in the vehicle type choice research of Manski and Sherman (1980) and Berkovec and Rust (1981). This file contains attribute information on over 750 vehicles from the model years 1967-1978. The vehicle attributes contained in this file include vehicle price (as of June 1978), vehicle weight, fuel efficiency (MPG), turning radius, estimate of seating space, 0-60 mph acceleration time in seconds, interior noise levels, and luggage space. Although reasonably detailed, the Cambridge Systematic's vehicle attribute file suffers from two weaknesses. First, information on the engine size of a specific make and model is excluded, and instead the attributes of the model's most popular engine size are assumed. Since engine options for particular vehicle models can have a substantial impact on a number of vehicle attributes e.g. acceleration, horsepower, and fuel efficiency), the assumption of the most popular engine size can be quite imprecise. Second, the Cambridge Systematics' file has many missing vehicle models and vintages for foreign manufacturers, thereby limiting its usefulness to vehicle ownership modeling.

In recognition of the deficiencies of the Cambridge Systematics vehicle attribute file, Booz, Allen, & Hamilton (1983) constructed a vehicle attribute file that provided information on engine options and expanded the number of foreign vehicle models and vintages considered. The resulting file consisted of over 2700 vehicles covering the model years (vintages) from 1969 to 1979 and contained information on engine size (displacement in cubic inches and number of cylinders), wheel base, weight, height, front and rear seating room, luggage space, horsepower, vehicle price as of November 1978, Consumer Report's maintenance index, fuel efficiency (mpg), the EPA roominess factor, and seating capacity by number of passengers. This vehicle attribute inromation was compiled from the Oak Ridge National Laboratories vehicle description data, the Automotive News market data book issue, Ward's Automotive Almanac, Consumer Reports' automotive issues, and the Red Book of retail car prices. It is strongly suspected that this vehicle attribute file is the most complete file in existence.

4.4 Description of Data Used in Estimation

For the purposes of the current study, the National Interim Energy Consumption Survey (NIECS) and the Household Transportation Panel (HTP) (both of which were discussed at length earlier) were combined to provide household samples capable of estimating the theoretical models derived in the preceding chapter. The strategy was to select the Household Transportation Panel Groups first entering in June, July and August 1979 (and returning to the panel in December 1979, and January and February 1980 respectively) and link these households with their corresponding NIECS information. The combination of these two surveys provides vehicle ownership information for the same households (a total of 962 households) from the fall of 1977 to the spring of 1980.

With the linkage of the two surveys completed, the resulting data was organized into five discrete time intervals of a six-month duration (this is illustrated in Figure 1). Thus, household vehicle holdings (quantity and type) are known as of December 1977, with corresponding utilization accumulated over the January 1978 to June 1978 period, holdings as of June 1978, with corresponding utilization from July 1978 to December 1978, and so on for December 1978, June 1979, and December 1979. However, the forthcoming empirical analysis is forced to begin with the vehicle holdings as of December 1978 since this was the first time period for which one and two time period utilization lags could be incorporated, as required for the restricted and intertemporal models derived in the preceding chapter. Hence in the actual estimations contained herein, three time periods were used: (1) vehicle holdings as of December 1978 with utilization from January 1979 to June 1979; (2) vehicle holdings as of June 1979, with utilization from July 1979 to December 1979; (3) vehicle holdings

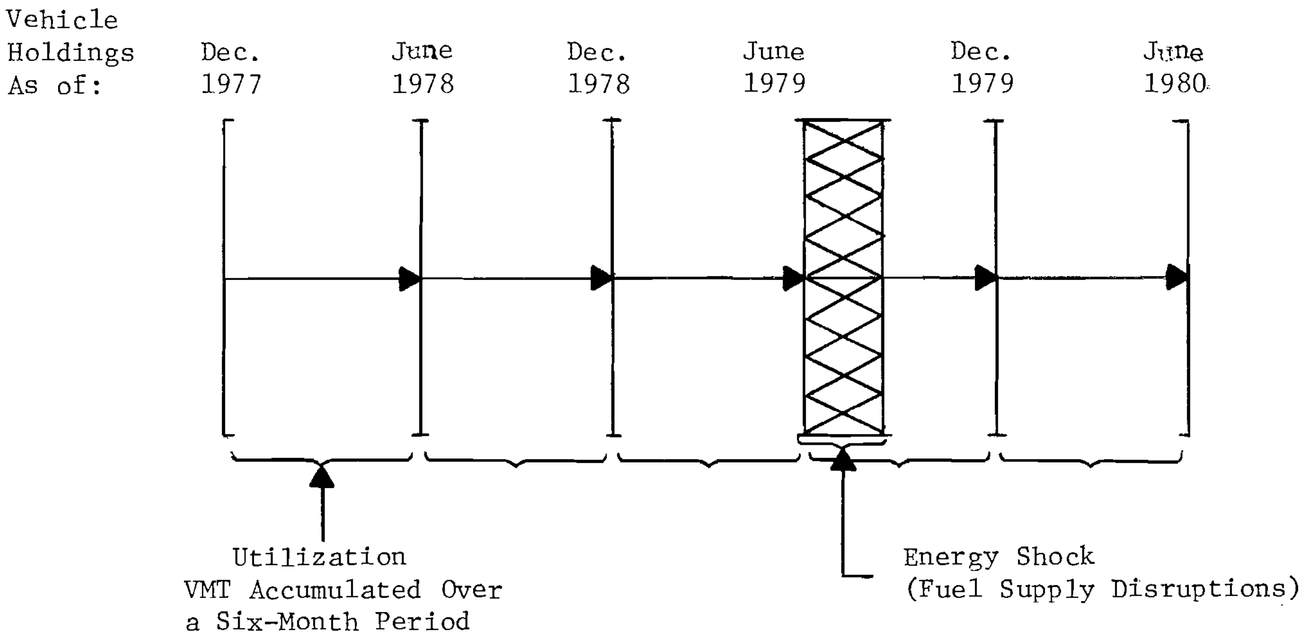

Figure 1. Illustration of the Discrete Time Household Data Organization Structure

as of December 1979, with utilization from January 1980 to June 1980. It should be noted that these periods respectively capture household vehicle ownership behavior before, during, and after the June 1979 energy shock.

To supplement the cross-sectional time series household data, the Booz, Allen & Hamilton vehicle attribute file was used as a basis for creating an expanded attribute file that would be suitable for the time periods over which household data was available. In summary, the Booz, Allen & Hamilton attribute file was modified as follows: (1) attribute information on 1980 model year vehicles was added since such vehicles were available to the household sample in the fall of 1979; (2) the Red Book retail car values were added to include values as of December 1977, June 1978, December 1978, June 1979, and December 1979; and (3) vehicle attributes of the pre-1969 model year vehicles were added to match those vehicles actually owned by the household sample.

The combination of the household and vehicle attribute files described above, provide a sufficiently detailed data base for estimation of the vehicle ownership and utilization models proposed in the preceding chapter. All items considered, the data base used in this study is arguably the richest and most complete data source ever used in the analysis of household vehicle ownership behavior.

CHAPTER 5. EMPIRICAL ESTIMATION AND RESULTS

This chapter presents the estimation results of vehicle ownership models of the form derived in Chapter 3. Also, to assess the current and future prospects of household vehicle demand, a number of applications of the estimated models are presented.

The organization of this chapter is as follows. First, a number of points are discussed relating to the differences between the theoretical models derived in Chapter 3 and the final specifications used in empirical estimation. Next, the estimation results of the type choice, utilization, and level choice models are presented and their implications are evaluated. Following this, an assessment of vehicle demand responsiveness is given, based on several applications of the estimated models. Finally, the chapter concludes with a number of specification tests performed to determine the validity of the econometric approach used in model estimation.

5.1 Final Empirical Specifications

There are a number of estimation considerations that determined the final model specifications. The first concern relates to the estimation of the indirect utility and utilization equation parameters (the A's in Equations (38), (39), and (40)) which have been up to now subscripted by i. Given the large number of vehicle type alternatives available to the household, it is empirically necessary to constrain these parameters to be equal across available vehicle alternatives. In a similar vein, typical utilization (r_{it}'s in Equation (38)) is not permitted to vary across i, again due to the large number of available vehicle alternatives.

The next issue concerns the estimation of the type choice models and of the estimation of a number of terms appearing in the indirect utility function, specifically $Z'\theta$, ν_t, πr_t, $A_2 I_t$, A_o, and $A_3 I_{t-1}$ (see Equation (38)). In practice these terms will vary across alternatives since they are multiplied by $e^{-A_2 p_{it}}$. Unfortunately, allowing these terms to vary across alternatives would make estimation difficult, if not impossible, since, for example, ν_t, the utilization equation distrubance, is not known. To resolve this problem and to retain a logit structure, consider a rewritten form of the total error term

$$\xi_{it} = \nu_t e^{-A_2 p_{it}} + \varepsilon_{it} . \quad (42)$$

applying a Taylor series expansion around the mean operating price $\bar{p}_t$ yields

$$\xi_{it} = \nu_t e^{-A_2 \bar{p}_t} [1+(p_{it}-\bar{p}_t) + \frac{(p_{it}-\bar{p}_t)^2}{2!} + \dots + \frac{(p_{it}-\bar{p}_t)^{N-1}}{(N-1)!} + \dots]+\varepsilon_{it}. \quad (43)$$

if higher order terms are assumed not to contribute significantly, the error term becomes

$$\xi_{it} = \nu_t e^{-A_2 \bar{p}_t} + \varepsilon_{it}. \quad (44)$$

This assumption is reasonable to the extent that there is a relatively small variance in operating prices (i.e. price per gallon ÷ vehicle miles per gallon). With this assumption accepted, the term $\nu_t e^{-A_2 \bar{p}_t}$ does not vary across alternatives. Similarly, the remaining terms A_o, πr_t, $A_2 I_t$, $A_3 I_{t-1}$, and $Z'\theta$ can also be eliminated from the indirect utility function.

The next two points relate to information that was obtained from initial estimation of the type choice and utilization models. First, recall that in the type choice model a number of terms are multiplied by $e^{-A_2 \bar{p}_t}$. During estimation of the type choice models it was found that the log-likelihood at convergence was relatively insensitive to values of $-A_2$. In fact, values of $-A_2$ in the range of -3.0 to +13.0 did not result in significant differences in the log likelihood at convergence or in parameter estimates. Consequently, for all the estimations carried out here, $-A_2$ was set equal to -.1. This is a theoretically plausible value in addition to being statistically within the range of admissible values that maximize the log-likelihood.

The second point concerns the dynamic structure of the empirical models. Initial estimations of specifications that incorporated lagged operating cost and lagged income variables yielded highly insignificant and small parameter estimates for these variables. This suggests that a theoretical model which is based on a state variable summarizing past utilizations and a constant rate of state depreciation may not be appropriate for analyzing household vehicle ownership. In particular, it appears that the assumption of a constant rate of state depreciation is highly questionable since empirical evidence indicates that the state variable may actually appreciate in some periods. This was found to be the case immediately following the energy crisis during the summer of 1979, as households valued pre-crisis habits more highly than crisis habits. In any event, the depreciation rate appears to be highly irregular and inconsistent with the constant rate assumed in the theoretical derivations. In order to resolve this problem, the estimated models excluded lagged operating cost and lagged income variables. As such, the final specifications actually estimated are more in line with the habit formation taste change work of Pollak and Wales (1969) and Pollak (1970).

Finally, to statistically test for structural stability of vehicle level, type, and utilization model parameters over time, data from various time periods was pooled to re-estimate model parameters. In so doing, the fact that there may be two or three observations from the same household was not accounted for. As pointed out by Chamberlain (1980), accounting for household specific effects in pooled time series data tends to be difficult for discrete models. Since there exists the possibility of omitted variable bias if this effect is not account for, the results of the combined time period estimations, which will be presented in forthcoming sections, should be viewed with some caution.

5.2 Type Choice Models: Single-Vehicle Households

The single vehicle household type choice model specifies the probability of the household selecting a specific vehicle type, defined by vehicle make (e.g. Chevrolet), model (e.g. Corvette), and vintage (e.g. 1975), conditioned on the fact that one and only one vehicle is selected (the vehicle level or quantity choice model will be presented later). With the vehicle attribute file prepared for this study (see the previous chapter for a description), the household theoretically can select from well over 2000 different vehicle type alternatives. Since the computational burdens of providing so many alternatives in the estimation process would be excessive, a sampling of available alternatives was undertaken since consistent parameter estimates can be obtained from such a procedure providing a logit structure is used (see the discussion presented in Section 3.4). For the empirical analysis carried out here, the household's choice set included ten vehicle type alternatives. In the case where a household owned a vehicle (or vehicles) in the preceding period, this vehicle (or vehicles) was included among the ten alternatives. Also, as a note, in order to test for the robustness of this sampling procedure, models were estimated with choice sets of eight, twenty, and thirty alternative vehicle types and virtually no change in parameter estimates was found.

With the above points in mind, attention can now be given to the precise specification of the indirect utility function. Although the indirect utility function derived earlier (Equation 38) completely specifies the dynamic aspect of the vehicle ownership decision, the vector of observable household and vehicle characteristics (Y'_{1i_1} in Equation (38)) influencing vehicle type choice still must be specified.

The complete list of explanatory variables ultimately used in model estimation is presented in Table 2 along with their summary statistics. Also, the resulting model parameter estimates for distinct and combined time periods are given in Table 3. To structure the discussion of the explanatory variable selection process and the resulting parameter estimates, four categories of variables are presented: 1) vehicle cost variables, 2) dynamic components, 3) general vehicle characteristics, and 4) brand (vehicle make) preference variables.

Vehicle Cost Variables

Essentially, two components of vehicle costs can be envisioned, operating costs and capital costs. In this analysis operating costs are measured as the fuel cost per mile (determined by dividing the prevailing per gallon price of fuel by the fuel efficiency of the vehicle type alternative measured in miles per gallon) multiplied by the typical or expected utilization measured as miles accumulated over respective six-month time periods. The result is the total expected fuel operating costs incurred during a six-month time period. In entering operating costs in the specification, the term is divided by annual household income to support the hypothesis that operating costs should be less onerous to high income households.

Over the three six-month time periods with which models were estimated (periods before, during, and after the June 1979 energy shock), the average per gallon fuel price increased from \$0.72 to \$1.17, making this overall time span particularly interesting in studying the effects of rapidly escalating operating costs. The parameter estimates of the

Table 2. Variables Used in Single-Vehicle Type Choice Models (Means for Chosen Alternatives)

Variable	Mnemonic	PRD 1[a] Mean	PRD 2[b] Mean	PRD 3[c] Mean
(Fuel cost ($/mi) * typical utilization (mi)[d]) ÷ Income ($/yr)	PIRO	.0201	.0259	.03304
Vehicle Capital Cost ÷ Income ($/yr)	CAPO	.2120	.2070	.2080
1 Period lagged utilization (mi.) Same vehicle	XT1	4519	4287	4491
2 Period lagged utilization (mi.) Same vehicle	XT2	3620	3829	3655
1 Period lagged utilization (mi.) Similar make vehicle	XPT1	148.2	131.0	136.0
2 Period lagged utilization (mi.) Similar make vehicle	XPT2	343.1	309.2	250.0
Front and rear shoulder room (in.) For households with 2 or less members	LFRSR	73.98	74.20	73.95
Front and rear shoulder room (in.) For households with 3 or more members	GFRSR	38.55	38.30	38.35
American Motors Dummy (1 if AMC, 0 otherwise)	AMC	.0380	.0352	.0302
Ford dummy (1 if Ford, 0 otherwise)	FORD	.2742	.2734	.2702
Chrysler dummy (1 if Chrysler, 0 otherwise)	CHRYS	.1265	.1271	.1264
Foreign car dummy (1 if foreign car, 0 otherwise)	FORN	.0878	.0861	.0906
Horsepower ÷ engine displacement (CI) For households with heads 35 years old or less	ETECH	.1871	.1885	.1906
Luggage space (ft^3) for household with four or more members	GLUG1	3.605	3.592	3.547
New vehicle dummy - vehicle 2 yrs old or newer	NEWAG	.2100	.1980	.2060
Old vehicle dummy - vehicle 8 yrs old or older	OLDAG	.3520	.3750	.3681
Number of observations	-	345	361	364

(Continued)

Table 2 (Continued)

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[a]Period 1 is type choice as of December 1978, with utilization from Jan. 1979 to June 1979. The mean fuel price in this six-month period is \$0.72 per gallon.

[b]Period 2 is type choice as of June 1979, with utilization from June 1979 to Dec. 1980. The mean fuel price in this six-month period is \$0.96 per gallon.

[c]Period 3 is type choice as of December 1979, with utilization from Jan. 1980 to June 1980. The mean fuel price in this six-month period is \$1.17 per gallon.

[d]Typical utilization is determined by applying the following equations for single vehicle households:

Typical utilization (r_{1t}) = 2684 +457.8 * number of household members + .05294 * income (\$/yr)

For two vehicle households

Typical utilization of each vehicle (r_{2t}) = 3331 + 151.1 * number of household members + .04686 + income (\$/yr)

The parameters in these equations were estimated by ordinary least squares using average utilizations derived from all available periods in the household sample.

Table 3. Type Choice Model Parameter Estimates (Standard Errors in Parentheses): Single Vehicle Households

Variable	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Period 1 & 3	All Periods	Period 1	Period 2	Period 3	Periods 1 & 3	All Periods
PIRO	-21.17 (11.91)	-23.40 (7.91)	-31.41 (7.85)	-26.20 (6.57)	-25.08 (5.01)	-23.70 (11.30)	-23.56 (7.88)	-31.93 (7.44)	-27.6 (6.21)	-25.85 (4.84)
CAPO	-2.80 (.535)	-2.32 (.489)	-2.45 (.522)	-2.51 (.375)	-2.46 (.298)	-2.86 (.529)	-2.33 (.489)	-2.61 (.563)	-2.65 (.375)	-2.53 (.298)
XT1	.675E-03 (.687E-04)	.777E-03 (.763E-04)	.591E-03 (.709E-04)	.629E-03 (.489E-04)	.668E-03 (.419E-04)	.850E-03 (.551E-04)	.840E-03 (.521E-04)	.914E-03 (.557E-04)	.880E-03 (.392E-04)	.861E-03 (.312E-04)
XT2	.211E-03 (.671E-04)	.663E-04 (.621E-04)	.414E-03 (.745E-04)	.312E-03 (.495E-04)	.226E-03 (.390E-04					
XPT1	.563E-04 (.100E-03)	.338E-03 (.117E-03)	.281E-03 (.13E-03)	.164E-03 (.773E-04)	.200E-03 (.682E-04)	.256E-03 (.929E-04)	.396E-03 (.828E-04)	.314E-03 (.861E-04)	.286E-03 (.647E-04)	.328E-03 (.518E-04)
XPT2	.264E-03 (.641E-04)	.587E-04 (.843E-04)	.549E-04 (.117E-03)	.197E-03 (.677E-04)	.158E-03 (.581E-04)					
LFRSR	.186E-01 (.619E-02)	.214E-01 (.635E-02)	.250E-01 (.686E-02)	.211E-01 (.454E-02)	.212E-01 (.366E-02)	.187E-01 (.615E-02)	.216E-01 (.637E-02)	.250E-01 (.657E-02)	.216E-01 (.448E-02)	.216E-01 (.364E-02)
GFRSR	.430E-01 (.125E-01)	.377E-01 (.110E-01)	.516E-01 (.136E-01)	.478E-01 (.925E-02)	.450E-01 (.720E-02)	.441E-01 (.12 E-01)	.371E-01 (.108E-01)	.567E-01 (.137E-01)	.500E-01 (.930E-02)	.446E-01 (.700E-02)
AMC	-.257 (.467)	-.072 (.409)	-.901 (.487)	-.550 (.336)	-.387 (.258)	-.364 (.458)	-.069 (.409)	-.940 (.489)	-.634 (.332)	-.425 (.256)
FORD	.555 (.229)	.146 (.218)	.298 (.223)	.442 (.158)	.351 (.127)	.529 (.223)	.139 (.218)	.345 (.215)	.447 (.154)	.346 (.125)
CHRYS	-.181 (.279)	-.512 (.281)	-.799 (.299)	-.466 (.203)	-.477 (.161)	-.195 (.270)	-.505 (.280)	-.699 (.282)	-.435 (.194)	-.451 (.159)
ETECH	1.27 (1.21)	1.92 (1.20)	1.03 (1.46)	1.23 (.942)	1.57 (.735)	1.27 (1.21)	1.86 (1.18)	1.00 (1.44)	1.21 (.934)	1.46 (.728)
GIJIG1	.381E-02 (.139E-01)	.436E-02 (.101E-01)	.200E-01 (.105E-01)	.132E-01 (.838E-02)	.863E-02 (.650E-02)	.453E-02 (.139E-01)	.475E-02 (.101E-01)	.204E-01 (.111E-01)	.134E-01 (.863E-02)	.882E-02 (.653E-02)
FORN	-.849 (.356)	-1.25 (.357)	-1.36 (.387)	-1.08 (.260)	-1.12 (.207)	-.884 (.347)	-1.26 (.357)	-1.28 (.360)	-1.07 (.249)	-1.13 (.203)
NEWAG	.554 (.276)	.760 (.270)	.564 (.291)	.525 (.196)	.583 (.157)	.515 (.272)	.750 (.270)	.374 (.282)	.446 (.193)	.537 (.156)
OLDAG	-.699 (.234)	-.357 (.218)	-.188 (.225)	-.421 (.158)	-.400 (.127)	-.683 (.229)	-.360 (.218)	-.230 (.217)	-.421 (.155)	-.403 (.126)
Log likelihood at zero	-794.4	-831.2	-838.1	-1633	-2464	-794.4	-831.2	-838.1	-1633	-2464
Log likelihood at convergence	-316.8	-354.4	-304.3	-630.5	-993.6	-323	-355.1	-324	-651.6	-1012
χ^2 Statistic (LR Test)				18.8	36.2				9.2	19.8

the operating cost variable (PIRO) are given in Table 3, and it is clear that these parameters are correctly signed (i.e. increased operating costs have a negative effect on vehicle selection probabilities) and statistically significant in all three time periods. Also, it should be noted that the magnitude of the PIRO parameter increases noticeably from time period 1 to time period 3 in both the restricted and intertemporal models, indicating that households' valuation of operating costs has been increasing over time. As a final point, other operating costs that may be presumed to influence the vehicle type decision, such as insurance costs, maintenance costs, and accident repair costs, were not included in the specification primarily due to the unavailability of such data.

The other important component of vehicle costs is the capital cost. This variable (CAPO) is entered into the specification as the prevailing Red Book price of the vehicle type, divided by household income to reflect the belief that capital costs are less onerous to high income households. As Table 3 indicates, the CAPO parameter estimates are properly signed and statistically significant for both the intertemporal and restricted models in all time periods. In terms of parameter magnitudes, the impact of the capital costs appear to be fairly stable over time.

With the PIRO and CAPO parameter estimates, it is possible to calculate the marginal rate of substitution (MRS) of operating and capital costs. As indicated in Table 4, the amount that a household is willing to pay in terms of increased capital costs for a one-cent

Table 4. Marginal Rates of Substitution of Operating and Capital Costs (Price willing to pay for 1¢/mi decrease in operating costs) and Implied Annualized Discount Factors: Single Vehicle Households (Standard Errors in Parentheses)

	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Period 1 & 3	All Periods	Period 1	Period 2	Period 3	Periods 1 & 3	All Periods
MRS	332.66 (195.68)	453.35 (178.13)	578.80 (186.14)	466.74 (134.51)	456.70 (103.80)	364.85 (184.27)	454.54 (177.00)	557.23 (149.39)	466.52 (122.35)	457.90 (99.98)
Mean Income	12960	14130	15120	14070	14090	12960	14130	15120	14070	14090
Mean Typical Utilization	4409	4501	4559	4483	4486	4409	4501	4559	4483	4486
Discount Factors (Percent)	26.4 (15.5)	19.8 (7.8)	15.6 (5.0)	19.2 (5.5)	19.6 (4.5)	24.1 (12.2)	19.8 (7.7)	16.3 (4.4)	19.2 (5.0)	19.6 (4.3)

per mile decrease in operating costs (in constant dollars) evaluated at the population mean, has increased substantially over time.

These estimated marginal rates of substitution provide some additional interesting information. For example, if a driving rate of 4500 miles per six-month period is assumed, then a \$45 savings can be expected for a one-cent reduction in vehicle operating costs. Further, if a constant vehicle depreciation rate of 9 percent is assumed along with a discount rate of 3 percent, then the semi-annual capital cost is 12 percent of the purchase price. Given these assumptions, the "rational" household could be expected to pay \$375 (i.e. \$45 ÷ 12%) for a one cent per mile reduction in operating costs. As indicated in Table 4, the MRS estimates are reasonably consistent with this example. The fact that the estimated marginal rates of substitution reported here are increasing over time most likely indicates an increase, among households, in expected fuel prices and/or a higher valuation of future reductions in operating expenses.

In a related matter, household discount factors were calculated and the resultant values are also presented in Table 4. It should be noted that the discount factors presented in Table 4 implicitly include the true discount rate plus expected vehicle depreciation. As such, estimated discount factors in the vicinity of 15-30% can be considered plausible in the sense that annual operating and capital costs will be equal. The fact that the discount factors are declining over time again reflects households' increased valuation of vehicle operating costs. In general, these results indicate that households are discounting the impacts of future operating costs at rates that are less than those rates indicated before the energy shock. In a sense, they are becoming less myopic and more aware of future costs.

Dynamic Components

As indicated in the derivations given in Chapter 3, the dynamic components of the vehicle type choice model are represented by the lagged utilizations of the same vehicle (i.e. indicating that the vehicle had been owned and operated in preceding periods) or of a vehicle of a similar make. Recall that the utilization of a vehicle of a similar make attempts to capture the notion of brand loyalty, defined as the accumulation of information through driving and ownership experience, on particular vehicle makes (brands). As indicated in Table 3, the parameter estimates of all the dynamic components, XT1, XT2, XPT1, and XPT2 are properly signed (i.e. past ownership has a positive effect on the probability of vehicle selection) and statistically significant across time periods. In terms of parameter magnitudes, the lagged utilizations of the same vehicle (XT1, XT2) are substantially larger than those of a similar make vehicle (XPT1, XPT2), as was initially expected.

Perhaps the most interesting aspect of the dynamic component parameter estimates is that they draw the only empirical distinction between the intertemporal and restricted models. Specifically, the intertemporal model contains the two-period lagged utilizations, XT2 and XPT2, and the restricted model does not. The inclusion of XT2 and XPT2 in the model structure produce correctly signed and statistically significant corresponding parameter estimates thereby indicating that the intertemporal model may be justified. However, the "non-dynamic" component parameter estimates are virtually identical as reflected in the results presented in Table 3. Subsequently, the substantive conclusions that can be drawn from the estimation results are quite similar for both the intertemporal and restricted models.

General Vehicle Characteristics

General vehicle characteristics can be classified into three categories; 1) dimensions, 2) performance, and 3) reliability. Vehicle dimensions can be included in the model estimation to reflect the effect that seating capacity, cargo storage area, passenger comfort, and maneuverability will have on the choice of vehicle types. In terms of data, information is available on front and rear seat shoulder rooms (seating capacity), luggage space (cargo storage area), vehicle weight (a proxy for ride comfort), and vehicle wheel base (a proxy for maneuverability). In the final estimations, only shoulder room and luggage space were found to produce significant results. The shoulder room variable was defined as the summation of front and rear seat space, and separate parameters were estimated for households with two or fewer members (LFRSR) and for households with three or more members. This separation supports the hypothesis that larger households will value seating capacity more than smaller households. Indeed, the estimations presented in Table 3 indicate that the parameters are properly signed (i.e. seating capacity has a positive impact on the probability of vehicle selection), statistically significant, and, in fact, the

GFRSR parameter is substantially larger in magnitude than the LFRSR parameter, as expected. Also, it appears that household valuations of seating capcity have increased slightly over time.

The luggage space variable, GLUG1, was defined as available cargo space in cubic feet, and was specified only for households with four or more members. The hypothesis here is that luggage space is important only for reasonably large-sized households. Luggage space was found to have little effect on the vehicle type choice decisions of smaller households. Although the GLUG1 variable is correctly signed, it is not highly significant, statistically, in most time periods. Also, the magnitude of the GLUG1 parameter estimate increases over time.

The next category of general vehicle characteristics is the performance category. Unfortunately, the amount of performance-related data available is somewhat limited. As a proxy for vehicle acceleration, horsepower divided vehicle weight was included in initial specifications, but improperly signed and statistically insignificant parameter estimates resulted. This is not surprising since it is the engine's torque, not horsepower, that determines the acceleration capability of the vehicle. The fact that horsepower and torque are correlated, to some extent, provided initial justification for considering such a variable, but the estimation results indicate that the horsepower/weight variable is inappropriate. The only performance variable found to yield reasonable results was defined as the horsepower divided by engine displacement (ETECH). Exploration of automotive road tests indicated that this variable is highly correlated with both engine torque and the cornering power of the vehicle (measured by lateral acceleration). The ETECH variable was defined only for households which had household heads of 35 years of age or less. The belief here is that performance is highly valued among young households. The ETECH parameter estimates are properly signed in all time periods and reasonably significant statistically.

The final category of vehicle characteristics is reliability. Accurate measures of reliability are difficult to obtain. One possible source is Consumer Reports where survey results from maintenance and reapir experiences are tabulated. Unfortunately, such information is available for a relatively small percentage of the total number of different makes, models, and vintages of vehicles available to the household, and as such, could not be used in model estimation. Ultimately, vehicle age was used as a proxy for reliability, since it is known that the general reliability of vehicles declines with over time. Two vehicle age dummy variables were found to produce the most satisfactory results: NEWAG which was specified only for vehicles two years old or less, and OLDAG which was specified for vehicles eight years old or older. In both cases, the parameter estimates were properly signed (i.e. newer vehicles are more desirable and older vehicles are less) and fairly significant, statistically. In terms of parameter magnitudes, it appears as though older vehicles were becoming less onerous over time while the desirability of newer vehicles remained relatively constant.

Brand Preference Variables

It should be noted that in this study a distinction between brand loyalty and brand preference is drawn. The process through which brand loyalty is developed consists of the accumulation of information, through driving and ownership experience, on particular vehicle makes (brands). Given this process, there is no reason to suspect that any one make of vehicle will have a higher degree of brand loyalty than another, since this would unrealistically imply that learning processes differ according to vehicle make. Brand preference is defined as a tendency to purchase a specific make of vehicle. This tendency may be influenced by the extent of the make's dealer network, reapir costs, parts availability, and so on. In the models estimated here, brand loyalty is captured by the XPT1 and XPT2 variables described earlier. On the other hand, brand preference (expected to differ among makes) is captured by a series of vehicle make dummies.

In all, brand preference is represented by four vehicle make dummy variables including products produced by; American Motors (AMC), Ford (FORD), Chrysler (CHRYS), and a dummy variable for all foreign makes (FORN). In selecting these variables, General Motors products are implicitly normalized to zero. The parameter estimates presented in Table 3 indicate that American Motors, Chrysler and Foreign Vehicles have a lower brand preference than GM products, while Ford vehicles have the highest brand preference. In terms of parameter magnitudes, foreign makes have far and away the worst brand preference. This fact suggests that domestic manufacturers have an inherent advantage over foreign producers in this regard. Also note that American Motors, Chrysler, and foreign manufacturers appear to have declining brand preferences over time, which indicates an increasing competitive advantage for both GM and Ford.

Structural Stability

To test for the stability of parameter estimates over time, a number of likelihood ratio tests were made. As the resultant χ^2 statistics indicate (see Table 3) the hypothesis of parameter stability, over all time periods, can be rejected at confidence levels of 80% and 14% for the intertemporal and restricted models respectively. If just the first and third periods are considered, thereby eliminating the relatively unstable period when the energy shock initially occurred, it is found that the hypothesis of structural stability can be rejected at the 71% confidence level for the intertemporal model, and at the 14% level for the restricted model. Therefore, it is apparent that, in both of the above tests, structural stability can only be rejected at relatively low confidence levels.

5.3 Type Choice Models: Two-Vehicle Households

The two-vehicle household type choice model specifies the probability of selecting a portfolio of specific vehicle types. In this case each alternative portfolio consists of two vehicles defined by make, model, and vintage. Again, due to the large number of two-vehicle combinations (portfolios) theoretically available to the household for selection, a sample of ten vehicle portfolios was selected at random for model estimation purposes, as was done in the estimation of the single-vehicle household type choice models. Also, the precise specification of the type choice indirect utility function was determined by a procedure similar to that followed in the case of the single-vehicle household. The complete list of explanatory variables ultimately used in model estimation is presented in Table 5 along with their corresponding summary statistics. The resulting model parameter estimates for distinct and combined time periods are given in Table 6. A discussion of the explanatory variable selection process and the resulting parameter estimates is given below.

Vehicle Cost Variables

Both operating (PIRO) and capital cost variables (CAPO) are specified exactly as in the single vehicle type choice model, with the exception being that the costs are now summed over both vehicles comprising the portfolio. As Table 6 illustrates, the resulting parameter estimates are properly signed and statistically significant in all time periods. These results indicate that for both the intertemporal and restricted models, household's valuations of operating costs have increased over time while their valuations of capital costs have decreased over time. This is reflected in the calculated marginal rates of substitution evaluated at the population mean, presented in Table 7. As this table shows, the price that two-vehicle households are willing to pay for a 1¢ per mile decrease in operating costs has increased noticeably over the three time periods for which models were estimated. Correspondingly, households' discount factors have decrease over time.

The general findings described above are essentially identical

Table 5. Variables Used in
Two-Vehicle Type Choice Models
(Means for Chosen Alternatives)

Variable	Mnemonic	PRD 1[a] Mean	PRD 2[b] Mean	PRD 3[c] Mean
(Fuel cost ($/mi) of both vehicles * typical utilization[d]) ÷ Income ($/yr)	PIRO	.02557	.03485	.04315
Capital cost of both vehicles ÷ Income ($/yr)	CAPO	.2993	.3029	.2939
1 period lagged utilization (mi.) of same vehicles in vehicle portfolio	XT1	10720	9185	9261
2 period lagged utilization (mi.) of same vehicles in vehicle portfolio	XT2	7990	8794	8113
1 period lagged utilization (mi.) of similar make vehicles in portfolio	XPT1	380.2	298.1	335.3
2 period lagged utiliaation (mi.) of similar make vehicles in portfolio	XPT2	856.9	746.5	527.6
Front and rear shoulder room summed over both vehicles	FRSR	212.5	215.2	213.0
Pickup truck dummy	PICK	.1361	.1114	.1271
Number of American Motors cars in portfolio	AMC	.07101	.0629	.0553
Number of Fords in portfolio	FORD	.5237	.5229	.5083
Number of Chryslers in portfolio	CHRYS	.2426	.2429	.2597
Number of foreign cars in portfolio	FORN	.2929	.2686	.2983
Number of vehicles 2 yrs old or newer in portfolio	NEWAG	.2278	.1943	.2265
Number of vehicles 8 yrs old or older in portfolio	OLDAG	.5110	.6600	.6436
Number of observations	--	338	350	362

[a]Period 1 is type choice as of December 1978, with utilization from Jan. 1979 to June 1979. The mean fuel price in this six-month period is $0.72 per gallon.

[b]Period 2 is type choice as of June 1979, with utilization from June 1979 to Dec. 1980. The mean fuel price in this six-month period is $0.96 per gallon.

(Continued)

Table 5. (Continued)

[c]Period 3 is type choice as of December 1979, with utilization from Jan. 1980 to June 1980. The mean fuel price in this six-month period is \$1.17 per gallon.

[d]Typical utilization is determined by applying the following equations for single vehicle households:

$$\text{Typical utilization } (r_{1t}) = 2684 + 457.8 * \text{number of household members} + .05294 * \text{income (\$/yr)}$$

For two vehicle households

$$\text{Typical utilization of each vehicle } (r_{2t}) = 3331 + 151.1 * \text{number of household members} + .04686 + \text{income (\$/yr)}$$

The parameters in these equations were estimated by ordinary least squares using average utilizations derived from all available periods in the household sample.

Table 6. Type Choice Model Parameter Estimates (Standard Errors in Parentheses): Two-Vehicle Households

Variable	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
PIRO	-13.19 (13.32)	-22.45 (12.71)	-20.43 (8.44)	-18.41 (7.15)	-18.71 (6.10)	-12.49 (13.27)	-22.49 (12.60)	-20.15 (8.46)	-18.17 (7.15)	-18.46 (6.09)
CAPO	-2.12 (.649)	-1.57 (.407)	-1.35 (.469)	-1.61 (.376)	-1.56 (.271)	-2.21 (.659)	-1.49 (.405)	-1.33 (.469)	-1.62 (.377)	-1.56 (.272)
XT1	.747E-03 (.850E-04)	.681E-03 (.727E-04)	.110E-02 (.749E-04)	.102E-02 (.509E-04)	.934E-03 (.371E-04)	.950E-03 (.695E-04)	.813E-03 (.535E-04)	.111E-02 (.751E-04)	.103E-02 (.509E-04)	.943E-03 (.370E-04)
XT2	.257E-03 (.802E-04)	.137E-03 (.578E-04)	.108E-04 (.690E-05)	.115E-04 (.554E-05)	.117E-04 (.515E-05)					
XPT1	.279E-03 (.909E-04)	.243E-03 (.101E-03)	.539E-03 (.810E-04)	.424E-03 (.610E-04)	.378E-03 (.508E-04)	.347E-03 (.747E-04)	.269E-03 (.702E-04)	.471E-03 (.716E-04)	.409E-03 (.524E-04)	.359E-03 (.413E-04)
XPT2	.891E-04 (.615E-04)	.341E-04 (.709E-04)	-.933E-04 (.681E-04)	-.147E-04 (.386E-04)	-.183E-04 (.325E-04)					
FRSR	.772E-02 (.501E-02)	.122E-01 (.463E-02)	.781E-02 (.476E-02)	.825E-02 (.339E-02)	.967E-02 (.271E-02)	.821E-02 (.492E-02)	.119E-01 (.458E-02)	.831E-02 (.475E-02)	.833E-02 (.339E-02)	.968E-02 (.271E-02)
PICK	.500 (.433)	-.266E-01 (.418)	.543 (.414)	.586 (.294)	.370 (.238)	.539 (.428)	-.480 (.414)	.574 (.413)	.589 (.294)	.370 (.237)
AMC	.146 (.506)	-.271 (.380)	-.520 (.465)	-.192 (.340)	-.228 (.252)	.143 (.507)	-.276 (.380)	-.496 (.468)	-.194 (.339)	-.230 (.252)
FORD	.016 (.244)	.089 (.214)	-.018 (.231)	.026 (.165)	.083 (.129)	.071 (.239)	.124 (.211)	-.026 (.231)	.027 (.165)	.083 (.129)
CHRYS	-.127 (.284)	-.425 (.242)	-.194 (.263)	-.157 (.189)	-.237 (.147)	-.110 (.275)	-.374 (.240)	-.187 (.261)	-.156 (.188)	-.234 (.147)
FORN	-.640 (.283)	-.714 (.240)	-.723 (.278)	-.685 (.194)	-.683 (.150)	-.660 (.280)	-.721 (.239)	-.702 (.276)	-.683 (.194)	-.682 (.149)
NEWAG	.174 (.337)	.764 (.311)	.817 (.313)	.446 (.225)	.496 (.180)	.137 (.331)	.651 (.305)	.704 (.303)	.418 (.220)	.466 (.176)
OLDAG	-.210 (.219)	-.141 (.185)	-.036 (.197)	-.132 (.143)	-.124 (.111)	-.236 (.216)	-.315 (.183)	-.045 (.195)	-.133 (.143)	-.123 (.111)
Log Likelihood at Zero	-778.3	-805.9	-833.5	-1612	-2418	-778.3	-805.9	-833.5	-1612	-2418
Log Likelihood at Convergence	-226.1	-291.2	-246.2	-482.7	-784.5	-232.3	-294.4	-248	-483.8	-786.2
χ^2 Statistic (LR Test)				20.82	42.0				7.0	23.0

Table 7. Marginal Rates of Substitution of Operating and Capital Costs (Price Willing to pay for 1¢/mi decrease in operating costs) and Implied Annualized Discount Factors: Two Vehicle Households (Standard Errors in Parentheses)

	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
MRS($)	300.31 (308.01)	693.58 (402.08)	739.66 (357.32)	554.68 (245.43)	580.28 (207.24)	273.45 (293.91)	733.94 (421.81)	736.72 (359.38)	543.71 (242.40)	572.68 (206.74)
Mean Income	21070	22460	22780	22340	22380	21070	22460	22780	22340	22380
Mean Typical Utilization for Each Veh.	4845	4869	4881	4860	4860	4845	4869	4881	4860	4860
Discount Factors (Percent)	32.1 (32.9)	14.0 (8.1)	13.2 (6.4)	17.4 (7.7)	16.7 (6.0)	35.4 (38.0)	13.2 (7.6)	13.2 (6.4)	17.8 (7.9)	16.9 (6.1)

to those found and discussed in the case of the single-vehicle household.

Dynamic Components

The dynamic components of the two-vehicle type choice model are represented by the lagged utilizations of the same vehicles in the vehicle portfolio (i.e. those vehicles owned in the preceding time periods) and the lagged utilizations of similar make vehicles in the vehicle portfolio. As indicated in Table 6, the parameter estimates of the utilization variables (XT1, XT2, XPT1, XPT2) are generally correctly signed and statistically significant. In comparing intertemporal and restricted models, the distinguishing variables (XT2 and XPT2) generally provide statistically significant parameter estimates, lending support to the superiority of the intertemporal model. However, as in the single vehicle household case, the resultant differences between the common parameter estimates of the intertemporal and restricted models is quite small.

General Vehicle Characteristics

In terms of vehicle dimensions, only the front and rear shoulder room, summed over both vehicles, (FRSR) was found to produce statistically significant results. As can be seen in Table 6, the FRSR parameter estimates are properly signed (i.e. more shoulder room has a positive effect on the portfolio's selection probability) and relatively stable over time. Also, it should be noted that interim estimations indicated little, if any, difference in the valuations that households of different sizes placed on the shoulder room variable, hence only one parameter estimate for all households was made.

For vehicle performance, none of the horsepower, weight, or engine displacement variables (or combinations thereof) were found to produce statistically acceptable results. The one performance related variable included in the estimation was a pickup truck variable (PICK) indicating the number of pickup trucks in the portfolio. The hypothesis here is that two-vehicle households are likely to find the specialized performance of a pickup truck desirable in a vehicle portfolio. In fact, this hypothesis is supported in both the intertemporal and restricted models for the first and third time periods as reflected by the positive PICK parameter estimates. However, during the period of the energy shock (Period 2), the PICK parameter estimates are negative indicating that pickup trucks were undesirable. This sign change may have been caused by the household's curtailment of vehicular trips that required the use of pickup trucks (e.g. moving of appliances, and so on).

Finally, for the reliability characteristics of the vehicle portfolio, vehicle age was used as a proxy for reliability in a manner similar to that used in the single-vehicle type choice estimations. The constructed variables NEWAG (the number of vehicles in the portfolio 2 years old or newer) and OLDAG (the number of vehicles 8 years old or older) produced correctly signed parameter estimates that were generally statistically significant. The results indicate (see Table 6) that the desirability of newer vehicles has increased over time while the undesirability of older vehicles has declined over time. This finding implies that vehicles in the 3 to 7 year old range have become generally less desirable over time.

Brand Preference Variables

Brand preference is accounted for by including variables defined as the number of: American Motors vehicles in the vehicle portfolio (AMC), Ford products in the portfolio (FORD), Chrysler products in the portfolio (CHRYS), and foreign-made vehicles in the portfolio (FORN). The estimation results are in general agreement with those obtained in the single-vehicle household case. That is, foreign producers have a brand perfernce disadvantage relative to all domestic manufacturers, and Ford and GM have a brand preference advantage over both Chrysler and AMC.

Structural Stability

A number of likelihood ratio tests were undertaken to test the stability of the model estimates over time. The χ^2 statistics presented in Table 6 indicate that it is possible to reject the hypothesis of parameter stability for the intertemporal and restricted models at the 95% and 46% confidence levels respectively when all periods are considered, and at the 88% and 14% confidence levels respectively when the second (energy shock) period is eliminated. These test results indicate that although the hypothesis of structural stability can be rejected with greater confidence in the two-vehicle case as opposed to the one-vehicle household case presented earlier. The confidence level at which structural stability can be rejected is not exceptionally high.

5.4 Vehicle Utilization Models: Single-Vehicle Households

The vehicle utilization model specifies the number of miles driven by the household over a six-month time period. The determinants of vehicle utilization can be classified into three categories: 1) operating costs, 2) dyanmic aspects, and 3) trip generation variables. The theoretical derivations given in Chapter 3 (see Equation (39)) completely specify the operating and dynamic cost variables. What remains, then, is the specification of the trip generation variables (i.e. the Z' vector in Equation (39)). The list of explanatory variables utimately used in model estimation is given in Table 8 along with their corresponding summary statistics. Also, the resulting parameter estimates for distinct and combined time periods are presented in Table 9. The discussion below focuses on the explanatory variable selection process and an interpretation of the resulting parameter estimates.

Operating Costs

The operating cost variable (PIRO) is defined, as in the model derivations, as the fuel cost per mile multiplied by the typical utilization. Since operating cost is a function of vehicle type (i.e. fuel efficiency in miles per gallon), and hence is endogenous, consistent parameter estimates are obtained by the procedure detailed in Section 3.4 (see Equation (41)). The resulting PIRO parameter estimates are, in most cases, properly signed and statistically significant. The exception occurs during the energy shock (Period 2) as the estimates are not statistically significant in either the intertemporal or restricted models, and the parameter estimate in the restricted model

Table 8. Variables Used in
Single Vehicle Utilization Models

Variable	Mnemonic	PRD 1[a] Mean	PRD 2[b] Mean	PRD 3[c] Mean
Fuel cost ($/mi) * typical utilization (mi.)[d]	PIRO	190.6	256.2	317.4
Income ($/yr)	IO	12970	14130	15120
1 period lagged utilization (mi.) Same vehicle	X1	4519	4287	4491
2 period lagged utilization (mi.) Same vehicle	X2	3620	3829	3655
1 period lagged utilization (mi.) Similar make vehicle	XP1	148.2	131.0	136.0
2 period lagged utilization (mi.) Similar make vehicle	XP2	343.1	309.2	250.0
Urban dummy (1 if urban location, 0 otherwise)	URB	.7768	.7701	.783
Northeast dummy (1 if Northeast location, 0 otherwise)	NEAST	.2464	.2493	.2308
Age dummy (1 if head of household 50 yrs old or less, 0 otherwise)	HAGE	.5159	.5291	.5165
Number of household workers	NWORK	.8754	.8809	.8929
Number of observations	--	345	361	364

[a]Period 1 is type choice as of December 1978, with utilization from Jan. 1979 to June 1979. The mean fuel price in this six-month period is $0.72 per gallon.

[b]Period 2 is type choice as of June 1979, with utilization from June 1979 to Dec. 1980. The mean fuel price in this six-month period is $0.96 per gallon.

[c]Period 3 is type choice as of December 1979, with utilization from Jan. 1980 to June 1980. The mean fuel price in this six-month period is $1.17 per gallon.

[d]Typical utilization is determined by applying the following equations for single vehicle households:

$$\text{Typical utilization } (r_{1t}) = 2684 + 457.8 * \text{number of household members} + .05294 * \text{income (\$/yr)}$$

(Continued)

Table 8 (Continued)

For two vehicle households

Typical utilization of each vehicle (r_{2t}) = 3331 + 151.1 * number of household members + .04686 + income ($/yr)

The parameters in these equations were estimated by ordinary least squares using average utilizations derived from all available periods in the household sample.

Table 9. Utilization Model Parameter Estimates (Standard Errors in Parentheses): Single-Vehicle Households

	Intertemporal Model					Restricted Model				
Variable	Period 1	Period 2	Period 3	Periods 1 & 3	All Periods	Period 1	Period 2	Period 3	Periods 1 & 3	All Periods
PIRO	-9.67 (3.18)	-1.12 (2.91)	-2.36 (1.70)	-4.98 (1.14)	-4.22 (1.12)	-8.36 (3.33)	1.55 (3.76)	-3.67 (1.86)	-4.93 (1.23)	-4.22 (1.33)
IO	.036 (.018)	.020 (.018)	-.002 (.014)	.013 (.010)	.016 (.009)	.038 (.018)	.008 (.023)	.007 .015	.019 (.011)	.022 (.011)
XI	.295 (.028)	.158 (.054)	.363 (.032)	.322 (.020)	.369 (.019)	.356 (.026)	.704 (.052)	.521 (.026)	.432 (.018)	.486 (.019)
X2	.278 (.051)	.554 (.036)	.310 (.041)	.315 (.031)	.447 (.021)					
XP1	.720 (.268)	.026 (.634)	.416 (.448)	.782 (.260)	.497 (.183)	.882 (.167)	.456 (.805)	.251 (.402)	.795 (.143)	.740 (.158)
XP2	.386 (.154)	.470 (.142)	.431 (.144)	.341 (.107)	.388 (.083)					
URB	-412.7 (371.5)	-418.8 (409.2)	-399.4 (313.1)	-415.4 (242)	-369.9 (212.2)	-466.9 (388.1)	-144.6 (528.4)	-378.5 (336.1)	-448.5 (258.6)	-422.6 (251.7)
NEAST	-207.7 (359.5)	104.2 (399.1)	30.34 (306.8)	-88.3 (235.6)	-11.55 (207.2)	-204.2 (375.6)	112.8 (512.4)	-83.37 (328.6)	-134.2 (251.8)	-61.41 (245.4)
HAGE	894.4 (353.9)	1007 (396.7)	458.3 (295.8)	669.1 (228.9)	842.2 (202.7)	973.2 (369.5)	1478 (510.9)	441 (317.6)	691 (244.5)	997.9 (240.2)
NWORK	413.2 (244.4)	-112.4 (276.1)	56.33 (200.9)	206.6 (156.1)	6.83 (138.1)	682.7 (249.8)	-319.2 (353.3)	241.7 (214.3)	470.1 (164.4)	258.5 (163.0)
CONSTANT	3220 (629.4)	1797 (768)	2077 (540.6)	2636 (344.5)	2366 (322.2)	3360 (659.5)	1033 (989.2)	2763 (579.7)	2986 (367.3)	2744 (382.6)
R^2	.512	.648	.644	.572	.600	.462	.409	.587	.510	.436
F-Statistic (Chow-test)				1.46	1.80				2.98	3.98

is improperly signed (i.e. higher operating costs increase the extent of vehicle utilization). This can be explained by the fuel supply constraints and fuel station queueing that prevailed during this time period. The combination of these two factors appears to have determined the extent of vehicle utilization in this period, as opposed to the more traditional determinates of vehicle use.

In terms of parameter magnitudes, it appears as though the importance of operating costs in determining vehicle utilization has declined over time. This is supported by the operating cost-utilization (VMT) elasticity estimates (evaluated at the population mean) presented in Table 10. Note that in this table the short-run elasticities are obtained directly from the equation estimates whereas the long-run elasticities are obtained by assuming that steady-state utilization is achieved (i.e. $x_t = x_{t-1} = x_{t-2} \ldots$). As expected, long-run elasticities tend to be larger than short-run elasticities. It is clear, however, that both short-run and long-run operating cost elasticities have tended to decline over time.

Dynamic Aspects

The dynamic aspects include, as specified by the derivations in Chapter 3, lagged utilization of the same vehicle (i.e. if owned and operated in previous time periods) and lagged utilization of a similar make vehicle (i.e. if the current vehicle was not owned previously but a vehicle of the same make was owned previously). Since these dynamic variables are vehicle specific, the procedure described in Section 3.4 is applied in estimation (see Equation (41)). As can be seen in Table 9,

Table 10. Utilization Elasticities (Standard Errors in Parentheses): Single-Vehicle Households

Elasticity with Respect to	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1 & 3	All Periods	Period 1	Period 2	Period 3	Periods 1 & 3	All Periods
Operating Costs (short run)	-.389 (.128)	-.061 (.146)	-.173 (.125)	-.284 (.065)	-.228 (.060)	-.336 (.134)	.078 (.188)	-.260 (.136)	-.281 (.070)	-.228 (.072)
Income (Short-run)	.100 (.050)	.058 (.052)	-.007 (.050)	.044 (.032)	.049 (.035)	.108 (.052)	.023 (.067)	.025 (.054)	.063 (.036)	.069 (.034)
Operating Costs (Long-run)	-.911 (.288)	-.212 (.507)	-.257 (.186)	-.446 (.102)	-.279 (.074)	-.522 (.208)	.264 (.635)	-.543 (.284)	-.495 (.123)	-.444 (.140)
Income (Long-run)	.234 (.117)	.201 (.181)	-.011 (.074)	.069 (.050)	.060 (.043)	.168 (.081)	.078 (.226)	.052 (.113)	.111 (.063)	.134 (.066)

these variables (X1, X2, XP1, and XP2) all produce properly signed and generally statistically significant parameter estimates. In terms of parameter magnitudes, there seems to be a considerable amount of instability over time, with no strong patterns indicated. A statistical test of the structural stability of the utilization equations will be presented shortly.

When interpreting the differences in empirical fit of the intertemporal and restrictive models, the same qualitative conclusions made in the type choice models can be made here. That is, although the variables distinguishing the intertemporal model (X2 and XP2) produce statistically significant parameter estimates, the impact that these additional variables have on the parameter estimates of variables shared by both models is not great.

<u>Trip Generation Variables</u>

The factors determining household trip generation include those relating to wealth, geographic location, and life cycle. To represent wealth, the household's annual income (IO) is included in the specification as suggested by the derivations in Chapter 3. As expected, the income parameter estimates were generally properly signed indicating that households with higher incomes tend to drive more than those with lower incomes. The magnitudes of the income parameter estimates decline over time reflecting the declining importance of income in determining utilization. This is further substantiated by the declining magnitudes of both long-run and short-run income/utilization elasticity estimates (interpreted at the population mean) as shown in Table 10.

Other variables affecting vehicle utilization relate to geographic location. Intuitively, the generation of trips requiring vehicle use will vary widely from urban to rural residential location, as well as from one region of the country to another. In the final model estimation, two geographic variables were included. The first is a dummy variable (URB) defined only for households residing in an urban area. As expected, the parameter estimate of this variable is negative indicating that urban households tend to drive less than their rural counterparts. This estimate reflects the fact that urban households have greater accessibility to alternate modes of travel (e.g. bus), the urban spatial distribution requires less vehicular trips to satisfy household activities, and the transportation infrastructure is less conducive to automobile travel (e.g. congestion, parking limitations, and so on). The URB parameter estimates seem to be reasonably stable over time.

The second geographic location variable (NEAST) is defined only for households living in the northeastern portion of the U.S. Initially, it was expected that northeastern households would travel less due to the higher population densities and the generally poorer quality of the highway transportation network. However, it was found that the NEAST parameter estimates were not always signed as expected, and the statistical significance of the results was not particularly high. It should be noted that other regional variables were considered in the estimation but the results were not satisfactory.

The final trip generation variables relate to the household's life cycle. Specifically, life cycle variables should capture components of the trip generation process that vary by the stage of household development (e.g. presence of children, working parents, retired parents, and so on). Ultimately, two life cycle variables were included in the estimations; the head of the household's age (HAGE) and the number of household workers (NWORK). The HAGE variable attempts to capture the fact that "older" households tend to generate fewer vehicular trips. The HAGE variable is defined only for households with heads fifty years old or less. The HAGE parameter estimates are properly signed and statistically significant (see Table 9). The parameter magnitudes indicate that the effect of the HAGE variable on utilization has tended to decline over time.

The remaining life cycle variable (NWORK) was expected to produce positive parameter estimates (i.e. the higher the number of workers, the higher the vehicle utilization). In most time periods, this expectation was borne out. However, during the energy shock (Period 2) negative and statistically insignificant parameter estimates resulted. This is probably due to the fuel supply constraints which seem to lead to a general "breakdown" of utilization model estimations.

<u>Structural Stability</u>

To test for the structural stability of the utilization equations over time, a number of Chow tests were conducted. When all periods were considered, it was found that the hypothesis of structural stability could be rejected at high levels of confidence in excess of 99% for both the intertemporal and restricted model specifications (see the

F-statistics in Table 9). However, when the fuel supply constrained second period is not included in the Chow tests, the hypothesis of structural stability can be rejected easily for the restricted model but only at the 80% confidence level for the intertemporal model. These results seem to indicate that the utilization model is substantially less stable over time than the corresponding vehicle type choice model (see Section 5.2).

5.5 Vehicle Utilization Models: Two-Vehicle Households

The two vehicle household utilization equations specify the number of miles driven by the household on each of the two vehicles comprising the household's vehicle portfolio. The model estimations were based on the utilization equation derived in Chapter 3 (Equation (40)). Again, as was the case in the single-vehicle household model, the estimation procedure detailed in Section 3.4 was applied to obtain consistent parameter estimates in the presence of the discrete/continuous model structure. The complete list of explanatory variables ultimately used in model estimation is given in Table 11 along with their corresponding summary statistics. In addition, the resulting parameter estimates for distinct and combined time periods are presented in Table 12. An interpretation of the resulting model estimates is given below.

Operating Costs

The operating cost variable (PITO) is defined as the combination of the total fuel expenses (i.e. fuel costs multiplied by typical utilization) of both vehicles comprising the household's vehicle

Table 11. Variables Used in Two-Vehicle Utilization Models

Variable	Mnemonic	PRD 1[a] Mean	PRD 2[b] Mean	PRD 3[c] Mean
Fuel cost ($/mi.) of both vehicles * Typical utilization (mi.)[d]	PITO	417.0	554.0	665.8
Income ($/yr)	IO	21870	22470	22790
1 period lagged utilization (mi.) of same vehicles in vehicle portfolio	X1	10720	9185	9261
2 period lagged utilization (mi.) of same vehicles in vehicle portfolio	X2	7990	8794	8113
1 period lagged utilization (mi.) of similar make vehicles in portfolio	XP1	380.2	298.1	335.3
2 period lagged utilization (mi.) of similar make vehicle in portfolio	XP2	856.9	746.5	527.6
Urban dummy (1 if urban location, 0 otherwise)	URB	.6805	.6800	.6713
Northeast dummy (1 if northeast location, 0 otherwise)	NEAST	.1953	.2200	.2293
Age dummy (1 if household head 50 yrs old or less, 0 otherwise)	HAGE	.6627	.6571	.6657
Number of household workers	NWORK	1.544	1.531	1.533
New vehicle dummy (1 if newer vehicle of pair, 0 otherwise)	NEWV	.5	.5	.5
Number of observations	--	676	700	724

[a]Period 1 is type choice as of December 1978, with utilization from Jan. 1979 to June 1979. The mean fuel price in this six-month period is $0.72 per gallon.

[b]Period 2 is type choice as of June 1979, with utilization from June 1979 to Dec. 1980. The mean fuel price in this six-month period is $0.96 per gallon.

[c]Period 3 is type choice as of December 1979, with utilization from Jan. 1980 to June 1980. The mean fuel price in this six-month period is $1.17 per gallon.

(Continued)

Table 11. (Continued)

[d]Typical utilization is determined by applying the following equations for single vehicle households:

Typical utilization (r_{1t}) = 2684 +457.8 * number of household members + .05294 * income ($/yr)

For two vehicle households

Typical utilization of each vehicle (r_{2t}) = 3331 + 151.1 * number of household members + .04686 + income ($/yr)

The parameters in these equations were estimated by ordinary least squares using average utilizations derived from all available periods in the household sample.

Table 12. Utilization Model Parameter Estimates (Standard Errors in Parentheses): Two-Vehicle Households

	Intertemporal Model					Restricted Model				
Variable	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
PITO	-1.32 (1.59)	-.040 (1.25)	-.923 (.846)	-.658 (.518)	-.557 (.489)	-1.35 (1.66)	-.073 (1.30)	-.959 (.846)	-.406 (.523)	0.269 (.500)
IO	.013 (.011)	.016 (.012)	.014 (.010)	.013 (.007)	.015 (.006)	.014 (.012)	.022 (.012)	.013 (.010)	.012 (.007)	.015 (.006)
X1	.195 (.020)	.273 (.028)	.392 (.029)	.259 (.016)	.255 (.014)	.299 (.015)	.401 (.021)	.405 (.017)	.342 (.011)	.356 (.010)
X2	.198 (.026)	.163 (.023)	.014 (.030)	.131 (.019)	.152 (.014)					
XP1	.027 (.095)	.199 (.158)	.238 (.077)	.125 (.063)	.129 (.060)	.092 (.079)	.247 (.143)	.297 (.078)	.181 (.055)	.192 (.054)
XP2	.094 (.062)	.109 (.069)	.176 (.083)	.110 (.052)	.124 (.041)					
URB	18.23 (274.3)	-71.77 (301.6)	38.3 (252.6)	12.26 (188.1)	-11.91 (159.9)	-86.9 (284.5)	105.1 (311)	17.5 (252.8)	-49.3 (190.5)	-4.45 (163.8)
NEAST	-214.7 (321.7)	-263.4 (339.1)	-3.40 (283.4)	-145 (215)	-186.1 (182.4)	-155.9 (334.1)	-383.9 (349.9)	-35.57 (283.1)	-130.3 (218.1)	-217.4 (186.7)
HAGE	134.6 (282)	195 (307.3)	234.2 (258.0)	173.3 (191.8)	186.3 (163.2)	100.8 (292.0)	385.1 (316.1)	259 (257.9)	188.9 (144.4)	253.6 (167.1)
NWORK	199.3 (175.8)	-59.48 (185)	76.48 (152.2)	154.4 (116.3)	91.5 (98.7)	268.8 (182.2)	-53.54 (191.4)	92.45 (152.1)	191.6 (117.9)	129.6 (101.1)
NEWV	1717 (253.8)	1705 (275.7)	1355 (233.7)	1516 (174)	1576 (147.9)	1749 (263.7)	1679 (285.1)	1338 (233.7)	1537 (176.6)	1585 (151.5)
CONSTANT	676.1 (670.8)	140.2 (706.5)	249.9 (583.8)	351.2 (360)	319.2 (319.5)	1167 (696.7)	143.5 (731.2)	339.5 (582.7)	463.4 (363.4)	364.9 (326.1)
R^2	.453	.439	.493	.459	.448	.407	.398	.490	.441	.420
F-statistic (Chow-test)				3.67	2.16				2.58	2.16

portfolio. The PITO parameter estimates are correctly signed but generally not very significant statistically. Also, it appears households' valuation of operating costs is reasonably stable over time providing the energy shock period is eliminated. This stability is supported by the long-run and short-run operating cost/utilization elasticities (calculated at the population mean) as indicated in Table 13.

Dynamic Aspects

The dynamic aspects include, as specified by the derivations in Chapter 3, the lagged utilization of the same vehicles in the vehicle portfolio (i.e. those vehicles owned in previous time periods) and the lagged utilization of similar make vehiclies in the portfolio. The parameter estimates for these variables (X1, X2, XP1, XP2) are all of plausible sign and generally statistically significant. Also, it should be pointed out that these parameter estimates appear to be quite unstable, as indicated by their magnitudes.

In comparing intertemporal and restricted models, the same qualitative conclusion found in previously presented estimations applies here. That is to say, that although the distinguishing variables X2 and XP2 result in statistically significant parameter estimates, the effect that the inclusion of such variables has on the remaining parameter estimates is not great.

Trip Generaion Variables

The trip generation variables included in the two-vehicle household utilization models where the same as those specified in the one-vehicle

Table 13. Utilization Elasticities (Standard Errors in Parentheses): Two-Vehicle Households

Elasticity with respect to	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
Operating Costs (Short-run)	-.102 (.121)	-.004 (.131)	-.127 (.116)	-.071 (.056)	-.059 (.052)	-.105 (.130)	-.008 (.136)	-.132 (.117)	-.044 (.056)	-.029 (.053)
Income (Short-run)	.055 (.048)	.069 (.052)	.067 (.047)	.058 (.053)	.065 (.027)	.058 (.050)	.094 (.054)	.064 (.047)	.055 (.032)	.066 (.030)
Operating costs (Long-run)	-.168 (.199)	-.007 (.232)	-.214 (.195)	-.116 (.092)	-.099 (.087)	-.150 (.185)	-.013 (.227)	-.222 (.197)	-.067 (.085)	-.045 (.082)
Income (Long-run)	.091 (.079)	.122 (.092)	.113 (.079)	.095 (.087)	.110 (.046)	.083 (.071)	.157 (.090)	.108 (.079)	.084 (.049)	.102 (.149)

household case; income (IO), urban location (URB), residence in the northeast (NEAST), age of household head (HAGE), and number of workers (NWORK). The income parameter estimates were properly signed and relatively stable over time as indicated in Table 12. This stability is also reflected in the long-run and short-run income/utilization elasticities presented in Table 3.

The URB parameter estimates were found to be statistically insignificant, which is somewhat surprising given the acceptably significant results found in the one-vehicle household case. Also, the other location specific variable (NEAST) produced insignificant parameter estimates as was the case with single vehicle households.

The lifestyle variable, the head of the household's age (HAGE) and the number of workers (NWORK), produced generally properly signed parameter estimates. The one noticeable exception is the NWORK parameter estimate in Period 2 which is negatively signed but not with a high degree of statistical significance. This can be explained, to some extent, by the fuel supply constraints that impacted utilization during the second period. As a final point, both the HAGE and NWORK parameter estimates appear to be unstable over time, as indicated by their corresponding parameter magnitudes.

The final variable included in the two-vehicle household utilization model is a dummy variable (NEWV) indicating if the vehicle is the newer (in terms of vintage) of the two vehicles comprising the household's vehicle portfolio. The hypothesis here is that newer vehicles will offer superior reliability and comfort thereby making them generally more desirable to use. Indeed, the NEWV parameter estimates were found to have a very strong influence on the determination of utilization, as indicated by the magnitude of the parameter estimate. Moreover, these estimates were found to be very highly statistically significant and reasonably stable over time.

Structural Stability

A number of Chow tests were conducted to test for the structural stability of the utilization equations over time. As the F-statistics indicate (see Table 12), the hypothesis of structural stability can be rejected at high confidence levels when all three periods are considered. When the turbulent energy shock period (Period 2) is excluded from consideration, it is found that the structural stability hypothesis can still be rejected with high confidence (i.e. greater than 99%). These results indicate that the utilization equations tend to be unstable over time, while the corresponding two-vehicle household type choice models indicated relative structural stability (see Section 5.3).

5.6 Level Choice Models

The level choice models specify the probability that a household will choose to own one or two vehicles. The general form of the level choice models is that indicated earlier by Equation (19). The actual variables included in estimation are presented in Table 14 along with their corresponding summary statistics. The resulting parameter estimates are provided in Table 15. Before proceeding with a discussion of these estimation results, it should be pointed out that the standard errors reported in Table 15 are not corrected for the fact that an

Table 14. Variables Used in the Level Choice Models

Variable	Mnemonic	PRD 1[a] Mean	PRD 2[b] Mean	PRD 3[c] Mean
Number of household members (Defined for 2 vehicle alt. only)	NMEM	2.748	2.770	2.772
Number of household workers (Defined for 2 vehicle alt. only)	NWORK	1.206	1.20	1.212
Income ($/yr) (Defined for 2 vehicle alt. only)	IO	17374	18234	18946
Urban dummy (1 if urban location, 0 otherwise) (Defined for 2 vehicle alt. only)	URB	.7291	.7257	.7273
Log sum from type choice models	LSUM	10.540	10.077	11.159
Choice dummy (1 if 2 vehicle alt., 0 otherwise)	ALT1	.4949	.4923	.4986
Number of observations	--	683	711	726

[a]Period 1 is type choice as of December 1978, with utilization from Jan. 1979 to June 1979. The mean fuel price in this six-month period is $0.72 per gallon.

[b]Period 2 is type choice as of June 1979, with utilization from June 1979 to Dec. 1980. The mean fuel price in this six-month period is $0.96 per gallon.

[c]Period 3 is type choice as of December 1979, with utilization from Jan. 1980 to June 1980. The mean fuel price in this six-month period is $1.17 per gallon.

estimated value of the logsum (which is the natural logarithm of the denominator of the logit type choice model) was used as opposed to the true value. Amemiya (1976) has shown that the use of estimated logsums results in standard errors that are biased downward (actual parameter estimates are not affected). As such, the standard errors reported in Table 15 should be viewed as a lower bound.

In structuring the following discussion, variables included in the level choice model specification are classified into two categories; 1) socioeconomic variables and 2) the vehicle type logsum variables.

Socioeconomic Variables

In all, four socioeconomic variables were included in the model specification; 1) the number of household members (NMEM), 2) number of household workers (NWORK), 3) household income (IO) and 4) an urban location variable (URB). Since parameter estimates of such variables can only be attained for one of the two alternatives (i.e. they do not vary across alternatives), all of these variables were defined only for the two-vehicle alternative.

The number of household members is inlcuded as an explanatory variable since it is hypothesized that larger households will be more likely to own two vehicles as opposed to one. As the estimates of Table 15 indicate, NMEM parameter estimates are properly signed (i.e. the larger the household, the greater the probability of owning two vehicles) and statistically significant. In terms of parameter magnitudes, there appears to be a slight decline in the importance that NMEM has on the probability of selecting two vehicles.

Table 15. Level Choice Model Parameter Estimates (Standard Errors in Parentheses)

Variable	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
NMEM	.372 (.080)	.387 (.075)	.247 (.071)	.311 (.052)	.345 (.043)	.379 (.082)	.392 (.075)	.293 (074)	.344 (.055)	.359 (.044)
NWORK	.508 (.141)	.581 (.135)	.618 (.128)	.593 (.093)	.559 (.076)	.482 (.142)	.561 (.136)	.511 (.133)	.482 (.097)	.472 (.079)
IO	.356E-04 (.100E-04)	.731E-05 (.811E-05)	.199E-04 (.758E-05)	.254E-04 (.597E-05)	.198E-04 (.48E-05)	.319E-04 (.100E-04)	.924E-05 (.804E-05)	.142E-04 (.778E-05)	.170E-04 (.611E-05)	.126E-04 (.48E-05)
URB	-.515 (.227)	-.453 (.214)	-.565 (.206)	-.557 (.150)	-.500 (.122)	-.487 (.232)	-.417 (.215)	-.503 (.212)	-.478 (.155)	-.447 (.126)
LSUM	.622 (.074)	.871 (.094)	.389 (.046)	.402 (.034)	.531 (.036)	.798 (.088)	.973 (.109)	.578 (.064)	.650 (.050)	.767 (.048)
ALT1	-2.34 (.327)	-1.95 (.304)	-1.86 (.283)	-2.14 (.212)	-2.17 (.174)	-2.47 (.336)	-2.03 (.303)	-2.13 (.297)	-2.29 (.223)	-2.23 (.180)
Log Likelihood at Zero	-473.4	-492.8	-503.2	-976.6	-1469	-473.4	-492.8	-503.2	-976.6	-1469
Log Likelihood at Convergence	-305.6	-331.5	-369.5	-691.6	-1029	-293.9	-326.8	-349.9	-646.2	-979
χ^2 Statistic (LR Test)				33.0	44.8				4.8	16.8

Based on the hypothesis that the number of household workers will be a strong determinant of the number of vehicles the household chooses to own, the variable NWORK is included in the model specification. The parameter estimates indicate that the greater the number of workers the greater the probability of the household selecting two vehicles as opposed to one. Moreover, Table 15 indicates that the NWORK parameters are statistically significant and relatively stable over time.

The income variable (IO) was also found to produce properly signed and statistically significant parameter estimates. That is to say, higher income households were found to be more likely to choose to own two vehicles than their lower income counterparts.

The final socioeconomic variable is defined for those households residing in an urban location. Due to the problems of parking, the availability of competing modes (e.g. bus), and the dense spatial distribution, it is hypothesized that urban households will be less likely to own two vehicles than rural households will. The parameter estimates in Table 15 support this hypothesis. Also, the URB parameter estimates appear to be relatively stable over time.

<u>The Logsum Variable</u>

The logsum variable (LSUM) is calculated as the natural logarithm of the denominator of the logit type choice models described in Sections 5.2 and 5.3. This variable represents the expected value of the maximum utility obtained from the vehicle type choice.

The resulting LSUM parameter estimates can be interpreted as measuring the degree of correlation of error terms within a level (one or two vehicles) choice. A parameter value of one indicates that the error terms are independent and hence the choice probabilities reduce to a simple multinomial logit form (i.e. a joint model of level and type). Conversely, a parameter value of zero indicates perfect correlation of error terms which in turn implies that for each level of ownership the household will select the vehicle type providing the highest utility with probability one.

Analogously, the LSUM parameter estimates can be viewed as a measure of substitutability (cross elasticity) between vehicle types. A parameter value approaching one indicates the substitutability between one- and two-vehicle ownership (i.e. levels) is high. Conversely, a parameter value approaching zero implies high substitutability among vehicle types within a given vehicle ownership level. In other words, demand shifts induced by external factors will result in the selection of different vehicle types as opposed to changes in vehicle ownership levels.

As a final point, McFadden (1981) has shown that a logsum parameter estimate must have a value between zero and one to be consistent with utility maximization.

The LSUM parameter estimates presented in Table 15 indicate a consistency with utility maximization. Moreover, the high statistical significance of the parameter estimates reflects the importance of the level and type choice relationship. It is also interesting to note that the magnitude of the parameter estimate changes markedly over time. In particular, note that during the energy shock (Period 2) the value of the LSUM parameter estimate approaches unity. This implies that the substitutability between ownership levels was quite high during this period. This estimate probably reflects the fact that households were feverishly adjusting their vehicle fleets (primarily the number) in response to rapidly changing fuel availability and cost structures.

A final point can be made with regard to the comparison between intertemporal and restricted model structures. In the case of the level choice model, the only distinction between the two models enters through the values of the LSUM variable which are determined from the estimated forms of the intertemporal and restricted type choice models. As Table 15 reveals, the parameter estimates of the LSUM variable do differ noticeably between intertemporal and restricted models. However, as was the case in the type choice and utilization models, the differences in the parameter estimates of variables common to both models are quite small.

Structural Stability

To test for structural stability in the level choice models, a number of likelihood ratio tests were conducted. The χ^2 statistics presented in Table 15 indicate that the hypothesis of structural stability can be rejected at high confidence levels for the intertemporal model, and at the 83% confidence level for the restricted model, when all time periods are considered. When the energy shock period is eliminated (Period 2) it is found that the hypothesis of structural stability can again be rejected at high confidence levels for the intertemporal model, and at the 43% confidence level for the restricted model. These results suggest a reasonable amount of instability (particularly in the case of the intertemporal model) in level choice parameter estimates. Recall that such instability was also suggested in the utilization models, but not in the type choice models.

5.7 Household Vehicle Demand Responsiveness

The objective of this section is to assess the sensitivity of households to changes in vehicle operating costs, vehicle capital costs, and household income. This is achieved by calculating (by enumeration over the household population) the elasticities of these factors with respect to the selection probability of a specific vehicle type (i.e. make, model, and vintage). The analysis of the resulting elasticities will be shown to provide information relating to changing demand responsiveness over time, comparisons of new and used vehicle responsiveness, the responsiveness of households owning different vehicle makes, and the competitiveness of specific vehicle manufacturers.

5.7.1 Overall Household Responsiveness

To begin, type choice elasticities are calculated for six vehicle types that include old and new domestic compact, foreign compact, domestic midsize, and domestic fullsize. The resulting elasticity estimates for income, capital costs, and operating costs are presented in Table 16 for single-vehicle households and in Table 17 for two-vehicle households. Before interpreting these results, it is important to point out that the vehicle type choice specifications employed in this study place the restriction that the summation of operating and capital cost

Table 16. Type Choice Elasticities: Single-Vehicle Households

Elasticity with Respect to	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
INCOME										
1972 Chevrolet Vega: Compact	.639	.678	.881	.728	.717	.685	.682	.904	.767	.729
1972 Toyota Corolla: Compact	.718	.752	.968	.808	.798	.767	.757	.995	.851	.809
1979 Chevrolet Chevette: Compact	1.817	1.53	1.58	1.64	1.65	1.94	1.54	1.65	1.73	1.64
1979 Toyota Corolla: Compact	1.99	1.62	1.67	1.73	1.75	2.06	1.63	1.74	1.82	1.74
1972 Ford Maverick: Midsize	.897	.922	1.17	.991	.976	.959	.927	1.20	1.04	.992
1979 Ford Granada: Midsize	2.16	1.85	2.01	1.98	1.99	2.25	1.86	2.09	2.09	1.99
1972 Oldsmobile Cutlass: Full Size	1.16	1.22	1.57	1.31	1.29	1.24	1.22	1.62	1.38	1.31
1979 Oldsmobile Cutlass: Full Size	2.23	1.90	2.05	2.04	2.05	2.32	1.91	2.14	2.15	2.04
CAPITAL COSTS										
1972 Chevrolet Vega: Compact	-.311	-.216	-.180	-.230	-.235	-.318	-.216	-.191	-.243	-.232
1972 Toyota Corolla: Compact	-.376	-.271	-.237	-.289	-.295	-.384	-.271	-.252	-.304	-.290
1979 Chevrolet Chevette: Compact	-1.59	-1.13	-.980	-1.21	-1.23	-1.63	-1.13	-1.04	-1.27	-1.21
1979 Toyota Corolla: Compact	-1.70	-1.22	-1.06	-1.30	-1.33	-1.74	-1.22	-1.13	-1.37	-1.31
1972 Ford Maverick: Midsize	-.466	-.315	-.253	-.337	-.343	-.476	-.316	-.269	-.355	-.338
1979 Ford Granada: Midsize	-1.73	-1.24	-1.09	-1.33	-1.35	-1.76	-1.25	-1.16	-1.40	-1.33
1972 Oldsmobile Cutlass: Full Size	-.576	-.398	-.331	-.426	-.435	-.588	-.400	-.352	-.448	-.428
1979 Oldsmobile Cutlass: Full Size	-1.80	-1.29	-1.13	-1.38	-1.41	-1.84	-1.30	-1.21	-1.46	-1.39
OPERATING COSTS										
1972 Chevrolet Vega: Compact	-.326	-.459	-.647	-.495	-.479	-.365	-.463	-.708	-.521	-.495
1972 Toyota Corolla: Compact	-.339	-.478	-.726	-.515	-.499	-.380	-.482	-.738	-.543	-.515
1979 Chevrolet Chevette: Compact	-.278	-.393	-.598	-.424	-.410	-.312	-.396	-.608	-.447	-.424
1979 Toyota Corolla: Compact	-.278	-.393	-.598	-.424	-.410	-.311	-.396	-.608	-.446	-.424
1972 Ford Maverick: Midsize	-.427	-.603	-.913	-.649	-.628	-.479	-.607	-.928	-.683	-.649
1979 Ford Granada: Midsize	-.423	-.598	-.908	-.644	-.623	-.474	-.602	-.923	-.679	-.644
1972 Oldsmobile Cutlass: Full size	-.578	-.815	-1.23	-.877	-.850	-.648	-.820	-1.25	-.924	-.877
1979 Oldsmobile Cutlass: Full size	-.423	-.598	-.908	-.644	-.623	-.474	-.602	-.923	-.678	-.644

Table 17. Type Choice Elasticities: Two-Vehicle Households

Elasticity with respect to	Intertemporal Model					Restricted Model				
	Period 1	Period 2	Period 3	Periods 1&3	All Periods	Period 1	Period 2	Period 3	Periods 1&3	All Periods
INCOME										
1972 Chevrolet Vega: Compact	.692	.962	.994	.840	.843	.692	.947	.980	.836	.836
1972 Toyota Corolla: Compact	.729	1.00	1.03	.876	.879	.730	.984	1.01	.873	.871
1979 Chevrolet Chevette: Compact	1.07	1.22	1.22	1.12	1.11	1.09	1.19	1.20	1.11	1.10
1979 Toyota Corolla: Compact	1.12	1.26	1.25	1.16	1.15	1.14	1.23	1.24	1.16	1.14
1972 Ford Maverick: Midsize	.764	1.07	1.11	.936	.940	.764	1.05	1.09	.932	.932
1979 Ford Granada: Midsize	1.18	1.38	1.39	1.26	1.25	1.19	1.35	1.37	1.25	1.24
1972 Oldsmobile Cutlass: Full Size	.856	1.22	1.28	1.06	1.07	.855	1.20	1.26	1.06	1.06
1979 Oldsmobile Cutlass: Full Size	1.20	1.40	1.41	1.28	1.27	1.22	1.37	1.39	1.27	1.26
CAPITAL COSTS										
1972 Chevrolet Vega: Compact	-.407	-.301	-.241	-.298	-.293	-.423	-.285	-.238	-.300	-.292
1972 Toyota Corolla: Compact	-.438	-.324	-.262	-.322	-.316	-.455	-.307	-.259	-.325	-.316
1979 Chevrolet Chevette: Compact	-.804	-.601	-.511	-.609	-.594	-.836	-.570	-.505	-.612	-.594
1979 Toyota Corolla: Compact	-.850	-.638	-.543	-.646	-.630	-.884	-.604	-.537	-.651	-.630
1972 Ford Maverick: Midsize	-.444	-.329	-.266	-.326	-.320	-.461	-.311	-.263	-.329	-.320
1979 Ford Granada: Midsize	-.860	-.643	-.548	-.652	-.636	-.894	-.609	-.542	-.656	-.636
1972 Oldsmobile Cutlass: Full Size	-.483	-.359	-.293	-.357	-.350	-.502	-.340	-.289	-.360	-.350
1979 Oldsmobile Cutlass: Full Size	-.884	-.662	-.565	-.672	-.655	-.919	-.627	-.559	-.676	-.655
OPERATING COSTS										
1972 Chevrolet Vega: Compact	-.319	-.692	-.806	-.586	-.590	-.304	-.693	-.796	-.580	-.583
1972 Toyota Corolla: Compact	-.322	-.703	-.816	-.593	-.598	-.307	-.704	-.805	-.587	-.590
1979 Chevrolet Chevette: Compact	-.300	-.650	-.758	-.552	-.555	-.285	-.652	-.749	-.544	-.549
1979 Toyota Corolla: Compact	-.297	-.651	-.755	-.549	-.553	-.283	-.652	-.745	-.543	-.546
1972 Ford Maverick: Midsize	-.357	-.775	-.903	-.657	-.661	-.340	-.776	-.892	-.650	-.653
1979 Ford Granada: Midsize	-.354	-.769	-.898	-.653	-.657	-.337	-.772	-.886	-.644	-.649
1972 Oldsmobile Cutlass: Full Size	-.412	-.899	-1.04	-.760	-.765	-.393	-.901	-1.03	-.751	-.756
1979 Oldsmobile Cutlass: Full Size	-.352	-.768	-.894	-.650	-.655	-.335	-.771	-.883	-.641	-.646

elasticities must be equal in magnitude (but opposite in sign) to the income elasticity. In preliminary estimations, it was found that such a restriction, which is not implausible, was necessary to obtain reasonable estimation results that controlled for income differences among households.

Turning now to the single-vehicle household elasticity estimates presented in Table 16, it is interesting to note that the earlier findings of increasing consumer's valuations of operating costs and decreasing valuations of capital costs (see Section 5.2), over time, are reflected in these type choice elasticities. Also notice that the income and capital cost elasticities are much larger for new vehicles than for old vehicles. This emphasizes the importance of pricing in the sale of new vehicles. In terms of operating cost elasticities, it appears as though older vehicles of the same class (e.g. compacts) are more elastic than their newer vehicle counterparts. As a final point, although the income and capital cost elasticities of foreign and domestic producers are similar, the domestic offerings are more sensitive to changes in operating costs. This reflects a general need for improved operating cost performance among domestic manufacturers. More on this matter will be said in Section 5.7.3.

For the case of two-vehicle households (see Table 17), it is first important to note that for all three elasticities (income, capital costs, and operating costs), two-vehicle households have much less variance across vehicle types than do single-vehicle household. It is speculated that this is so due to the flexibility that is afforded by the ownership of an additional vehicle, which leads to more uniform responses across vehicle types with respect to changes in vehicle costs and income. Also, in comparing one- and two-vehicle household responsiveness, Tables 16 and 17 indicate that income and capital cost elasticities are similar for old vehicles, but two-vehicle households are much less elastic with regard to income and capital cost elasticities for new vehicles. This is probably due in large part to the generally higher incomes of the two-vehicle household population. Finally, it is observed that the operating cost sensitivities of two-vehicle households have increased, over time, at higher rates than the single-vehicle household operating cost sensitivities. Again, this probably reflects the additional flexibility of the two-vehicle household in that they are more likely to enter the market and seek vehicles that are more appropriate in the face of the prevailing costs and economic climate.

5.7.2. Household Responsiveness by Vehicle Make

With the general responsiveness to various vehicle types discussed above, it is interesting to direct attention to the responsiveness of owners of specific makes of vehicles. This is done by estimating elasticities, as before, but enumerating only over that portion of the population owning vehicles of a specified make. In all, households of seven vehicle makes (Ford, Chevrolet, all foreign makes, Chrysler, American Motors, Oldsmobile, and Toyota) were considered. The elasticities were calculated only from the intertemporal type choice model (since the earlier estimates in Tables 16 and 17 revealed little difference between the restricted and intertemporal models) and only for the periods before and after the energy shock.

The resulting elasticity estimates for single-vehicle households are presented in Table 18. For income elasticities, Ford, AMC and Toyota owners have the highest elasticities followed by Chrysler, Chevrolet, Oldsmobile, and foreign vehicle owners. The AMC owners had the interesting effect of slightly increasing income elasticities for old cars and greatly decreasing elasticities for new cars, over time. It is possible that this irregular effect was caused by different households, with different socioeconomic conditions, owning AMC vehicles in the two time periods.

The capital cost elasticities reflect the same pattern with Ford, AMC and Toyota owners being the most elastic followed by Chrysler, Chevrolet, Oldsmobile, and foreign vehicle owners. The AMC owners again demonstrate unusual instability over time as they become much less elastic with respect to capital costs. For operating cost elasticities, the same rank of makes resulted, with households becoming more elastic over time as opposed to the capital cost case, in which they became less elastic. In terms of absolute values, before the energy shock, operating cost and capital costs elasticities were about equal for older vehicles, and capital cost elasticities were greater than operating cost eleasticities for new vehicles. After the shock, operating cost elasticities exceed capital cost elasticities for older vehicles but capital cost elasticities still dominate operating cost elasticities for newer cars. This suggests that even though fuel efficiency has become more important, the vehicle cost is still the critical factor. This finding underscores the importance of new vehicle

Table 18. Type Choice Elasticities by Make: Single-Vehicle Households (Intertemporal Model)

	Ford		Chevrolet		Foreign		Chrysler		AMC		Oldsmobile		Toyota	
Income	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3
'72 Vega	.767	1.16	.658	.931	.468	.758	.640	.998	1.02	1.12	.472	.797	.743	1.17
'72 Corolla	.863	1.26	.738	1.01	.525	.822	.718	1.08	1.14	1.22	.529	.864	.835	1.27
'79 Chevrolet	2.29	2.28	1.92	1.82	1.36	1.47	1.86	1.92	3.02	2.26	1.36	1.54	2.20	2.28
'79 Corolla	2.43	2.38	2.03	1.90	1.44	1.53	1.97	2.00	3.20	2.37	1.44	1.61	2.33	2.39
'72 Maverick	1.08	1.58	.923	1.27	.656	1.03	.897	1.36	1.43	1.53	.661	1.08	1.04	1.59
'79 Granada	2.63	2.80	2.21	2.23	1.57	1.80	2.14	2.36	3.47	2.76	1.57	1.89	2.53	2.80
'72 Cutlass	1.39	2.09	1.19	1.67	.849	1.36	1.16	1.79	1.84	2.02	.856	1.43	1.35	2.10
'79 Cutlass	2.72	2.87	2.28	2.29	1.63	1.85	2.22	2.42	3.59	2.83	1.62	1.94	2.61	2.87
Capital Costs														
'72 Vega	-.382	-.299	-.317	-.238	-.225	-.190	-.307	-.248	-.504	-.302	-.223	-.200	-.365	-.298
'72 Corolla	-.462	-.362	-.383	-.288	-.272	-.230	-.371	-.300	-.608	-.365	-.270	-.242	-.441	-.350
'79 Chevrolet	-1.96	-1.53	-1.62	-1.21	-1.16	-.975	-1.57	-1.27	-2.58	-1.55	-1.14	-1.02	-1.87	-1.53
'79 Corolla	-2.09	-1.64	-1.74	-1.30	-1.24	-1.04	-1.68	-1.36	-2.76	-1.66	-1.22	-1.10	-2.00	-1.63
'72 Maverick	-.573	-.448	-.475	-.357	-.338	-.285	-.460	-.372	-.755	-.453	-.334	-.299	-.546	-.446
'79 Granada	-2.12	-1.66	-1.76	-1.32	-1.25	-1.06	-.171	-1.38	-2.80	-1.68	-1.24	-1.11	-2.03	-1.65
'72 Cutlass	-.707	-.553	-.586	-.440	-.417	-.352	-.568	-.459	-.932	-.558	-.413	-.369	-.675	-.550
'79 Cutlass	-2.22	-1.73	-1.84	-1.38	-1.31	-1.10	-1.78	-1.44	-2.92	-1.75	-1.29	-1.16	-2.11	-1.72
Operating Costs														
'72 Vega	-.383	-.857	-.339	-.689	-.241	-.564	-.331	-.745	-.508	-.817	-.248	-.593	-.376	-.867
'72 Corolla	-.399	-.893	-.353	-.718	-.251	-.588	-.345	-.776	-.529	-.851	-.258	-.618	-.392	-.904
'79 Chevrolet	-.327	-.735	-.290	-.591	-.206	-.484	-.282	-.639	-.434	-.700	-.211	-.509	-.321	-.744
'79 Corolla	-.326	-.735	-.289	-.591	-.206	-.484	-.282	-.639	-.434	-.700	-.211	-.509	-.321	-.744
'72 Maverick	-.502	-1.12	-.444	-.903	-.316	-.739	-.434	-.976	-.667	-1.07	-.324	-.777	-.493	-1.14
'79 Granada	-.497	-1.12	-.440	-.897	-.313	-.735	-.429	-.970	-.660	-1.06	-.321	-.773	-.488	-1.13
'72 Cutlass	-.679	-1.52	-.602	-1.22	-.428	-.999	-.587	-1.32	-.902	-1.44	-.439	-1.05	-.668	-1.54
'79 Cutlass	-.496	-1.12	-.440	-.897	-.313	-.735	-.429	-.970	-.659	-1.06	-.321	-.773	-.488	-1.13

pricing even when considerable changes in the valuations of other vehicle attributes have occurred.

The elasticity estimates for two vehicle households are given in Table 19. The order of the makes, by magnitude of the income elasticity, is substantially different than that order found in the single vehicle case. Specifically, Oldsmobile owners are the most elastic, followed by Chevrolet, Chrysler, AMC, Ford, foreign makes, and finally Toyota owners. The differences in these orderings as opposed to those in the single vehicle household case, may be the result of a number of factors including the fact that the "other" vehicle owned in the vehicle portfolio (which may or may not be of the same make) can have a considerable impact on elasticity estimates.

For both operating cost and capital cost elasticities, the order of the vehicle makes based on the absolute values of their elastcities is essentially the same as that found in the income elasticity case discussed above. Also, in contrast to the single vehicle household case, the absolute value of the capital cost elasticity is greater than that of the operating cost elasticity before the energy shock, but the oppositve is true for all vehicle types (old and new) after the energy shock. Therefore, in the case of the two vehicle households, the sensitivity to the fuel efficiency of new vehicles now outweights the sensitivity to capital costs. The fact that this is not the case in the single vehicle household may be the result of the differing income levels of the two populations.

Table 19. Type Choice Elasticities by Make: Two-Vehicle Households (Intertemporal Model)

	Ford		Chevrolet		Foreign		Chrysler		AMC		Oldsmobile		Toyota	
Income	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3	PRD1	PRD3
'72 Vega	.575	.886	.684	1.07	.467	.637	.596	.907	.770	.902	.819	1.68	.454	.599
'72 Corolla	.606	.917	.725	1.12	.487	.659	.624	.938	.819	.934	.899	1.73	.491	.628
'79 Chevette	.902	1.09	1.06	1.32	.699	.775	.919	1.12	1.33	1.12	1.75	2.03	.724	.714
'79 Corolla	.941	1.12	1.11	1.36	.726	.795	.956	1.14	1.39	1.15	1.85	2.07	.764	.737
'72 Maverick	.631	.980	.761	1.21	.512	.715	.657	1.02	.874	1.02	.979	1.85	.511	.671
'79 Granada	.984	1.23	1.17	1.52	.766	.887	1.01	1.28	1.48	1.28	1.98	2.27	.809	.821
'72 Cutlass	.717	1.14	.849	1.39	.570	.823	.735	1.17	1.01	1.17	1.17	2.08	.585	.775
'79 Cutlass	1.02	1.26	1.19	1.53	.790	.897	1.03	1.29	1.52	1.30	2.03	2.28	.821	.829
Capital Costs														
'72 Vega	-.333	-.212	-.406	-.252	-.313	-.229	-.350	-.212	-.378	-.190	-.742	-.437	-.242	-.202
'72 Corolla	-.358	-.230	-.439	-.276	-.331	-.242	-.374	-.231	-.420	-.209	-.758	-.467	-.262	-.212
'79 Chevette	-.673	-.453	-.792	-.545	-.556	-.396	-.686	-.461	-.957	-.447	-1.07	-.838	-.527	-.346
'79 Corolla	-.710	-.480	-.842	-.583	-.582	-.414	-.723	-.488	-1.02	-.476	-1.17	-.881	-.555	-.360
'72 Maverick	-.360	-.231	-.446	-.281	-.335	-.244	-.380	-.235	-.431	-.214	-.782	-.473	-.268	-.215
'79 Granada	-.712	-.479	-.853	-.591	-.590	-.418	-.733	-.495	-1.04	-.483	-1.20	-.893	-.566	-.366
'72 Cutlass	-.397	-.258	-.483	-.310	-.359	-.260	-.413	-.259	-.487	-.239	-.841	-.510	-.296	-.229
'79 Cutlass	-.739	-.500	-.876	-.608	-.604	-.428	-.752	-.509	-1.07	-.497	-1.25	-.913	-.582	-.374
Operating Costs														
'72 Vega	-.275	-.728	-.321	-.887	-.196	-.463	-.289	-.750	-.413	-.737	-.730	-1.29	-.212	-.397
'72 Crolla	-.281	-.742	-.317	-.887	-.204	-.477	-.294	-.764	-.420	-.751	-.741	-1.31	-.229	-.418
'79 Chevette	-.258	-.684	-.302	-.834	-.182	-.430	-.271	-.705	-.386	-.691	-.690	-1.22	-.197	-.368
'79 Corolla	-.259	-.686	-.293	-.821	-.185	-.433	-.271	-.707	-.386	-.694	-.690	-1.22	-.209	-.379
'72 Maverick	-.322	-.838	-.350	-.976	-.226	-.533	-.324	-.843	-.465	-.830	-.806	-1.42	-.243	-.458
'79 Granada	-.319	-.833	-.346	-.971	-.224	-.529	-.321	-.838	-.461	-.824	-.797	-1.41	-.241	-.455
'72 Cutlass	-.316	-.954	-.406	-1.13	-.267	-.635	-.376	-.981	-.543	-.968	-.928	-1.65	-.289	-.548
'79 Cutlass	-.307	-.814	-.346	-.971	-.224	-.529	-.321	-.838	-.461	-.824	-.807	-1.44	-.241	-.454

5.7.3 Responsiveness to Manufacturer Offerings

To assess the relative competitivenss of vehicle manufacturers as of the spring of 1980, the capital cost, oeprating cost, and income elasticities were calculated for the manufacturers' 1980 model year vehicle offerings. The elasticities were estimated using the entire one- and two-vehicle populations, and the type choice parameter estimates of the Period 3 (i.e. spring of 1980) intertemporal model. The resulting elasticities for single-vehicle households are presented in Table 20, and the estimates for two-vehicle households are given in Table 21.

In interpreting the single-vehicle household results, it is first noticed that luxury makes have model offerings that are very sensitive to capital costs and income. Examples of this include Cadillac, Lincoln, BMW, Jaguar, Mercedes, and Volvo. It is speculated that high sensitivities reflect the fact that such vehicles are not economically accessible to a large portion of the single-vehicle household population. Another important finding is that the sensitivity of domestic vehicles to operating costs tend ot be greater than that of their foreign counterparts. This is reflected in the fact that, although many domestic vehicle models have operating cost elasticities with an absolute value greater than unity, only one foreign model is in such a category (the Jaguar XJ6). This reflects the potential of domestic manufacturers to benefit from the improved fuel efficiency of their vehicle offerings, as of the spring of 1980. Of course any improvement directed towards fuel efficiency must be made with the demand sensitivities to capital costs and income in mind.

Table 20. Type Choice Elasticities by 1980 Model Year Offerings: Single-Vehicle Households (Intertemporal Model)

Make and Model	Elasticity with Respect to Capital Costs	Operating Costs	Income
American Motors			
Concord	-1.42	-.785	2.22
Pacer	-1.59	-1.01	2.63
Spirit	-1.39	-.785	2.19
Buick			
Century	-1.70	-.955	2.67
Electra	-2.47	-1.14	3.64
Le Sabre	-1.85	-1.01	2.88
Regal	-1.87	-.954	2.85
Riviera	-3.14	-1.06	4.24
Skylark	-1.59	-.784	2.39
Skyhawk	-1.68	-.821	2.51
Cadillac			
De Ville	-3.20	-1.21	4.46
Eldorado	-3.91	-1.21	5.16
Seville	-4.18	-1.20	5.43
Fleetwood	-3.53	-1.21	4.78
Chevrolet			
Chevette	-1.49	-.597	2.10
Corvette	-3.71	-1.06	4.80
Impala	-1.74	-1.07	2.84
Malibu	-1.65	-.956	2.63
Monte Carlo	-1.89	-.954	2.86
Monza	-1.51	-.720	2.24
Camaro	-1.97	-.954	2.94
Citation	-1.90	-.783	2.70

(Continued next page)

Table 20 (Continued)

Make and Model	Capital Costs	Operating Costs	Income
	Elasticity with Respect to		
Chrysler			
Cordoba	-1.82	-1.07	2.91
Le Baron	-1.72	-1.07	2.81
Newport	-1.88	-1.22	3.13
New Yorker	-2.30	-1.22	3.54
Dodge			
Aspen	-1.42	-.957	2.39
Colt	-1.48	-.509	1.99
Omni	-1.72	-.690	2.42
Diplomat	-1.66	-1.07	2.87
St. Regis	-1.78	-1.07	2.87
Ford			
Fairmont	-1.57	-1.07	2.67
Fiesta	-1.41	-.617	2.03
Granada	-1.62	-.905	2.54
LTD	-1.71	-1.14	2.88
Mustang	-1.68	-.829	2.51
Thunderbird	-1.88	-1.22	3.13
Pinto	-1.33	-.785	2.12
Escort	-1.75	-.557	2.31
Lincoln			
Mark VI	-3.08	-1.41	4.53
Versailles	-3.29	-1.06	4.39
Mercury			
Bobcat	-1.28	-.597	1.88
Cougar	-1.54	-1.22	2.79
Monarch	-1.67	-1.01	2.70
Zephyr	-1.59	-.910	2.51
Capri	-1.77	-.860	2.65

(Continued next page)

Table 20 (Continued)

Make and Model	Elasticity with Respect to Capital Costs	Operating Costs	Income
Oldsmobile			
Cutlass	-1.69	-.906	2.61
Delta	-1.94	-.859	2.82
Omega	-1.78	-.749	2.55
Starfire	-1.62	-.719	2.35
Toronado	-3.14	-1.06	4.24
Ninety-Eight	-2.43	-1.13	3.60
Plymouth			
Arrow	-1.62	-.617	2.24
Fury	-1.57	-1.07	2.67
Horizon	-1.72	-.690	2.42
Volare	-1.42	-.957	2.39
Champ	-1.55	-.509	2.06
Pontiac			
Firebird	-1.74	-1.07	2.83
Grand Prix	-1.96	-.953	2.93
Pheonix	-1.34	-.751	2.10
Sunbird	-1.41	-.720	2.14
Foreign			
Audi Fox	-2.03	-.748	2.79
BMW 320i	-3.62	-.682	4.32
Datsun 200 SX	-1.89	-.749	2.65
Datsun 210	-1.54	-.495	2.04
Datsun 280Z	-3.13	-.946	4.10
Datsun 510	-1.69	-.719	2.42
Datsun 810	-1.85	-.869	2.73
Fiat X19	-1.82	-.639	2.47
Honda CIVIC	-1.55	-.618	2.18
Honda CVCC	-1.65	-.596	2.25

(Continued next page)

Table 20 (Continued)

Make and Model	Capital Costs	Operating Costs	Income
	Elasticity with Respect to		
Honda Accord	-2.01	-.638	2.66
Jaguar XJ6	-5.14	-1.11	-6.31
Mazda GLC	-1.47	-.577	2.06
Mazda RX7	-3.09	-.946	4.06
Mercedes 280	-6.10	-.927	7.07
MG MGB	-2.06	-1.07	3.15
Peugeot 504	-2.49	-.746	3.26
Porsche 924	-4.30	-.706	5.03
Renault Le Car	-1.34	-.665	2.01
Subaru DL	-1.42	-.618	2.05
Subaru Wagon	-1.21	-.642	1.85
Subaru GF	-1.53	-.617	2.15
Toyota Corona	-1.85	-.954	2.82
Toyota Celica	-2.02	-.954	3.00
Toyota Corolla	-1.60	-.558	2.16
Toyota Cressida	-2.37	-.951	3.34
Triumph TR7	-2.10	-.688	2.80
VW Dasher	-2.08	-.748	2.84
VW Rabbit	-1.70	-.690	2.41
VW Diesel Rab.	-1.76	-.422	2.19
VW Scirrocco	-2.17	-.688	2.87
Volvo 260 S	-3.03	-.898	3.95

The two-vehicle household type choice elasticities (see Table 21) reveal patterns similar to those found in the single-vehicle household case. First, the capital cost and income elasticities of luxury vehicles (e.g. Cadillac,Lincoln, Mercedes, and so on) are high relative to other vehicle classes, but not nearly as high as they were in the single-vehicle household case. This is probably due to the higher two-vehicle household incomes and the greater vehicle ownership flexibility afforded to two-vehicle households. In terms of operating cost elasticities, single- and two-vehicle households have elasticities of similar magnitude, with the two-vehicle household having noticeably less variance in elasticities across vehicle makes and models. This finding supports the results presented in the preceding two sections of this chapter. Finally, the two-vehicle households demonstrate the same higher operating cost sensitivity to domestic offerings, as opposed to foreign offerings, although the differences between these sensitivities do not appear to be as high as they were in the single-vehicle household case.

5.8 Model Specification Tests

A number of specification tests were conducted to evaluate the validity of the multinomial logit (MNL) structure used in the estimation of the vehicle type choice models. Specifically, tests are made to assess the reasonableness of the limitations that the MNL model imposes on the substitutability of the type choice alternatives. This MNL limitation, of course, is the widely known "independence of irrelevant alternatives" (IIA) property.

Table 21. Type Choice Elasticities by 1980 Model Year Offerings: Two-Vehicle Households (Intertemporal Model)

Make and Model	Capital Costs	Operating Costs	Income
American Motors			
Concord	-.662	-.839	1.45
Pacer	-.722	-.941	1.62
Spirit	-.653	-.839	1.44
Buick			
Century	-.756	-.915	1.62
Electra	-1.01	-.997	1.97
Le Sabre	-.809	-.939	1.70
Regal	-.815	-.914	1.68
Riviera	-1.24	-.963	2.16
Skylark	-.719	-.837	1.51
Skyhawk	-.749	-.854	1.56
Cadillac			
DeVille	-1.27	-1.03	2.26
Eldorado	-1.51	-1.02	2.49
Seville	-1.60	-1.03	2.59
Fleetwood	-1.37	-1.03	2.36
Chevrolet			
Chevette	-.686	-.757	1.39
Corvette	-1.44	-.969	2.36
Impala	-.769	-.974	1.68
Malibu	-.741	-.921	1.61
Monte Carlo	-.819	-.920	1.68
Monza	-.692	-.814	1.46
Camaro	-.846	-.921	1.71
Citation	-.825	-.842	1.62

(Table continued next page)

Table 21 (Continued)

Make and Model	Capital Costs	Operating Costs	Income
Chrysler			
Cordoba	-.797	-.968	1.72
Le Baron	-.763	-.968	1.69
Newport	-.819	-1.04	1.81
New Yorker	-.960	-1.03	1.94
Dodge			
Aspen	-.663	-.917	1.53
Colt	-.683	-.714	1.35
Omni	-.764	-.796	1.52
Diplomat	-.745	-.969	1.66
St. Regis	-.786	-.969	1.71
Ford			
Fairmont	-.714	-.973	1.63
Fiesta	-.657	-.766	1.37
Granada	-.729	-.896	1.58
LTD	-.760	-1.00	1.71
Mustang	-.747	-.851	1.55
Thunderbird	-.818	-1.04	1.81
Pinto	-.631	-.842	1.42
Escort	-.772	-.737	1.47
Lincoln			
Mark VI	-1.22	-1.12	2.30
Versailles	-1.29	-.961	2.22
Mercury			
Bobcat	-.616	-.753	1.33
Cougar	-.704	-1.04	1.69
Monarch	-.748	-.940	1.64
Zephyr	-.722	-.892	1.57

(Table continued next page)

Table 21 (Continued)

Make and Model	Capital Costs	Operating Costs	Income
Capri	-7.81	-.871	1.61
Oldsmobile			
Cutlass	-.754	-.892	1.60
Delta	-.842	-.871	1.67
Omega	-.787	-.821	1.51
Starfire	-.731	-.808	1.49
Toronado	-1.25	-.962	2.17
Ninety-Eight	-1.00	-.997	1.96
Plymouth			
Arrow	-.730	-.761	1.43
Fury	-.716	-.969	1.64
Horizon	-.765	-.795	1.52
Volare	-.664	-.916	1.53
Champ	-.707	-.713	1.38
Pontiac			
Firebird	-.771	-.968	1.69
Grand Prix	-.848	-.913	1.72
Pheonix	-.635	-.822	1.42
Sunbird	-.659	-.809	1.43
Foreign			
Audi Fox	-.871	-.822	1.65
BMW 320i	-1.41	-.789	2.17
Datsun 200SX	-.824	-.822	1.61
Datsun 210	-.705	-.707	1.37
Datsun 280Z	-1.24	-.911	2.12
Datsum 510	-.757	-.809	1.53
Datsun 810	-.812	-.873	1.64
Fiat X19	-.802	-.773	1.54
Honda Civic	-.707	-.763	1.43

(Table continued next page)

Table 21 (Continued)

Make and Model	Capital Costs	Operating Costs	Income
Honda CVCC	-.743	-.753	1.45
Honda Accord	-.866	-.772	1.60
Jaguar XJ6	-1.93	-.986	2.89
Mazda GLC	-.681	-.745	1.39
Mazda RX7	-1.23	-.911	2.10
Mercedes 280	-2.25	-.898	3.13
MG MGB	-.882	-.969	1.81
Peugeot 504	-1.03	-.820	1.81
Porsche 924	-1.64	-.800	2.42
Renault Le Car	-.637	-.785	1.38
Subaru DL	-.667	-.764	1.39
Subaru Wagon	-.591	-.775	1.32
Subaru GF	-.702	-.743	1.43
Toyota Corona	-.811	-.916	1.68
Toyota Celica	-.870	-.915	1.74
Toyota Corolla	-.726	-.736	1.42
Toyota Cressida	-.987	-.914	1.86
Triumph TR7	-.896	-.795	1.65
VW Dasher	-.889	-.822	1.67
VW Rabbit	-.760	-.796	1.51
VW Diesel Rabbit	-.779	-.674	1.42
VW Scirrocco	-.918	-.794	1.67
Volvo 260 S	-1.21	-.889	2.06

In the case of vehicle type choice modeling, there are some intuitive reasons for suspecting possible IIA violations. For example, using the MNL structure, an increase in the capital cost of a Ford Escort will necessarily result in the household's probability of selecting any other vehicle type to increase by the same percentage. It may be more realistic to expect the household's probability of selecting other compact cars to increase more than their probability of selecting a large luxury car (e.g. Cadillac). This type of possible IIA violation led Berkovec and Rust (1981) to estimate a nested logit structure in which households first select the class of vehicle to own and then the type of vehicle within a given class (see Chapter 2 for a further discussion of this effort). Their empirical results seem to point towards rejection of the IIA principle and an MNL type choice specification. More recently, Booz, Allen & Hamilton (1983) attempted to estimate a nested structure similar to the Berkovec and Rust model, but the idea was abandoned when implausible empirical results were obtained.

In point of fact, a number of statistical tests are available to evaluate the validity of an MNL structure. These tests include those of McFadden, Train and Tye (1977), Horowitz (1981), Hausman and McFadden (1981), and Small and Hsiao (1982). The recent work of Small and Hsiao has indicated that both the McFadden-Train-Tye and Horowitz tests are asymptotically biased, and that the Hausman and McFadden test can be exceedingly difficult to use in certain applications. Subsequently, the tests conducted in this work use the asymptotically unbiased likelihood ratio test developed by Small and Hsiao.

The Small-Hsiao test procedure is relatively easy to conduct. First, the household sample is randomly divided into two equal sizes, N^A and N^B, and model parameter estimates are obtained for each of these samples, vectors $\hat{\theta}_0^A$ and $\hat{\theta}_0^B$. A weighted average of these parameters is obtained from:

$$\hat{\theta}_0^{AB} = (1/\sqrt{2})\ \hat{\theta}_0^A + (1-1/\sqrt{2})\ \hat{\theta}_0^B \qquad (45)$$

Then, a restricted choice set, D, is created as a sub-sample from the full choice set, and the household sample N^B is reduced to include only those households which actually choose alternatives that lie in D. Two models are estimated with the reduced N^B household sample using the choice set D as if it were the entire choice set. One model is estimated by constraining the parameter vector to be equal to the $\hat{\theta}_0^{AB}$ vector defined above. The second model estimates the unconstrained parameter vector $\hat{\theta}_1^B$. The resulting log-likelihoods can be used to evaluate the suitability of the MNL model by creating a Chi-square statistic with the number of degrees of freedom equal to the number of parameters in the vectors $\hat{\theta}_0^{AB}$ and $\hat{\theta}_1^B$. This statistic is:

$$\chi^2 = -2[L_1^B(\hat{\theta}_0^{AB}) - L_1^B(\hat{\theta}_1^B)] \qquad (46)$$

The Small-Hsiao test should also be estimated by interchanging the roles of the N^A and N^B sub-samples (i.e. reduce the N^A household sample to those households whose chosen alternatives lie in D, and proceed). Using the same notation, Equation (45) is rewritten as:

$$\hat{\theta}_0^{BA} = (1/\sqrt{2})\ \hat{\theta}_0^{B} + (1 - 1/\sqrt{2})\ \hat{\theta}_0^{A} \qquad (47)$$

and the Chi-square statistic is now:

$$\chi^2 = -2[L_1^A\ (\hat{\theta}_0^{BA}) - L_1^A\ (\hat{\theta}_1^{A})] \qquad (48)$$

Tests of the multinomial logit type choice structure were conducted with the single- and two-vehicle household intertemporal model specifications. The results of these tests are presented in Table 22, and their interpretation is presented below.

In all, three distinct Small-Hsiao specification tests were undertaken in the case of single-vehicle households. The primary distinction of these tests is the method by which the restricted choice set, D, is determined. In the first instance, the restricted choice set consists of five alternatives that were selected at random from the original ten alternative choice sets. This random choice set should give some indication if in fact an IIA problem exists. The test restuls indicate (see Table 22) that the null hypothesis of an MNL structure cannot be rejected at reasonable confidence levels (only at the 29 or 35 percent confidence levels).

In the second test, the restricted choice set consists of only U.S. made cars (one degree of freedom is lost since the FORN parameter estimate cannot be determined). The belief here is that U.S. cars may be viewed as grouped, and therefore share unobservables in violoation of logit assumptions. Again, the null hypothesis of an MNL structure cannot be rejected at reasonable conficence levels (only at the 2 or 10 percent confidence levels).

Table 22. Test of the Multinomial Logit Type Choice Specification

(χ^2 Statistic)

Intertemporal Model

	Single Vehicle Households			Two Vehicle Household
	Random Alternatives[a]	U.S. Cars[b]	Large Cars[c]	Random Alternatives[a]
Small-Hsiao Statistic	12.46	5.8	19.63	5.2
Small-Hsiao on interchanged subsamples	13.22	8.4	15.76	5.8
Degrees of Freedom	16	15	16	14

[a]Five alternatives are selected at random from the original ten alternative choice set.

[b]Only American made vehicles comprise the restricted choice set.

[c]Only automobiles with curb weights exceeding 3500 lbs comprise the restricted choice set.

In the final case, the restricted choice set consists only of those automobiles with curb weights exceeding 3500 lbs (i.e. large cars). This is done based on the suspicion that cars of the same class are viewed as grouped. This, of course, is the premise of the Berkovec and Rust (1981) vehicle class model. Again it is found that the null hypothesis of an MNL structure cannot be rejected at acceptable confidence levels (only at the 76 and 53 percent confidence levels).

For two vehicle households, the Small-Hsiao test was conducted only for a random restricted choice set. With five alternatives selected at random from the original ten, it is found that the MNL specification can only be rejected with 2 or 3 percent confidence.

In summary, there does not appear to be any statistical justification for believing that the single- and two-vehicle household type choice models estimated in this work are misspecified. Indeed, the MNL vehicle type choice specification seems to be quite satisfactory.

CHAPTER 6. SUMMARY AND CONCLUSIONS

The objective of this work was to assess the demand for motor vehicles in the U.S. To achieve this, the analysis was undertaken at the household level, and full explicit consideration was given to the interrelationships between the household's choices of quantity of vehicles to own, types of vehicles to own (defined by make, model, and vintage) and the extent to which these vehicle types are utilized (measured in vehicle miles traveled). Moreover, the dynamic aspects of the household's vehicle ownership and utilization decision were accounted for by viewing dynamics as the evoluation of household tastes. Based on fundamentally different economic theories relating to the manner in which households address the intertemporal nature of their vehicle ownership problem, two dynamic econometric models of vehicle ownership and utilization were derived.

The derived models were estimated with a national household sample in which all relevant vehicle ownership information was available for the same households for a two-and-one-half year period, December 1977 to June 1980. The resulting model estimations indicate the following:

1. Domestic manufacturers enjoy an inherent preference in the household's vehicle type selection process as opposed to their foreign counterparts.
2. Households' valuations of operating costs in the determination of the type of vehicle to own has increased over the 1978 to 1980 time period. Correspondingly, the rate at which

future operating costs are discounted has declined, indicating less myopic behavior and/or an expectation of future increases in fuel prices.

3. The elasticities of operating costs and income with respect to household vehicle utilization (VMT) are quite small. This is an important point to keep in mind in the formulation of national energy policies.
4. As expected, the process through which vehicle utilization is determined was strongly impacted by the supply restrictions of the energy shock period (June 1979 to December 1979).
5. A strong relationship was found to exist between the choice of the number and types of vehicles to own. This relationship is an important concern that should be addressed in any vehicle demand study.
6. Domestic manufacturers could benefit significantly by improving the fuel efficiencies of their model offerings.
7. Household income is a driving force in the determination of both the quantity and the types of vehicles to own. This underscores the important role that macroeconomics play in the viability of the automobile industry.

In summary, the results of this study suggest that vehicle demand conditions favor the survival of the domestic automobile industry. This is reflected in the inherent preference of consumers towards GM and Ford products, and to a lesser extent Chrysler and AMC products, as opposed to foreign made vehicles. However, to exploit this preference, domestic manufacturers must be able to offer reasonably competitive vehicle models, both in terms of performance and capital costs. Whether or not this can be achieved is an important supply oriented question that should be addressed in future research.

Appendix A. Derivation of the Restricted Dynamic Utilization Equation

The following procedure is used to eliminate the unmeasurable state variable from the restricted dynamic utilization equation. Recall that the utilization equation is of the form:

$$x_{it} = \tau_i + \beta_i(I_i - C_{it}) + \alpha_i \bar{S}_{it} \tag{1a}$$

By definition,

$$\bar{S}_{it} = 1/2(S_{it} + S_{it-1}) \tag{2a}$$

To begin, recall from the text that

$$\frac{\partial S_i}{\partial t} = \dot{S}_{it} = J_{it} - \delta_i S_{it} \tag{3a}$$

Now, consider an approximation of equation (3a),

$$\dot{S}_{it} = S_{it} - S_{it-1} = J_{it} - \delta_i \bar{S}_{it} \tag{4a}$$

Also, from equations (2a) and (4a):

$$\begin{aligned} 2(\bar{S}_{it} - \bar{S}_{it-1}) &= (S_{it} + S_{it-1}) - (S_{it-1} + S_{it-2}) \\ &= (S_{it} - S_{it-1}) + (S_{it-1} - S_{it-2}) \qquad (5a) \\ &= (J_{it} + J_{it-1}) - \delta_i(\bar{S}_{it} + \bar{S}_{it-1}) \end{aligned}$$

Differencing equation (1a) (and using approximations as in equation (4a)), and substituting equation (5a), yields

$$\begin{aligned} 2(x_{it} - x_{it-1}) &= 2\beta_i(\lambda_{it} - \lambda_{it-1}) + 2\alpha_i(\bar{S}_{it} - \bar{S}_{it-1}) \qquad (6a) \\ &= \alpha_i(J_{1t} + J_{it-1}) - \alpha_i\delta_i(\bar{S}_{it} + \bar{S}_{it-1}) + 2\beta_i(\lambda_{it} - \lambda_{it-1}) \end{aligned}$$

where: $\lambda_{it} = I_t - C_{it}$ and $\lambda_{it-1} = I_{t-1} - C_{it-1}$.

Write equation (1a) as

$$-\alpha_i \delta_i \bar{S}_{it} = \delta_i \tau_i + \delta_i \beta_i \lambda_{it} - \delta_i x_{it}. \qquad (7a)$$

Substituting equation (7a) into equation (6a) and using the definition of J_{it} given in the text (equation (8)), yields

$$\begin{aligned} 2(x_{it} - x_{it-1}) &= -\delta_i (x_{it} + x_{it-1}) + 2\delta_i \tau_i \\ &+ \delta_i \beta_i (\lambda_{it} - \lambda_{it-1}) + 2\beta_i (\lambda_{it} - \lambda_{it-1}) \\ &+ \alpha_i ((a x_{it} + c x'_{it}) + (a x_{it-1} + c x'_{it-1})). \end{aligned} \qquad (8a)$$

Since the choice of only one vehicle is being permitted x'_{it} will be zero. Solving for x_{it} (the utilization of the chosen vehicle i in time interval t) gives

$$x_{it} = A_{io} + A_{i1} x_{it-1} + A_{i2} \lambda_{it} + A_{i3} \lambda_{it-1} + A_{i4} x'_{it-1} \qquad (9a)$$

where

$$A_{io} = \frac{2\delta\tau_i}{2 - \alpha_i a + \delta_i} \qquad A_{i1} = \frac{\alpha_i a - \delta_i + 2}{2 - \alpha_i a + \delta_i}$$

$$A_{i2} = \frac{\beta_i (\delta_i + 2)}{2 - \alpha_i a + \delta_i} \qquad A_{i3} = \frac{\beta_i (\delta_i - 2)}{2 - \alpha_i a + \delta_i}$$

$$A_{i4} = \frac{\alpha_i c}{2 - \alpha_i a + \delta_i}$$

and:

$$\tau_i = \frac{(A_{io} - A_{i6}w_{it})(A_{i2}-A_{i3})}{(1+A_{i1})(A_{i2}+A_{i3})} \qquad \delta_i = \frac{2(A_{i2} + A_{i3})}{A_{i2} - A_{i3}}$$

$$\beta_i = \frac{A_{i2} - A_{i3}}{1 + A_{i1}} \qquad \alpha_i a = \frac{2(A_{i2} + A_{i3})}{A_{i2}-A_{i3}} - \frac{2(1-A_{i1})}{1 + A_{i1}}$$

$$\alpha_i c = A_{i4} \left[2 - \frac{4(A_{i2}+A_{i3})}{A_{i2}+A_{i3}} + \frac{2(1-A_{i1})}{(1+A_{i1})} \right],$$

and the parameters α_i, a, c, are not recoverable.

Equation (9a) is now an estimable dynamic equation of vehicle utilization, since the unmeasurable state variable has been removed. All remaining variables are readily measurable.

Appendix B. Derivation of the Intertemporal Dynamic Utilization Equation

The elimination of the unmeasurable state and costate variables from the intertemporal dynamic utilization equation is accomplished as follows, with all variables defined as in the text:

The problem is placed in discrete time by using approximations of the form:

$$\bar{x}_{it} = \int_t^{t+1} x(t)\, dt \qquad (1b)$$

and similarly for $\bar{\lambda}_{it}$, $\bar{S}_{it}$, $\bar{\psi}_{it}$. To simplify notation the bars and the subscript i are deleted. The dynamic intertemporal utilization is (as from the text):

$$x_t = \tau + \beta\lambda_t + \alpha S_t + \omega\psi_t \qquad (2b)$$

where: $\lambda_t = (I_t - C_t)$.

Also, the following approximations are made:

$$\Delta\psi_t = \psi_{t+1} - \psi_t \qquad (3b)$$

$$\Delta S_t = S_{t+1} - S_t \qquad (4b)$$

$$S_{t+1} - S_t \simeq \frac{1}{2}(\Delta S_{t+1} + \Delta S_t) \qquad (5b)$$

$$\psi_{t+1} - \psi_t \simeq \frac{1}{2}(\Delta\dot{\psi}_{t+1} + \Delta\psi_t) \qquad (6b)$$

In addition, from the text:

$$\dot{S}_t = J_t - \delta S_t \qquad (7b)$$

$$\dot{\psi}_t = (\gamma+\delta)\psi_t - (\tilde{b} + \tilde{c}S_t + Bx_t), \qquad (8b)$$

where $J_t = ax_t + cx_t'$. (8b')

To begin, equation (8b) is written as:

$$\Delta\psi_{t+1} + \Delta\psi_t = (\gamma+\delta)(\psi_{t+1}+\psi_t) - [2\tilde{b} + \tilde{c}(S_{t+1}+S_t) + B(x_{t+1}+x_t)] \tag{9b}$$

or (by substituting 6b):

$$(\delta+\gamma-2)\psi_{t+1} + (\delta+\gamma+2)\psi_t = 2\tilde{b} + \tilde{c}(S_{t+1}+S_t) + B(x_{t+1} + x_t) \tag{10b}$$

Similarly for Equation 7b:

$$\Delta S_{t+1} + \Delta S_t = (J_{t+1}+ J_t) - \delta(S_{t+1}+ S_t) \tag{11b}$$

and (by substituting equation (5b)):

$$S_{t+1} = (2+\delta)^{-1}(J_{t+1}+ J_t) + (2+\delta)^{-1}(2-\delta)S_t \tag{12b}$$

To eliminate ψ, Equation 2b is substituted into 10b giving:

$$\begin{aligned}(\tfrac{1}{\omega}(\delta+\gamma-2)-B)x_{t+1} &= 2[\tilde{b} + \tfrac{\tau}{\omega}(\delta+\gamma)] \\ &+ (\tfrac{1}{\omega}(\delta+\gamma+2) +B)x_t + \tfrac{\beta}{\omega}(\delta+\gamma-2)\lambda_{t+1} \\ &+ \tfrac{\beta}{\omega}(\delta+\gamma+2)\lambda_t + (\tilde{c} + \tfrac{\alpha}{\omega}(\delta+\gamma-2))S_{t+1} \\ &+ (\tilde{c} + \tfrac{\alpha}{\omega}(\delta+\gamma+2))S_t\end{aligned} \tag{13b}$$

Substituting equation (12b) into (13b) gives:

$$\begin{aligned}(2+\alpha)(\tfrac{1}{\omega}(\delta+\gamma-2)-B)x_{t+1} &= (2+\delta)(\tfrac{1}{\omega}(\delta+\gamma-2)+B)x_t \\ &+ (\tilde{c} + \tfrac{\alpha}{\omega}(\delta+\gamma-2))J_{t+1}+ (\tilde{c} + \tfrac{\alpha}{\omega}(\delta+\gamma-2))J_t \\ &+ \tfrac{\beta}{\omega}(2+\delta)(\delta+\gamma-2)\lambda_{t+1} + \tfrac{\beta}{\omega}(2+\delta)(\delta+\gamma+2)\lambda_t \\ &+ 4zS_t + (2+\delta)\ 2(\tilde{b}+ \tfrac{\tau}{\omega}(\delta+\gamma))\end{aligned} \tag{14b}$$

where: $z = \frac{\alpha}{\omega}(\gamma + 2\delta) + \tilde{c}$

Equation (14b) is now differenced and equation (12b) is introduced giving:

$$(2+\delta)(\tfrac{1}{\omega}(\delta+\gamma-2)-B)\ (x_{t+2} - x_{t+1}) =$$

$$(2+\delta)(\tfrac{1}{\omega}(\delta+\gamma-2)+B)(x_{t+1}-x_t)+(\tilde{c}+ \tfrac{\alpha}{\omega}\ (\delta+\gamma-2))(J_{t+2}-J_{t+1})$$

$$+ (\tilde{c} + \tfrac{\alpha}{\omega}(\delta+\gamma-2))(J_{t+1}-J_t) + \tfrac{\beta}{\omega}(2+\delta)(\delta+\gamma-2)(\lambda_{t+2}-\lambda_{t+1})$$

$$+ \tfrac{\beta}{\omega}\ (2+\delta)(\delta+\gamma+2)(\lambda_{t+1}-\lambda_t) + 4z(2+\delta)^{-1}(J_{t+1}+ J_t) \qquad (15b)$$

$$+ (\tfrac{2-\delta}{2+\delta} - 1)\ 4zS_t$$

Finally, substituting (14b) into (15b), using (8b'), and solving for utilization yields

$$x_t = A_o + A_1 x_{t-2} + A_2 x_{t-1} + A_3\lambda_{t-2} + A_4\lambda_{t-1} + A_5\lambda_t \qquad (16b)$$

$$A_6 x'_{t-2} + A_7 x'_{t-1}\ ,$$

where:

$$A_o = \frac{2\delta(2[\tilde{b}+ \frac{\tau}{\omega}\ [\delta+\gamma]])}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B)+a(\tilde{c}+ \frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_1 = \frac{(\delta-2)(\frac{1}{\omega}(\delta+\gamma+2)+B)\ -\ a(2+\delta)^{-1}[(2-\delta)(\tilde{c}+ \frac{\alpha}{\omega}(\delta+\gamma-2))\ -\ 4z]}{(2+\delta)\ (\frac{1}{\omega}(\delta+\gamma+2)-B)\ +\ \bar{a}(\tilde{c}+ \frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_2 = \frac{2(2+\delta)\frac{1}{\omega}(\delta+\gamma)-2\delta(\frac{1}{\omega}(\delta+\gamma-2)-B)+a(\frac{(2-\delta)}{(2+\delta)}\ -\ 1)(-\tilde{c}-\ \frac{\alpha}{\omega}(\delta+\gamma-2))\ +\ \frac{a4z}{2+\delta}}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B)\ +\ a(\tilde{c}\ +\ \frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_3 = \frac{(\delta-\ 2)(\delta+\gamma+2)}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B)+a(\tilde{c}+ \frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_4 = \frac{2\,\frac{\beta}{\omega}[\delta^2 + \gamma\delta + 4]}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B)+a(\tilde{c}+\frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_5 = \frac{\frac{\beta}{\omega}(2-\delta)(\delta+\gamma-2)}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B) + a(\tilde{c} + \frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_6 = \frac{-c(2+\delta)^{-1}[(2-\delta)(\tilde{c}+\frac{\alpha}{\omega}(\delta+\gamma-2)) - 4z]}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B)+a(\tilde{c}+\frac{\alpha}{\omega}(\delta+\gamma-2))}$$

$$A_7 = \frac{c[\tilde{c}+\frac{\alpha}{\omega}(\delta+\gamma-2)-(2+\delta)^{-1}[(2-\delta)(\tilde{c}+\frac{\alpha}{\omega}(\delta+\gamma-2))-4z]]}{(2+\delta)(\frac{1}{\omega}(\delta+\gamma+2)-B) + a(\tilde{c}+\frac{\alpha}{\omega}(\delta+\gamma-2))},$$

and the parameters τ, β, α, ω, δ, and γ are not recoverable.

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