II AN APPLICATION TO AUTOMOBILE DEMAND

7 Previous Research on Automobile Demand[1]

7.1 Introduction

Forecasts of auto demand and use play a central role in the planning and decisionmaking of numerous public agencies and private organizations. For example:

- The U.S. Department of Energy, and the equivalent agencies for various states, are responsible for anticipating gas shortages and establishing policies and programs to reduce gas consumption to prevent future shortages and reduce U.S. dependence on foreign oil. Projections of future gas consumption, and the impact on gas consumption of various possible forms of government intervention, are routinely based on forecasts of auto demand and use.
- State Departments of Transportation depend on revenues from gas taxes to finance the construction and maintenance of highways. The size of these revenues depends on the demand and use of autos, so that the prediction of this demand and use is critical to these departments' planning of capital programs.
- Air quality boards at the local, state, and federal levels are mandated to monitor air quality and recommend policies to reduce air pollution. Since auto emissions are a large component of pollution, air quality standards and policies are largely based upon projected auto use.
- The health of the auto industry in general depends on consumers' demand for autos, and consumers' choices among the various makes and models determine the relative well-being of individual firms within the industry. Auto manufacturers use demand forecasts in their financial planning and in decisions regarding expansions and contractions of plant capacity.
- Local transit agencies employ models of transit patronage in assessing carrier requirements (e.g., how many buses are needed) and in planning for service changes. In most of the more recent patronage forecasting models, the number of autos owned in the area is an important input. Consequently, transit agencies utilize projections of auto ownership levels as a step toward obtaining accurate projections of transit patronage.
- Recently, electric utilities have been interested in assessing the potential impact that electric autos would have on total electricity demand and time-of-day use patterns for electricity. These investigations have been based on various forecasts of the potential demand for electric cars over the next

twenty years (see, for example, the analysis by Beggs, Cardell, and Hausman, 1979, for the Electric Power Research Institute).

Given the important role that auto forecasts play in a wide variety of settings, it is no surprise that auto demand and use has been a lively area of research. Numerous models have been constructed to forecast auto demand, and the accuracy and usefulness of these models in forecasting and policy analysis has, in general, increased steadily over time. A review of these models is the topic of this chapter.

The purpose of this review is twofold. The first is to identify factors that have been found consistently in previous research to affect auto demand. The emphasis here is on consistency across studies. Any one study can identify factors that, with its data and methodology, seem to affect auto demand; the value of a review of numerous studies is the ability to compare results across data sets and methodologies to find factors that arise persistently and, hence, cannot be thought to be data- or methodology-dependent. The second purpose is to identify limitations that are consistently encountered in previous models. Knowing these limitations allows for more accurate forecasting and policy analysis since the effects of the limitations on the models' forecasts can be understood and, if necessary, compensated for. Furthermore, limitations that are common to all previous models define the frontier in the field and, as such, guide the way for future research.

Both of these purposes serve the ultimate aim of the literature review, which is to motivate and place in perspective the new model of automobile demand presented in the following chapter. The set of factors found in previous research to influence auto demand becomes, in considering the new model, a list of variables that the model should incorporate; and the new model's findings regarding what factors significantly affect demand are verified, or validated, by comparison with the previous findings. In addition, for the new model to be considered an advance toward more complete and more accurate assessment of auto demand, it should overcome some of the limitations found in previous research. That is, the limitations of previous research become the benchmark for evaluating new research.

This chapter is organized along methodological lines. That is, the previous research is divided into groups on the basis of the methods employed for addressing the issue of auto ownership, and studies within each of the groups are discussed together. This organizational scheme serves three functions. First, it saves space since the method used in a given group is

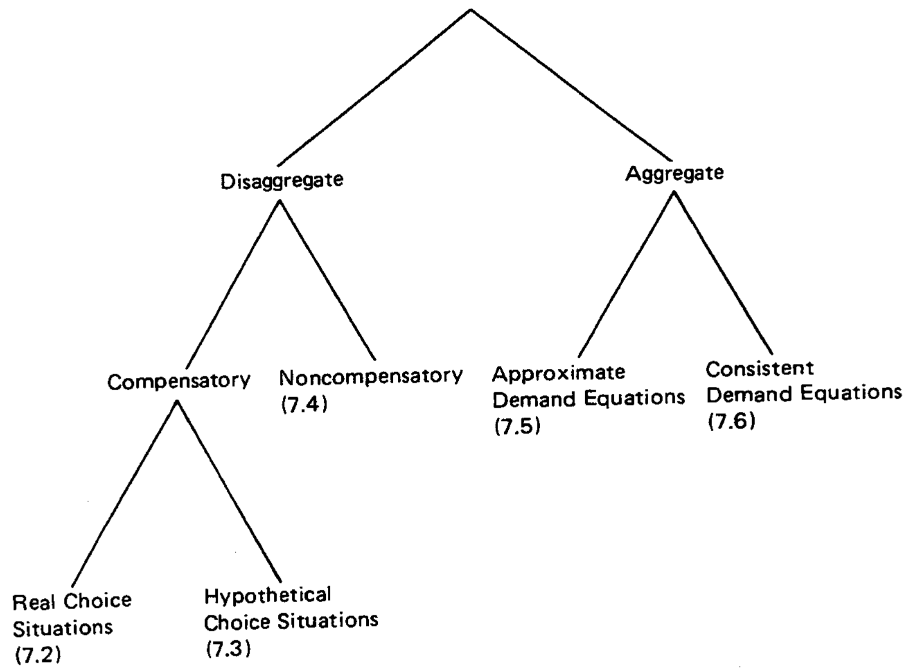

Figure 7.1
Categorization of previous research on auto ownership decisions. Note: The numbers in parentheses denote the sections in which the categories of research are discussed.

discussed only once and then applied to each of the studies in the group. Second, the scheme facilitates an understanding of the kind of information that can be obtained with each method, and consequently aids in the planning of future research. Third, the relation of the new demand model presented in chapter 8 to previous studies, and, in particular, the methodological tradition in which this new model was bred, is more easily discernible.

The categories of research are depicted in figure 7.1, with the numbers in parentheses designating the chapter sections in which each group is discussed. The terms, and the relevant distinctions that motivate this categorization, are defined and delineated in the appropriate sections.

7.2 Disaggregate, Compensatory Models Based on Real Choice Situations

Studies within this group apply the qualitative choice methods discussed in part I to households' auto ownership decisions. The approach, in this context, consists of the following set of assumptions. Each household decides how many autos and which autos to own. These decisions entail a choice among several alternatives. In deciding how many autos to own, the consumer has a choice of zero, one, two, and so on. In deciding which autos to own, the choice is among all the available makes, models, and vintages of automobiles. Each alternative that is available to the household is seen by the household as consisting of a set of characteristics. In the choice of which autos to own the household characterizes each make, model, and vintage of auto by its purchase price, fuel economy, number of seats, luggage-carrying capacity, and so on. In the choice of how many autos to own, the relevant characteristics include the cost of owning the number of autos designated by the alternative (e.g., the cost of owning two autos) and the usefulness to the household of having the number of autos designated by the alternative (as reflected in such factors as the number of people in a household, the number of household members who need to drive an auto to work, and so on).

The household would derive some happiness or "utility" from each alternative if it were to choose that alternative. This utility depends on the characteristics of the alternative; in particular, the consumer places some value on each of the characteristics of the alternative, and the utility derived from the alternative is the aggregate of the utility from each of the characteristics of the alternative. The household chooses the alternative that provides it higher utility than any of the other alternatives. In the choice of how many autos to own, the household chooses one auto if it obtains more utility from having one auto (considering both the cost of owning autos and their usefulness) than from having no autos or more than one auto. In the choice of which auto to own, the household chooses the particular make, model, and vintage of auto that it sees as having the most desirable set of characteristics, including price, operating cost, seating, and so on.

The researcher observes the actual choices that a sample of households makes (that is, the researcher observes how many and which autos each household in a given sample owns). The researcher also observes the characteristics of the alternatives that were available to the household. With this information, the researcher statistically infers the value that households place on each characteristic. The inferred values are those that would result in the households' choosing the alternatives that they actually chose.

Studies that use this method are labeled "disaggregate compensatory models based on real choice situations" because

1. the unit of analysis is the individual consumer (or household), and hence the term "disaggregate";
2. the household is assumed to trade off characteristics in the sense that a high value of one characteristic can compensate for a low value of another characteristic (for example, the household would choose an auto that is smaller than it wants if the price is sufficiently low)—therefore the models are "compensatory"; and
3. the researcher observes the household's actual choice in a real choice situation, rather than asking the household what it would do in a hypothetical situation.

Numerous studies of this type have examined consumers' choices of **how many** autos to own: Farrell (1954), Janosi (1959), Kreinin (1959), Huang (1964, 1966), Burns and Golob (1975), Johnson (1975, 1978), Lerman and Ben-Akiva (1976), Kain and Fauth (1977), Mogridge (1978), Train (1980a), Hocherman, Prashker, and Ben-Akiva (1982),[2] Booz, Allen, and Hamilton, Inc. (1983), Hensher and Le Plastrier (1983), and Mannering and Winston (1983).

There is a fair degree of consistency among the findings of these studies. First, each of the studies included income as an explanatory variable, and it entered significantly in all but two. Second, Farrell; Huang; Kreinin; Lerman and Ben-Akiva; Mogridge; Train; Hocherman, Prashker, and Ben-Akiva; Booz, Allen, and Hamilton, Inc.; Hensher and Le Plastrier; and Mannering and Winston included a variable, which in each case entered significantly, reflecting the cost of owning an auto, either purchase price or an annualized user cost.[3] Third, the availability and ease of travel on public transit entered as an explanatory variable (in different forms in different studies) in the models of Burns and Golob; Lerman and Ben-Akiva; Train; Hocherman, Prashker, and Ben-Akiva; and Hensher and Le Plastrier. This variable had a strong influence in all of these models; furthermore, its omission in the other studies is due to the fact that the other researchers did not construct such a variable, rather than that they attempted to do so and found that the variables did not enter significantly. Finally, the number of workers in the household significantly affects the household's choice of how many autos to own in the models of Lerman and Ben-Akiva; Train; Booz, Allen, and Hamilton, Inc.; Hensher and Le Plastrier; and Mannering and Winston. This reflects, of course, the high probability of a worker needing to use an auto for the commute to work.

The studies do not exhibit consistency with respect to any other variables; that is, no other variable enters significantly in several of the studies. It seems, therefore, that these studies demonstrate that (at least) four factors affect consumers' decisions as to how many autos to own, namely, the cost of auto ownership, the availability/ease of public transit, the income of the household, and the number of workers in the household.

Recently, research has focused on the choice of which vehicle to own. Such studies have been conducted by Lave and Train (1979), Cambridge Systematics, Inc. (as reported by Cambridge Systematics, Inc., 1980a and 1980b, and Manski and Sherman, 1980), Charles River Associates (as reported by Beggs and Cardell, 1980, and Charles River Associates, 1980), Lave and Bradley (1980), Hocherman, Prashker, and Ben-Akiva (1982), Booz, Allen, and Hamilton, Inc. (1983), Hensher and Le Plastrier (1983), Mannering and Winston (1983), Winston and Mannering (1984), and Berkovec and Rust (1985).

While these studies used a common methodology, they are not completely comparable because each study examined a somewhat different aspect of consumers' choice of auto type. Lave and Train, and Winston and Mannering, focused on new car purchases, with Winston and Mannering examining the household's choices among each make and model of new vehicle and Lave and Train examining which class of new auto was chosen (with all makes and models of new autos aggregated into ten classes). The other studies included both new and used vehicles in their analyses, but did so in quite different ways. The model of Hocherman, Prashker, and Ben-Akiva described households' purchases (i.e., make, model, and vintage choice conditioned upon a purchase being made), while the remaining studies examined vehicle holdings (i.e., the types of vehicles held by a household at a given point in time). Among the latter studies, Berkovec and Rust restricted their analysis to one-vehicle households, and Charles River Associates to households with two or more vehicles. Furthermore, Cambridge Systematics, Inc.; Booz, Allen, and Hamilton, Inc.; Berkovec and Rust; and Mannering and Winston examined the choice among each available make and model of vehicle, while Lave and Bradley examined only the choice between domestic and foreign vehicles and Hensher and Le Plastrier examined the choice among the three makes and models that the houehold stated it considered most closely. As a final anomaly, Charles River Associates examined the choice of class and vintage for the **smallest** vehicles owned by multivehicle households.

Given the differences among the studies, there is a surprising consistency among the results. Table 7.1 presents the explanatory variables that entered

Table 7.1
Explanatory variables entering models of auto type choice

		Cambridge Systematics, Inc.			
	Lave and Train	One-auto household	Two-auto household	Charles River Associates	Lave and Bradley
Choices examined	Class of new car to purchase (ten size classes)	Make, model, and vintage of vehicle held	Make, model, and vintage of pair of vehicles held	Class and vintage of the smallest vehicle held by multi-vehicle households, with five size classes and four vintage categories	Foreign or domestic cars held
Vehicle characteristics	Purchase price Operating cost Number of seats Weight Horsepower to weight ratio	Purchase price Operating cost Number of seats Weight Acceleration time Turning radius Braking distance Luggage space Scrappage probability	Purchase price Operating cost Number of seats Weight Acceleration time Luggage space Scrappage probability	Purchase price Operating cost Wheelbase "Depreciated luxury" Age of vehicle	
Characteristics of consumers (households)	Income Number of people in household Age Education Number of autos owned Vehicle miles traveled per month	Income Number of people in household Age Education Whether households lives in a city or rural area	Income Number of people in household Age Education Whether household lives in a city or rural area	Income Number of people in household Distance to parking	Education Number of autos owned Whether household lives near coast or not Percent of U.S. built cars assembled in state in which household lives

Table 7.1 (continued)

	Hocherman, Prashker, and Ben-Akiva	Booz, Allen, and Hamilton, Inc. One-auto household	Booz, Allen, and Hamilton, Inc. Two-auto household	Hensher and Le Plastrier
Choices examined	Make, model, and vintage of vehicle to purchase	Make, model, and vintage of vehicle held	Make, model, and vintage of pair of vehicles held	Make, model, and vintage of each vehicle held from among three most closely considered
Vehicle characteristics	Purchase price Fuel efficiency Length and width Horsepower to weight ratio Luggage space Engine size Age of vehicle	Purchase price Operating cost Number of seats Horsepower to weight ratio Reliability (*Consumer Reports*) Age of vehicle	Purchase price Operating cost Number of seats Horsepower to weight ratio Age of vehicle	Registration charge Service and repair expense Sales tax on purchase price Number of seats Fuel efficiency Weight Luggage space Age of vehicle
Characteristics of consumers (households)	Income Number of people in household Age Whether car is used for work Whether driver is disabled and hence exempt from sales tax[a] Whether household is reimbursed for operating expenses by employer or business	Income Number of people in household Age Education Whether household lives in a city or rural area Region of country in which household resides Number of miles the household drives annually	Income Number of people in household Age Education Region of country in which household resides Number of miles the household drives annually	Age Number of passengers normally carried Whether vehicle is driven over 600 miles per month Whether auto is used for paid work

	Mannering and Winston			
	One-auto household	Two-auto household	Winston and Mannering	Berkovec and Rust
Choices examined	Make, model, and vintage of vehicle held	Make, model, and vintage of pair of vehicles held	Make and model of new vehicle to purchase	Make and model of vehicle held, for one-auto household
Vehicle characteristics	Purchase price Operating cost Shoulder room Horsepower to engine displacement ratio Luggage space Age of vehicle	Purchase price Operating cost Shoulder room Age of vehicle	Purchase price Fuel efficiency Weight Horsepower Expected collision costs Probability of injury over $1,000 given an injury occurs	Purchase price Operating cost Number of seats Horsepower to weight ratio Turning radius Age of vehicle
Characteristics of consumers (households)	Income Number of people in household Age Number of miles driven in previous year	Income Number of people in household Number of miles driven in previous year	Income Number of vehicles owned Number of miles driven in previous year	Income Number of people in household Age Whether household lives in a city with over one million people, smaller city, or rural area

a. Study conducted in Israel.

each model. Excluding the Lave and Bradley study (which did not attempt to enter vehicle characteristics), each of the studies found that consumers consider price,[4] operating cost (or fuel efficiency), and some measure of size (e.g., number of seats, weight, and/or wheelbase) when deciding which auto to buy or own. In addition, the age of the auto appears as a factor affecting consumers' decisions in all of the models except those of Lave and Train, and Winston and Mannering, which examined new car purchases only and hence cannot logically include a vehicle age variable.[5]

The power of the vehicle (as measured by horsepower, horsepower to weight ratio, or acceleration time) enters seven of the models. However, the studies were consistently unable to find a significant and general relation of vehicle power to households' choices. Power variables enter with an incorrect sign in one study (Cambridge Systematics, Inc.) and with inconsistent results in each of two others (Booz, Allen, and Hamilton, Inc., and Berkovec and Rust). In Lave and Train, and in Mannering and Winston, the sign is correct, but the variable does not enter significantly. In the two studies in which vehicle power entered significantly and with the correct sign, it does so for only a part of the population (drivers 30 to 45 years of age) in one (Hocherman, Prashker, and Ben-Akiva) and with regard only to new car purchases in the other (Winston and Mannering). Furthermore, the researchers at Charles River Associates, who decided not to enter a power variable, apparently did not do so because of problems in estimating a sensible coefficient for the variable (see the discussion of model C in Beggs and Cardell, 1980). It seems reasonable to conclude, therefore, that vehicle power plays little or no role in consumers' choices of vehicle. On this point, the studies are quite consistent in their lack of positive results.

There is also a fair degree of consistency regarding the characteristics of households that most affect the choice of auto type. Eight of the ten studies found income to be important. (Lave and Bradley, and Hensher and Le Plastrier, are the exceptions; they did not enter an income variable and consequently could not determine whether income was important.) The number of people in the household and variables denoting the age of the household head or primary driver entered seven models. The number of autos owned by the household was found to affect the choice of auto type in six of the studies.[6] However, of the four studies that did not include the number of autos, one study could not logically do so (Berkovec and Rust analyzed one-vehicle households only) and another could do so only if the effect of owning three vehicles is different from that of owning two (Charles

River Associates examined only households with more than one vehicle). Therefore, the number of autos was found to be important in six of the eight studies in which its effect could be examined.

In summary, it seems that previous research indicates that the following factors affect consumers' choices of which type of auto to own: the price, operating cost, size, and age of the auto, and the income, size, and age of the household, as well as the number of autos that is owns.

Despite the consistency among these studies in their appraisal of the factors that affect consumers' choices, all of the models have serious limitations that inhibit their accuracy and usefulness in forecasting and policy analysis. The first and perhaps most serious limitation is that previous models examine only a few of the many interrelated choices that determine a household's demand for vehicles. For example, most of the models examine either the household's choice of how many vehicles to own or its choice of vehicle class or make/model, but not both.[7] Insofar as these two choices are interrelated, ignoring one in the analysis of the other could, in addition to rendering the analysis less complete, produce bias in the estimated parameters.

Similarly, the interrelation of vehicle choice and vehicle use is not usually incorporated in a consistent fashion. Only one of the studies (Mannering and Winston) has modeled the household's choice of how much to drive each vehicle and the interrelation of this choice with the choice of how many and what class or make/model of vehicles to own. Most of the studies ignore the amount the household drives in the analysis of how many or what class or make/model of vehicle the household owns, implicitly assuming that there is no relation among the choices. A few of the studies have included the household's annual vehicle miles traveled as an explanatory variable, reflecting the idea that households that drive a lot have an incentive to buy vehicles with low operating costs.[8] However, in reality, the amount that a household drives is itself affected by the cost per mile of the household's vehicles; that is, the number of miles a household drives both affects and is affected by its choice of vehicle class and make/model, since the operating cost that the household faces is determined when the household chooses a particular class and make/model of vehicle. Consequently, including vehicle miles traveled, which is an endogenous variable, in a model of the choice of class or make/model, and estimating the model as if the variable were exogenous, produces classic simultaneity bias in the estimated parameters.

As stated, only Mannering and Winston have specified, and determined an appropriate estimation procedure to account for, the interrelated choice of how many vehicles to own, and what class and make/model of vehicles to own, and how much to drive. Unfortunately, their model examines only the choices of households that own at least one vehicle and ignores the household's choice of whether or not to own any vehicle. This means that no model currently exists that describes, in a consistent manner, the interrelated decisions of how many vehicles to own (including none), what types of vehicles to own, and how much to drive each vehicle. Such a model is needed for accurate assessment of the impact of policies and changes in demographics, fuel prices, and vehicle characteristics on the demand for automobiles and consumption of gasoline.

The second problem, or unsolved dilemma, in previously estimated models concerns their handling of individual makes and models of vehicles. Lave and Train; Charles River Associates; and Lave and Bradley grouped makes and models of vehicles into classes, calculated the average characteristics (e.g., average price) for each class,[9] and described the household's choice among these classes. Any two classes that have the same average characteristics are predicted by these models to have the same demand. However, in reality, the demand for two classes will be very different if one class has a wider variety of vehicles within it than another class, even if average characteristics of makes/models within the two classes are the same.

The other seven studies of vehicle type choice avoided this problem by describing the demand for each individual make and model of vehicle. However, their approaches to doing so entailed different problems. First, each of the studies used a logit model to describe the choice among each make and model of vehicle. While simple computationally, the independence from irrelevant alternatives property of the logit model is most definitely violated in this application.[10] Unobserved factors that affect the utility that households obtain from a particular vehicle are related to those for a similar vehicle; consequently, the unobserved component of utility is correlated over similar alternatives, in contradiction to the assumptions of the logit model. For example, Toyotas and Nissans are similar to each other and different from Cadillacs and Oldsmobiles in ways that are not measured by the researcher, just as Cadillacs and Oldsmobiles are similar to each other and different from Toyotas and Nissans in characteristics that are not entered by the researcher into the models. Treating the choice situation as if unobserved factors were uncorrelated across vehicles results in inconsistent estimates of model parameters.[11]

In forecasting, the specification of the model in terms of makes and models of vehicles presents difficulties at a practical level. First, the models require an unwieldy amount of input data when forecasting (namely, projections of the characteristics of each future make and model). Second, some ad hoc procedures are required in forecasting to reduce the enormous number of calculations that are necessary. For example, the standard way to predict market demand is to calculate, for each sampled household, the probability of choosing each make and model of vehicle, and to sum these probabilities over the sampled household (i.e., the market demand for any make/model is the sum over households of the probability of the household choosing that make/model). However, this procedure is very expensive since the number of makes and models is so large. To reduce costs, Cambridge Systematics, Inc., for example, assigned to each household a particular make/model on the basis of a random number generator that reflects the probability of choosing each make and model; market demand for a make/model is obtained by counting the number of households that are assigned that make/model. This procedure, which is equivalent to raising the probability of the assigned make/model to one and lowering all the other probabilities to zero, requires less calculation but necessarily reduces the forecasting accuracy. If the sample size is small compared with the number of makes and models (as it is likely to be), this reduction in accuracy can be substantial.[12]

A final limitation in the previous research is that most of the models that contain a sufficient number of explanatory variables to be potentially useful in policy analysis also contain estimated parameters that have unreasonable implications. For example, the Lave and Train model contains squared terms that can dominate nonsquared terms and thereby give nonsensical results. Specifically, the model includes two terms for vehicle price: price divided by the household's income, and this quantity squared. As expected, the nonsquared term enters with a negative coefficient, and the squared term with a positive coefficient. However, for low income households and high-priced vehicles the squared term dominates, implying that an increase in the vehicle's price will increase the probability that the household will choose it. Similar results are also obtained for the terms representing the interaction of vehicle weight and the age of the household head and for the terms representing the interaction of vehicle performance and education level of the household. Other models also contain unreasonable implications. These anomalies are often minor and would not interfere with most uses of the models; they do, however, limit the usefulness of the models.

In summary, three limitations are evident in previous research using disaggregate compensatory models on real choice situations: (1) the interrelated set of decisions that affect auto demand are not fully incorporated; (2) the handling of makes and models of vehicles in describing household's vehicle type choices is not completely satisfactory; and (3) the models often contain unreasonable implications. Despite these limitations, each of the models can and has been very useful in policy analysis (see, for example, Train, 1980b, and Millar et al., 1982). In fact, delineation of the limitations allows for more accurate analysis, since the effect of the limitations on analysis thereby can be understood and compensated for. It would be desirable, of course, to have a model with fewer limitations; this was the goal in developing the model presented in chapter 8.

7.3 Disaggregate, Compensatory Models Based on Hypothetical Choice Situations

For some types of analysis, the real world does not provide sufficient information to the researcher on factors that are perhaps quite important. For example, from examining real choice situations, it is impossible to infer the value of a vehicle characteristic if no autos currently exhibit this characteristic. This problem is particularly relevant in forecasting the demand for new types of vehicles, such as electric vehicles. The limited range of electric vehicles, that is, the fact that they can only be driven a certain number of miles before a lengthy recharging is required, is a characteristic of electric vehicles that no currently (or widely) available autos exhibit. Therefore, by observing consumers' choices in the real world, consumers' value of the range of an auto cannot be determined.

A less extreme version of this limitation arises when in the real world vehicle characteristics are highly correlated, so that there is little independent variation in each characteristic. For example, it is probably the case that consumers are affected by both a vehicle's interior size and its weight.[13] However, these two characteristics are highly correlated in the real world; autos with large interiors generally weigh more than those with smaller interiors. Because of this, the separate effects of weight and interior size cannot be accurately determined by inference from observed choices in the real world, and policy analysis that depends on knowing the separate effects is thwarted.

To circumvent these problems, one can turn from the real world to the world of hypotheticals. That is, the researcher can present hypothetical choice situations to a sample of respondents and infer the value of factors entering the choice process from the respondents' stated choices in these hypothetical situations. For example, the researcher can describe several hypothetical autos to a consumer and ask the consumer which vehicle he would choose. Since the researcher makes up the autos that are described to the respondent, the researcher can (1) construct hypothetical vehicles that include characteristics that are not exhibited by currently available autos and (2) ensure that the set of hypothetical vehicles exhibits sufficient independent variation in each characteristic to allow the value of each to be estimated precisely.

The potential difficulty with this type of data is, of course, that respondents' choices in hypothetical situations will not necessarily be the same as if they were actually faced with the choice in the real world. Furthermore, the more dissimilar the hypothetical alternatives (e.g., hypothetical vehicles) are from real world alternatives, and hence the more useful the data could potentially be to the researcher, the less able the respondent will be to choose as he would if actually faced, somehow, with the choice in the real world.

Two studies have used the device of hypothetical choice situations for studying auto ownership decisions: one by Calfee (1980) and another by Charles River Associates (as reported by Beggs, Cardell, and Hausman, 1979, and Charles River Associates, 1980). In both of these studies, sets of hypothetical autos were presented to consumers and the consumers' preferences were elicited. Both studies included electric vehicles in the sets of hypothetical autos. Calfee presented several sets of autos to each consumer and asked which auto was preferred in each set; he used this information to estimate the "value" of each auto characteristic in the same way as the studies in section 7.2. Charles River Associates presented one set of hypothetical autos to each consumer and asked the consumer to rank order the autos by preference. The rankings were used to infer the "value" of each characteristic in a way that is similar to the studies of section 7.2, but incorporated the information concerning which auto was second most preferred, third most, and so on. (In real choice situations only the first choice is observed, not the second, third, and so on.)

The following auto characteristics were found to affect consumers' decisions in both of these studies: purchase price, operating cost, number of seats, top speed (or acceleration), and range. These results are quite consistent with those obtained by the studies of auto type choice in real situations, in which purchase price, operating cost, size (such as number of seats) entered. The fact that vehicle power (top speed, acceleration, or horsepower to weight ratio) entered the studies based on hypothetical choices but not those based on real choices could reflect either that (1) power is too highly correlated with other vehicle characteristics in the real world to allow its value to be estimated in studies with real choice data, or (2) relative power will affect consumers' choices between electric and gas vehicles (which have quite different power) but not their choices among gas vehicles.

7.4 Disaggregate, Noncompensatory Models Based on Both Real and Hypothetical Choice Situations

In all the studies discussed so far, it was assumed that the consumer trades off auto characteristics in the sense that a low value for one characteristic can be offset, in the consumer's evaluation, by a high value of another characteristic. For example, it is assumed that a consumer who wants a five-seat auto would choose a four-seat auto if the price were sufficiently low, or the gas mileage were sufficiently good, or there were some other characteristic that "compensated" for the small number of seats.

However, the consumer might actually make decisions in some noncompensatory manner. For example, if a household wants a five-seat auto, it might eliminate from consideration any auto that has fewer than five seats. That is, no matter how inexpensive or how good the gas mileage is, the household would never choose a four-seat auto; nothing could compensate for not having five seats.

In noncompensatory models, the consumer is assumed to have an importance ranking of characteristics of the alternatives, and, for each characteristic, have some minimum acceptable level, called a "threshold." It is easiest to think of the decision process as occurring in steps sequential over time (though this is not necessarily a part of the models). First, the consumer faces all the possible alternatives. He eliminates from consideration all the alternatives that do not meet the minimum acceptable standard (threshold) for the characteristic which he considers most important. Next, if more than one alternative remains after elimination in the first step, then the consumer looks at his second ranked characteristic and eliminates any alternatives that are not above the threshold for this characteristic. This process continues until only one alternative remains; that is the alternative which the consumer chooses.

To model this form of decisionmaking, two things must be learned by the researcher: the importance ranking of characteristics of the alternatives and the threshold for each characteristic. The importance ranking is essential since the process of successive elimination could result in different choices if applied in different orders. Similarly, the thresholds allow determination of which alternatives will be eliminated at each stage.[14]

Two studies of consumers' choices of which type of auto to own have been based on noncompensatory models of consumer behavior, namely, those by Recker and Golob (1978), and Murtaugh and Gladwin (1980). Recker and Golob presented consumers with a set of hypothetical, small, special purpose urban vehicles. The consumers were asked to tell the researcher how important they considered each characteristic of these autos; that is, in essence, consumers were asked to rank order the auto characteristics in terms of importance. This information was used, along with the researchers' observation of which auto the consumer said he preferred, to infer the threshold values for each characteristic.

The study by Murtaugh and Gladwin was somewhat different. Their approach was based on in-depth interviews with consumers who had recently purchased autos, eliciting the reasons for the consumer choosing the auto that he did. On the basis of the information obtained through numerous interviews, they constructed an algorithm that represented a noncompensatory decision process that they felt accurately reflected the decisions of most of the consumers they interviewed. The essential difference, therefore, between this study and that by Recker and Golob (aside from the fact that Recker and Golob used hypothetical choice situations and Murtaugh and Gladwin used real ones) is simply that Recker and Golob used statistical methods to determine the threshold values, whereas Murtaugh and Gladwin established threshold values on the basis of their extensive interviews without formal statistics.

Table 7.2 gives the order in which characteristics were considered by consumers in their noncompensatory choices. A couple of things are interesting. First, both studies found that vehicle size was the characteristic that households considered first. This is consistent with the studies discussed in sections 7.2 and 7.3. Note in the Recker and Golob study that size was a

Table 7.2
Noncompensatory models of auto type choice: order in which characteristics are considered

Recker and Golob	Murtaugh and Gladwin
Vehicle size	Vehicle size
Perceived safety	Vehicle purpose (for specific purposes or general use)
Flexibility of use	Price
Parking	Domestic or foreign
Number of passengers	
Fuel economy	
Ability to be seen	
Seating comfort	
Cargo space	

separate characteristic from the number of seats; therefore, vehicle size might denote weight in this study. Second, safety was found by Recker and Golob to be the second most important characteristic. Of the studies discussed so far only Winston and Mannering have found safety to be an important factor. This could easily be due to the fact that none of the other studies attempted to enter a variable for safety, which is notoriously difficult to measure in the real world. Recker and Golob used hypothetical choice situations and hence were able simply to specify the safety level of the vehicles they described.

Other explanations are also possible. Recker and Golob described small, special purpose vehicles; consumers might be more concerned with safety in these vehicles than in conventional autos. Also, the order in which characteristics are considered in the Recker and Golob model is based on the rank orderings that respondents state to the researcher. It is possible that respondents guess that safety is an important factor in their decisions (or feel that it "should" be) when indeed it is not. This possibility of respondents' not being able accurately to assess the relative importance of characteristics is one of the major drawbacks of this type of study. The difficulty becomes greater if the consumer does not actually choose on a noncompensatory basis, in which case the question of "which characteristic is most important" has no tangible meaning.

Neither of the studies based on noncompensatory models tested these models against compensatory models. Therefore, they do not provide evidence on how people make decisions concerning auto ownership. However, Gensch and Svestka (1978) examined consumers' choices of mode of travel (auto versus transit) with both noncompensatory and compensatory models. In particular, they compared the predictive ability of the two models and found that, for their sample, the noncompensatory model predicted mode choice better than the compensatory model. This provides indirect evidence in support of the noncompensatory model. This evidence should not be overemphasized, however. Aside from the fact that mode choice was examined instead of auto ownership, there are problems in the way that Gensch and Svestka made predictions with the compensatory model that impaired its performance: a person was predicted to take the mode for which there was the highest probability, rather than predicting aggregate mode shares by summing individual probabilities over people. However, the evidence provided by Gensch and Svestka is the only evidence available, and therefore is necessarily the best available.

7.5 Approximate Aggregate Demand Equations

Because of the difficulty and expense of collecting data on individual consumers, many studies have observed the total, or aggregate, demand for autos in an area (e.g., a state or the nation as a whole) and have related this aggregate demand to various explanatory variables, such as average auto prices in the area and average household income.

By definition, the true aggregate demand function for an area is the sum of the demand functions for all the individuals in the area. That is, if the demand function for person n is f_n, then the true aggregate demand function for an area is necessarily

$$F = \sum_{n \in S} f_n,$$

where S is the set of individuals in the area. The straightforward way to specify an aggregate demand function is, therefore, to specify demand functions at the individual level and sum them over individuals. Alternatively, one can specify an aggregate demand function and demonstrate that there exist individual demand functions that, when summed, equal the aggregate function. Aggregate demand functions obtained in either of these ways are called "consistent," since they are consistent with underlying demand at the individual level.

An aggregate demand equation that is consistent is not necessarily the true aggregate function. For example, it is possible for an aggregate demand function to be consistent, but only with individual demand functions that are unrealistically simplistic. By way of illustration, a linear aggregate demand function is consistent with linear individual demand functions; however, unless individual demand is truly linear (which is unlikely, particularly for auto choice), the linear aggregate demand function is, at best, an approximation to the true aggregate demand function.

Specifying and estimating demand equations that are consistent with realistic individual demand functions is difficult because of the complexity of such functions. Consequently it is customary to specify an aggregate demand function that is not necessarily consistent with realistic individual demand equations and consider it an approximation to the true aggregate demand function. In this section we discuss studies that have estimated approximate aggregate demand functions; in the next we examine two recent studies that estimated aggregate demand equations that are indeed consistent with a fairly realistic specification of individual demands.

Most studies that estimate approximate aggregate demand equations have examined only the total number of automobile purchases (or number of automobiles owned) and have ignored the consumers' choices of type of auto. These studies are the following: Wolff (1938), Roos and von Szelski (1939), Chow (1957, 1960), Nerlove (1957, 1958), Suits (1958, 1961), Kain and Beesley (1965), Dyckman (1966), Houthakker and Taylor (1966), Hamburger (1967), Evans (1969), Bos (1970), Hymans (1970a, 1970b), Wyckoff (1973), Juster and Wachtel (1974), Wildhorn et al. (1974), and Hess (1977).

Each of these models includes auto price and average income as explanatory variables. In addition, most of the models include some type of lagged dependent variable. Beyond this, however, the models differ as to which explanatory variables are included. Some variable, such as interest rates or money holdings, reflecting the ease of obtaining credit, is included in the models of Chow, Suits, Dyckman, Hamburger, Evans, and Juster and Wachtel. Wolff includes corporate profits as an explanatory variable. Suits includes a dummy variable for the years of World War II in order to reflect the disruption in buying patterns that occurred during those years. Kain and Beesley include population density as a proxy for the ease of reaching shopping and other destinations without an automobile. Hymans included an index of changes in stock prices as an indication of consumers' sentiments. Juster and Wachtel include an index of unemployment in their model. Finally, Wildhorn et al. included a dummy variable for years in which strikes of auto workers occurred. It is significant, however, that none of these models includes any auto characteristics other than price.

These studies examined the number of autos owned but not the type. Two studies have estimated approximate aggregate demand equations for the share of autos of each type that are owned (or purchased), namely, those by Chamberlain (1974) and Lave and Bradley (1980). Chamberlain's equations include the average price of autos and the price of fuel (which captures the difference in fuel economy, or operating cost, among types of autos). In addition, she included average income as an explanatory variable. Lave and Bradley entered no auto characteristics, but included several socioeconomic variables, such as average income, percent of people who are college educated, percent of population between the ages of 1 and 5, and so on. Neither of the studies examined auto characteristics other than price.

The more recent studies based on approximate aggregate demand equations have examined both the total number of autos and the share of autos of each type. These studies are Chase Econometrics Associates (1974), Energy and Environmental Analysis, Inc. (1975), Ayres et al. (1976), Difiglio and Kulash (1976), and Wharton Econometric Forecasting Associates, Inc. (1977).

The Chase model predicts the total number of new automobile sales and then divides total sales among classes on the basis of share equations. Five classes of automobiles were considered: subcompact, compact, intermediate, standard, and luxury. The predicted shares depend on the average price for automobiles of each class, the average fuel economy for automobiles of each class, the price of fuel, and the rate of unemployment, while predicted total sales depend on disposable income, automobile and fuel prices, credit conditions and previous purchases of autos.

The models of Energy and Environmental Analysis, Inc. (EEA), Difiglio and Kulash, and Ayres et al. are similar to the Chase model in that market shares by automobile class are determined as well as total new automobile purchases. The models of Difiglio and Kulash and Ayres et al. differ from that of Chase in that three auto classes are considered rather than five, and fewer explanatory variables appear. The EEA model, on the other and, includes all the explanatory variables that the Chase model includes, plus a variable reflecting the growth in vehicle miles traveled.

The last, and by far the most complete, aggregate econometric study is that by Wharton. This model is like the Chase model in that it has equations that determine the number of new automobiles purchased and the market share held by each automobile class. In addition, however, the model determines the number of used automobiles owned by automobile class. Consequently, the model can determine the effect of changes in new vehicle designs on consumers' choices of whether to own new or used automobiles.

The Wharton model includes a large array of independent variables. Among the socioeconomic variables that enter the model are the number of households, the number of licensed drivers, the number of persons driving to work, the number of persons between 20 and 29 years of age, the percent of the population living in urban areas, and average income. Rather than including variables for the average prices of automobiles in each class and the average fuel economy of automobiles in each class, the Wharton model includes only one variable, called the "cost per mile." From an intuitive point of view, this variable is the fixed cost of owning the automobile plus the yearly operating cost of a vehicle.

None of these models includes any noncost characteristics of autos, and as a consequence, consumers' responses to changes in seating capacity, luggage space, horsepower, etc., cannot be determined. This is a serious limitation, even if one is interested only in the effect of changes in cost. For example, increased fuel efficiency in a vehicle is generally achieved by changing noncost characteristics (e.g., size). Consequently, examining the effect of changes in operating cost without also considering the effect of concomitant changes in noncost characteristics can seriously bias the demand predictions.

7.6 Consistent Aggregate Demand Equations

Two studies have recently estimated aggregate demand equations with explicit account taken of the fact that aggregate demand is the sum of individual demands. Both of these studies were performed at Charles River Associates, one by Boyd and Mellman (1980) and the other by Cardell and Dunbar (1980), and both used the same model of aggregate demand. In particular, each study assumed that each consumer chooses the auto that maximizes his utility, with utility being a function of the characteristics of the auto and the tastes of the consumer. Under this assumption, different consumers choose different autos, even though all consumers face the same characteristics of the autos, because different consumers have different tastes and hence value the various auto characteristics differently. The distribution of tastes in the population was specified and aggregate demand equations were derived by aggregating individual demands in accordance with the distribution of tastes. Consequently, the estimated equations for aggregate demand in these studies are consistent with a realistic model of an individual consumer's behavior.[15]

Both of the studies that employed this approach were able to examine the effect of a variety of auto characteristics on consumers' choices of auto type. Cardell and Dunbar found six characteristics to be important factors in consumers' decisions: price, fuel economy, acceleration, frequency of repairs (as rated by *Consumer Reports*), luxury (as rated by *Consumer Reports*), and interior space. The Boyd and Mellman study found the first four of these to affect consumers' decisions, but entered styling and noise (as rated by *Consumer Reports*) in their model rather than luxury and interior space. In particular, Boyd and Mellman found that, when the styling variable was included, no measures of internal space, exterior size, or weight entered the model significantly.

These findings are somewhat consistent with the previously discussed demand analyses. Price and operating cost (i.e., fuel efficiency), are found to be important in both studies, while interior space entered one. Power (i.e., acceleration), which was found in the studies in section 7.2 and 7.4 not to be important but was relevant in the studies in section 7.3, entered strongly in both of these models. Apparently, the verdict on vehicle power is not yet in.

Neither of the models included any socioeconomic variables. This limits their usefulness in forecasting to periods during which socioeconomic variables (or, more precisely, the distribution of tastes in the population) do not change significantly. They could be used, for example, in performing "what if" analyses for the year in which they were estimated (e.g., what would demand for a particular vehicle have been if its fuel efficiency had been 10% better), but not for projecting demand over several years under various policy scenarios. There is no inherent limitation of the methodology that prevents socioeconomic variables from being included; this is an area in which further research promises to be quite fruitful.