**DETERMINANTS OF ALTERNATIVE FUEL VEHICLE CHOICE
IN THE CONTINENTAL UNITED STATES**

by

RECEIVED
SEP 16 1999
OSTI

Melanie Tompkins
Decision and Information Sciences Division
Argonne National Laboratory
PH: 630-252-6108, FAX: 630-252-4546,
E-Mail: mtompkins@anl.gov

David Bunch
University of California, Davis

Danilo Santini
Center for Transportation Research
Argonne National Laboratory

Mark Bradley
Mark Bradley Research and Consulting, Inc.

Anant Vyas
Center for Transportation Research
Argonne National Laboratory

David Poyer
Decision and Information Sciences Division
Argonne National Laboratory

The submitted manuscript has been authored
by a contractor of the U.S. Government
under contract No. W-31-109-ENG-38.
Accordingly, the U.S. Government retains a
nonexclusive, royalty-free license to publish or
reproduce the published form of this
contribution, or allow others to do so, for U.S.
Government purposes.

For Presentation at the
77th Annual Meeting
Transportation Research Board

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DETERMINANTS OF ALTERNATIVE FUEL VEHICLE CHOICE IN THE CONTINENTAL UNITED STATES

by

Melanie Tompkins, David Bunch, Danilo Santini,
Mark Bradley, Anant Vyas, and David Poyer

Abstract

This paper describes the ongoing investigation into the determinants of alternative fuel vehicle choice. A stated preference vehicle choice survey was conducted for the 47 of continental U.S. states, excluding California. The national survey is based on, and is an extension of, previous studies on alternative fuel vehicle choice for the State of California conducted by the University of California's Institute of Transportation Studies (UC ITS). Researchers at UC ITS have used the stated-preference national survey to produce a series of estimates for new vehicle choice models. Three of these models are presented in this paper. The first two of the models were estimated using only the data from the national survey. The third model presented in this paper pools information from the national and California surveys to estimate a true national model for new vehicle choice.

DETERMINANTS OF ALTERNATIVE FUEL VEHICLE CHOICE IN THE CONTINENTAL UNITED STATES

INTRODUCTION

Vehicles powered by such fuels as electricity, natural gas/propane, and alcohol will reduce U.S. petroleum usage and could improve urban air quality. Alternative fuel vehicles (AFVs) differ from gasoline vehicles in terms of cost (purchase price and fuel cost) and, in terms of such attributes as vehicle range between refueling, fuel availability and convenience of refueling, operating performance, reliability, and interior space. The traditional "revealed preference" (RP) approach, in which actual consumer purchases are analyzed to evaluate the effect of these attributes on vehicle preference, is not applicable to AFVs because they are limited in supply and have not been marketed on full-scale basis. As a result, "stated preference" (SP) methods have been developed to estimate consumers' responses to hypothetical AFVs with a specified set of attributes.

The University of California's Institute of Transportation Studies (UC ITS) has conducted several RP and SP surveys and developed a microsimulation forecasting system based on these data [see (2), (3); (4); (8); and (16)]. Coefficients from a model estimated by using one of the early California surveys have been used selectively by the U.S. Department of Energy's (DOE's) Office of Transportation Technologies (OTT) and the Energy Information Administration (EIA) to develop coefficients for national projections of market shares of AFVs (7);(15). The obvious drawback of using models based on California data for national projections is that Californians might have significantly different preferences than the rest of the nation because that state has long pursued adoption of AFVs as a means for improving air quality. The DOE/OTT sponsored a "national" survey (NS) to collect data to support development and enhancement of vehicle choice models so that true national estimates could be obtained. In fact, that survey was not national, instead covering 47 of the "lower 48" states in the Continental U.S. aside from California, but being designed to allow combination with the previously collected UC ITS sample for California.

The first sections of this paper describe the NS methodology and survey procedure. Simple descriptive statistics highlighting the demographic characteristics of the sample are presented in the next section. The final sections are devoted to the ongoing development of vehicle choice models using the survey data. National coefficients estimates have been obtained and used in a DOE/OTT market share prediction spreadsheet model by using a conditional, multinomial model based on the SP data from the NS sample (12); (15). The preliminary and final statistical models providing the 47-state NS coefficients currently used in the DOE/OTT spreadsheet model are presented here, along with tests of the validity of those coefficients when tested in combination with the California survey.

NATIONAL SURVEY

The objective of the 47-state NS is to perform an independent survey of consumers in states other than California concerning their vehicle preferences in a manner that would allow the vehicle selection and usage patterns of households in the rest of the nation to be compared to the preferences of California households. To accomplish this goal, the NS was designed to be as comparable as possible to the latest available version of the sequence of California surveys. An

important focus of both surveys is to measure consumer response to the significantly different (from gasoline) vehicle attributes of AFVs because the results are to be used to develop methodologies for vehicle choice projections of gasoline vehicles and AFVs at the California, regional (Census Division and metropolitan statistical areas [MSAs]), and national levels.

The California data and models developed from them played a key role in determining the general survey methodology. The national survey was designed to yield results that would be compatible with those from the California survey and, at the same time, encompass the national interest in a larger set of AFV types as compared with California since one of the main objectives is to support development of coefficients for the long-term forecasting models for use by OTT and EIA to project AFV market shares. Working with Argonne National Laboratory (ANL), UC ITS developed the NS experimental design to ensure consistency with the California surveys, so that true "national" estimates could be obtained by combining the California and NS samples.

Several factors led to the development of the final sampling plan. The California and NS data had to provide vehicle choice estimates that could support DOE long-term forecasting models. The NS sample had to be representative of the 47 contiguous states (excluding California). The data had to be compatible with the California data to obtain national estimates. The sample also had to be selected to allow disaggregated analysis by geographic region, such as Census Division or groups of MSAs. The MSA coverage is necessary for analyzing classes of metropolitan areas consistent with the requirements of the Energy Policy Act and/or Clean Air Act (CAA). For example, geographic identifiers were included in the survey data so that ANL could identify respondents within the 22 metropolitan areas that have serious or worse air quality problems and that are subject to CAA regulations that differ from those in the remainder of the country. In addition, it was recognized at the start that the survey could be potentially valuable to all offices within DOE, not just OTT. Accordingly, given the history of use of Census Divisions by EIA, building in the potential to test for statistical differences among Census Divisions also seemed desirable (6).

Sampling Procedure and Survey Instrument

The sampling methodology, experimental design, and survey instrument were developed by UC ITS staff in consultation with Argonne National Laboratory to ensure compatibility with the California survey while meeting the DOE/OTT objectives.

The survey consisted of three stages: (1) initial computer-aided telephone interview (CATI-1) of households, (2) development of a customized questionnaire to be mailed to households, and (3) a second computer-aided telephone interview (CATI-2) to retrieve the responses to the mailed questionnaire. A random-digit-dialing sampling procedure was used, and the sample was stratified by Census Division, using 1993 population proportions. Data collection began in August 1995, with the final surveys completed in January 1996.

Computer-Aided Telephone Interview No. 1

The initial computer aided telephone interview (CATI-1) yielded 1,904 respondents. Information collected in the CATI-1 included data on household structure, vehicle holdings, housing characteristics, and basic employment and commuting patterns for all adults in the household. Respondents were asked detailed information about the household's current vehicle holdings, expected future purchases, and which vehicle they would most likely replace with an

AFV. In addition to this information, the CATI-1 also included demographic variables, such as household income, race, age, gender, and education level of household members. This information was then used to produce a customized questionnaire for mailing to those sampled households that agreed to participate in the second part of the survey. Of the 1,904 respondents to the CATI-1, 1,711 agreed to complete the mail survey and participate in the CATI-2 interview.

Computer-Aided Telephone Interview No. 2

There were 1,149 respondents that participated in the second telephone interview (CATI-2). The CATI-2 survey consisted of the following five parts.

Part 1 asked for detailed information on commuting patterns and vehicle usage, such as number of trips per day; distance traveled by purpose, such as work, school, and shopping; and the vehicle being used.

Part 2 explored how the household might use an AFV, given a single AFV to replace one of their current vehicles. For the utilization portion of the CATI-2, respondents were randomly assigned one of the AFV types—electric, natural gas/propane or alcohol—with shares equal to 40%, 40%, and 20%, respectively. The California surveys, as compared to the NS, allocated less to alcohol AFVs, using percentages of 45%, 45%, and 10% for electric, natural gas, and alcohol, respectively. The change in the AFV percentages preserved consistency with the California sample but reflected DOE interest in alcohol vehicles. Respondents were provided specific information about the AFV, such as fuel cost, range, tailpipe emissions, possibility of home refueling, and, if applicable, time and cost to refuel at home. For electric vehicles peak and off-peak charging costs were included when home refueling was available. The respondent was then asked to imagine how they would use one of their current vehicles if it were the specified type of AFV rather than the present gasoline vehicle that it hypothetically replaced.

Part 3 contained the SP experiments in which respondents were asked to choose a vehicle in two future years: 1998 and 2001. Used AFVs were included as possible vehicle choices in the 2001 choice set, reflecting the assumption of greater acceptance and resale potential of AFVs into the personal vehicle market by that time. The survey attempted to simulate a realistic “transition” world in which new AFVs are introduced and then become available as used vehicles a few years later. Each respondent received two sets of vehicle choice cards—one set describing the cars and light trucks hypothetically available in 1998 and another set in 2001. A card for each vehicle specified the attributes of the vehicle including body type, price, fuel type, fuel cost, primary fuel range, secondary fuel range for dual fuel and flex-fuel vehicles, reliability, home refueling availability, and luggage space. Respondents were first asked which vehicles they would consider buying and then asked which one would they buy.

Part 4 of the CATI-2 questionnaire contained information on the respondent’s attitude about allocating funds to solve various social problems. Although modeled after the California survey, questions in Part 4 were expanded in the NS to obtain additional information on the respondent’s attitude toward several different options for reducing dependence on foreign oil and improving urban air quality.

Part 5 of the CATI-2 survey obtained information on the household members who completed the mail survey and asked a series of questions pertaining to the respondent’s general impressions and awareness of characteristics of AFVs such as, performance, reliability, safety, and

emissions. Questions in Part 5 were not included as part of the mail survey. Rather, respondents were asked this final set of questions at the end of the CATI-2 interview.

Stated Preference Design

The SP design was developed to estimate discrete choice models for vehicle purchases using vehicle attributes as inputs into the households' utility function. The underlying assumption of such models is that the decision to purchase a particular vehicle is based on an array of household and vehicle attributes. The attribute data collected through the two SP tasks form the basis of the variables to be used in the modeling of vehicle choice.

For the SP tasks, households were asked to consider purchasing a vehicle from a set of 17 vehicles available to them in two future years: 1998 and 2001. Each of vehicles in the choice set were described in a 'full profile' approach as shown in the sample vehicle card provided in Figure 1. In addition to the vehicle-specific information, respondents were provided a detailed description of the general market setting for AFVs, including number of vehicles on the road, service station availability, incentive programs, and relative emissions.

Figure 1: Sample Vehicle Description Card

Vehicle 1 New 1998 Nat. Gas/Propane Pickup From a Foreign Manufacturer	
SPECIFICATIONS	
Price:	\$14,000; Leasing option is available.
Fuel:	Runs on nat. gas/propane only. Refueled at nat.gas/propane station or at home.
Fuel Cost:	3.4 cents/mile (like 36 MPG gasoline) 4 hours to fill at home. 15 minutes at station.
Range:	250 miles
MAINTENANCE	
Annual Cost:	Oil changes/lube/etc. \$600 per year.
Warranty:	Full 4-year warranty.
PERFORMANCE	
Acceleration:	0-30 MPH in 3 seconds (Like a Camaro).
Top Speed:	95 MPH
GENERAL DATA	
Similar Vehicles:	Isuzu Pickup; Mitsubishi Pickup; Nissan Pickup
Luggage Space:	Like comparable gasoline vehicles.
Reliability:	No track record. Car magazines predict above average reliability.

The experimental design manipulated a total of 26 attributes to construct the hypothetical vehicles and their descriptions. The NS incorporated 11 body type and size classes, counting the neighborhood electric vehicle as a separate body type/size class. Because the underlying premise was increased penetration of AFVs into traditional vehicle markets, these 11 classes were expanded to encompass the additional dimension of fuel type. A total of 33 vehicle classes were produced by combining fuel type with body type/size classes. The 33 vehicle classes used in the SP tasks are provided in Table 1.

The experimental design generated 192 card sets, containing 34 distinct vehicle descriptions,—17 for each SP choice set defined by year. Respondents were randomly assigned one of the 192 cardsets for the SP tasks. The neighborhood electric vehicle appeared as one of the 17 vehicles in each choice set (1998 and 2001) so that a common 'base' vehicle class was represented in all choice sets. The remaining 16 vehicles in each set were produced by a partitioning of the 32 non-neighborhood vehicle classes. Using this design, each respondent evaluated all 33 vehicle classes. All non-neighborhood vehicles were evaluated once and the neighborhood electric vehicle twice (in 1998 and in 2001). As a result of the design, the relative proportions of observing the fuel types in the SP tasks were: gasoline, 29%, alcohol, 26%, natural gas/propane, 24%, and electric, 21%.

Table 1: Vehicle Classes —Body Type and Size by Fuel Type

Body Type	Size	Gasoline	Alcohol	Natural Gas/ Propane	Electric
Car	Neighborhood				33
	Small	1			28
	Compact	2	11		29
	Midsize	3	12	20	
	Large	4	13	21	
Pickup	Compact	5	14	22	30
	Standard	6	15	23	
Van	Minivan	7	16	24	31
	Standard	8	17	25	
Sport Utility	Compact	9	18	26	32
	Standard	10	19	27	

Reasonable ranges for vehicle attributes such as price, range, fuel cost, and fuel efficiency were defined for each of the 33 classes. The experimental design developed by David Bunch of UC ITS was used to create allowable combinations of these features. Particular attention was given to the values for each of the levels included in the design so that the resulting hypothetical vehicles were a realistic representation of technologies available in 1998 and 2001. The project staff collected data on gasoline vehicles from such sources as *Automotive News Data Book* (1) and *Wards' Automotive Yearbook* (20). Attribute ranges for each of the 33 vehicle classes were developed on the basis of this information explicitly to avoid unreasonable vehicle representations. Within those ranges, values were randomly assigned to the attribute variable.

Table 2 contains a list of the 26 vehicle attributes that are manipulated by the experimental design to generate the hypothetical vehicle descriptions. Some attributes listed in Table 2 do not

appear directly in the survey but are used by the experimental design to produce the vehicle information. For example, fuel efficiency (mpg) and fuel cost (cents per gallon) are combined to obtain fuel cost in cents per mile. Three of the four generic AFV attributes—fuel availability, number of vehicles on the road, incentive programs, and relative emissions—together with the vehicle-specific information were used to estimate the conditional logit models presented here. Incentives are not examined here.

Table 2: Vehicle Attributes Used in the Experimental Design

No.	Name	Description
1	SP Year	1998 or 2001
2	Fuel Type	Gasoline, alcohol, nat gas/propane, or electricity
3	Body and Size	One of 11 body types (see Table 1)
4	Vehicle Class	One of 33 vehicle classes (see Table 1)
5	Multiple Fuel	Yes/no applicable to flex-fuel alcohol, dual-fuel natural gas/propane, and hybrid electric (with attribute 2, yields attribute 6)
6	Extended Fuel Type	One of seven types -- four fuels and three multifuel
7	New/Used	Two levels
8	Domestic/Foreign	Two levels (U.S. and Foreign)
9	Prestige Variable	Dummy variable indicating high price/status tier
10	Price	Purchase price of vehicle (nominal dollars)
11	Comparable vehicles	Text descriptions, depend on attributes 3, 8, 9.
12	Lease Option	Two levels (yes or no)
13	Home Refueling	Two levels (yes or no), for natural gas/propane and electric
14	Fuel Efficiency	Fuel Efficiency (mpg or per gasoline equivalent gallon).
15	Fuel Costs	Dollars per gallon (or equivalent).
16	Refuel Time--Station	Refueling time at station (minutes)
17	Refuel Time-- Home	Refueling time at home (hours)
18	Range 1	Vehicle range on primary fuel (miles)
19	Range 2	Range on secondary fuel, if applicable (miles)
20	Maintenance	Text descriptions and annual costs
21	Battery Exchange Cost	One of six levels
22	Warranty	Vehicle warranty in years (none, 1, 3, or 4)
23	Acceleration	Time in seconds 0 to 30 mph; values between 2 and 10 seconds
24	Top Speed	Miles per hour
25	Luggage Space	Fraction of luggage space of the comparable gasoline vehicle—values of 0, .67 and 1.0
26	Reliability	One of six levels (Three levels each for new and used cars: average, above average, excellent)

DESCRIPTIVE STATISTICS

Demographic indicators and geographic identifiers can be used to analyze and correct for deviations between the NS sample and the national population. The demographic characteristics of respondents to the CATI-1 and CATI-2 surveys, when compared to national Census information indicate that the samples are slightly low in representation of single-person households and slightly high in representation of two-person households. In terms of the number of vehicles per household, the samples, particularly the CATI-2 survey, tend to underrepresent those households that do not have a vehicle or that own one vehicle, and overrepresent those with two or more vehicles. Sample respondents also tend to be better educated and earn higher incomes when compared with national

figures. Nearly 30% of the sample consists of high school graduates and 20% consists of college graduates. As expected, more educated respondents showed higher participation rates in the CATI-2 survey. The response rate among those who did not finish high school was only 49% while more than 65% of those with a college degree or graduate work completed the CATI-2. Slightly more than 40% of the sample earn more than \$45,000, with nearly 75% of the respondents falling in the middle income categories (between \$15,000 and \$75,000). Survey respondents in the lowest income range, i.e. earning less than \$15,000, represent only 11% of the sample.

Similar biases were observed in the California sample and a binomial logit weighting scheme was used to adjust for deviations from the general(4). With regard to the representativeness of the national sample, it should be noted that from the NS sponsor's perspective, the target population of interest is "new vehicle buyers", not the general population, and, therefore, the composition of the sample should also be compared with that subpopulation.

Demographic Characteristics: National Survey vs. General Population vs. New Vehicle Buyers

Table 3 provides a comparison of the demographic characteristics for these three groups. The demographics presented for the national sample correspond to those respondents who chose a new vehicle in the SP tasks a subset of all respondents described in the preceding section. This is the subset used in estimates presented in remaining sections. The data from the SP experiments were merged with the demographic data obtained in the CATI-1 interview to develop the demographic profile of new vehicle buyers.

While some differences are immediately apparent in reviewing the three groups, the comparisons suggest that the NS respondents who chose new vehicles are more representative of the characteristics of new vehicle buyers than the general population. Income distribution of respondents choosing new vehicles in the NS sample is more closely aligned with the income distribution of new vehicle buyers, although households earning greater than \$75,000 a year represent a lower share in the NS. Similarly, with respect to education, while the sample distribution is biased toward higher education, as compared with the general population, it is representative of new vehicle buyers. Age groups 35-64 tend to be overrepresented in the sample, as compared to both the general population and new vehicle buyers. With respect to the number of vehicles owned, the national sample appears to be heavily biased toward two-vehicle households even when compared with new vehicle buyers.

The SP experiments contain information that could be used to analyze new and used vehicle markets. The primary research objective, however is forecasting the market shares for new technologies. As a result, respondents selecting a used vehicle in either 1998 or 2001 were dropped from the analysis. The elimination of used vehicles from the sample and, therefore, the choice set had a greater impact on the 2001 SP experiment because both used gasoline and AFVs were offered in that year. All subsequent analysis has been conducted using data on new vehicle choices only.

The SP data from the NS have been used to estimate a restricted conditional multinomial logit model to ascertain the role of a particular attribute in determining vehicle choice. Demographic and geographic characteristics that are likely to be important factors in vehicle choice have not been incorporated into the models constructed so far. The model results presented

here reflect the desire to produce for Department of Energy use relatively straightforward models that can be easily implemented in a spreadsheet model for long-term forecasting.

Table 3: Demographic Characteristics: General Population vs. New Vehicle Buyers vs. National Sample

Demographic Characteristic	Population (%)	New Vehicle Buyers (%)	Sample (%)
Income			
<\$15,000	18.4	5.9	8.8
\$15,000-\$29,000	26.7	19.2	17.7
\$30,000-\$44,000	23.4	23.5	21.2
\$45,000-\$59,000	15.5	21.3	18.4
\$60,000-\$74,000	7.5	11.6	10.1
>\$75,000	8.5	18.6	12.2
Don't know			4.0
Refused			7.6
Population and New Vehicle Buyers Source: <i>1990 Nationwide Personal Transportation Survey (NPTS)</i> .			
Education			
Some High School	24.8	6.4	5.9
High School Graduate	30.0	25.6	28.5
College/Technical School	45.2	68.0	65.5
Don't know			0.1
Population Source: <i>Statistical Abstract of the United States 1996</i> .			
New Vehicle Buyers Source: <i>Newsweek</i> , 1990 New Car Buyers, Section G.			
Age			
Under 25	13.1	7.7	7.2
25-34	21.5	19.0	21.7
35-44	21.7	24.0	27.6
45-54	15.5	15.9	20.1
55-64	10.9	15.4	11.3
>65	17.2	17.8	11.1
Refused/Don't know			1.0
New Vehicle Buyers Source: <i>Newsweek</i> , 1990 New Vehicle Buyers, Section G.			
Population Source: <i>Statistical Abstract of the United States 1996</i> .			
Number of Vehicles			
0	9.2	not included in total	2.4
1	32.8	23.3	25.5
2	38.4	40.5	48.3
3 or Greater	19.6	36.2	23.8
New Vehicle Buyers Source: <i>Newsweek</i> , 1990 New Car Buyers, Section G.			
Population Source: <i>1990 NPTS</i> .			

Slightly more than 30% of all new vehicle buyers chose gasoline vehicles. Of the 70% choosing AFVs, only 15% selected an electric vehicle, 29% selected a natural gas/propane fueled vehicle, and 25% selected an alcohol fueled vehicle. The fact that 70% respondents chose AFVs may indicate bias. However, the survey design was such that long-run mass production costs for AFVs were specified, and the sample design was set up to make all vehicles "competitive" with one another by varying attributes such as fuel cost and retail price within overlapping ranges. Accordingly, if fuel type is significantly less important than vehicle size, or price, or operating cost, or range, etc., one might expect the share of AFVs to be close to the design share (71%).

The distribution across body type was significantly skewed to the “van and sport utility vehicle (SUV)” category, with 40% of the respondents selecting a vehicle in that class. Vehicles classified as midsize and large were selected by 22% of new vehicle buyers, pickup trucks by 18%, and small cars by 20%. Table 4 shows the submarket shares for all vehicle classes.

Table 4: Percentage of New Vehicles Selected by Vehicle Class

Body Type and Size		Gasoline	Alcohol	Natural Gas/ Propane	Electric	All Fuel Types
Car	Neighborhood				5.35	5.35
	Small	2.29			3.06	5.35
	Compact	2.85	4.10		2.15	9.10
	Midsize	3.47	5.35	6.67		15.49
	Large	1.53	2.08	3.06		6.67
Pickup	Compact	2.22	1.67	3.06	1.67	8.61
	Standard	4.17	2.08	2.85		9.10
Van	Minivan	3.40	2.57	3.19	0.83	10.00
	Standard	0.90	1.94	1.18		4.03
SUV	Compact	5.69	3.19	6.81	2.29	17.99
	Standard	3.75	2.36	2.22		8.33
All Body/Size Types		30.28	25.35	29.03	15.35	100.00

Table 5 displays the sample distribution of demographic characteristics with respect to body type choice. The aggregate body-type categories were formed by combining the body type/size classes in the following manner: small car includes small and compact cars; large car includes midsize and large cars; work truck includes compact pickup, standard pickup, and standard van; and passenger truck includes minivan, and compact and standard SUVs. The demographic variables include education, income, number of vehicles owned, gender of respondent, and age of respondent.

Some observations can be made with respect to the demographic information. Passenger trucks/(minivans and SUVs) capture the largest share of the market, with 36% overall. Across all levels of education, income, gender and number of vehicles the passenger truck category has the highest percentage. The only case in which the passenger truck is not the most selected vehicle is for those in the 54-65 age category—they prefer large cars. Body-type selection exhibits significant variation by gender, with females less likely to purchase work trucks and more likely to select midsize cars. The most preferred body-type by both males and females, however, is the passenger truck.

Table 5: Demographic Characteristics of New Vehicle Buyers—Distribution by Body Type in Percent

Item	Body Types				Row Total
	Small Car	Midsize and Large Car	Work Truck	Passenger Truck	
Body Type Distribution	19.79	22.15	21.74	36.32	100.00
Education					
<High School	1.53	1.11	1.32	1.95	5.91
High School Grad	4.38	6.05	8.14	9.94	28.51
College or Tech School	4.80	4.80	5.29	7.86	22.74
Tech School Degree	1.25	1.74	1.53	2.92	7.44
College Degree +	7.86	8.48	5.42	13.63	35.40
Income					
<\$15,000	2.22	1.46	1.81	3.33	8.82
\$15,000-\$29,999	3.82	4.10	4.65	5.14	17.71
\$30,000-\$44,999	3.89	3.82	5.42	8.06	21.18
\$45,000-\$59,999	3.19	3.68	4.03	7.50	18.40
\$60,000-\$74,999	2.01	2.85	1.60	3.61	10.07
\$75,000-\$99,999	1.32	1.81	1.04	2.15	6.32
\$100,000-\$125,000	0.56	0.76	0.63	1.25	3.19
>\$125,000	0.63	0.76	0.28	1.04	2.71
Don't Know	0.42	0.90	1.18	1.53	4.03
Refused	1.74	2.01	1.11	2.71	7.57
Age					
Under 25	1.82	1.40	1.61	2.46	7.30
25-34	3.30	4.00	4.91	9.75	21.96
35-44	4.77	5.82	6.11	11.16	27.86
45-54	4.77	4.21	4.21	7.09	20.28
55-64	2.18	3.65	3.16	2.39	11.37
>65	2.88	3.16	1.68	3.51	11.23
Don't know	0.28	0.14	0.28	0.35	1.04
Gender					
Male	8.96	9.51	12.43	17.57	48.47
Female	10.83	12.64	9.31	18.75	51.53
Number of Vehicles in Household					
0	0.69	0.35	0.49	0.83	2.36
1	6.18	6.25	4.31	8.75	25.49
2	8.68	10.14	10.97	18.54	48.33
3	4.24	5.42	5.97	8.19	23.82

INITIAL MODELING RESULTS

Researchers at UC ITS have used the stated-preference national survey to produce a series of model estimates for new vehicle choice models. Three of these numerous models are presented in this paper. The third combines both the NS and California surveys. UC ITS researchers relied extensively on data from the national survey's antecedent for the State of California [see (2); (3); (4); (8); and (16)]. However, they were also directed in their NS estimation to use a vehicle body type grouping specified by Argonne staff (unpublished communication from Santini to Bradley),

developed as a result of discussions with the sponsor concerning the number of vehicle types which could usefully be modeled. Note that these restrictions were determined in part because input information on anticipated future alternative fuel vehicle characteristics had to be obtained from and in consultation with the four Offices within the Office of Transportation Technologies. Each added level of detail to the model makes the task of the individuals preparing input estimates more onerous. In the case of OTT, the model's purpose is, in part, to provide internal evaluation of competing R&D projects for vehicles that may not enter the market in large percentages for more than a decade. The version of the model developed for OTT needed to reflect some of the important details of the light duty vehicle market, but not all of the detail needed by an automaker attempting to market specific vehicles within the next few years. This is not to say that the sample is not useful or potentially informative for such a purpose. Rather, it is to explain the reasons for condensing the number of classes of vehicles to a smaller number than allowed by the sample itself. It is anticipated that future estimation with the sample, to be conducted to meet the needs of the Energy Information Agency - which generates projections for a shorter time horizon than OTT - will develop models with much fewer constraints than imposed here.

Two models of particular interest are presented and discussed in this section. These models have been used by the OTT in their analysis of the future potential of AFVs through 2020 (12); (15). The spreadsheet vehicle market share model used by Moore et al. makes use of most, but not all of the coefficients in the second statistical model presented here.

The unrestricted and restricted models estimated by UC ITS provide estimates of vehicle shares by four body types. Vehicles were placed into the following four classes based on body-type: small car, large car, work truck, and passenger truck. The "small car" class consists of body types identified as small and compact car in Table 4, as well as the neighborhood electric vehicle. The "large car" consists of midsize and large cars; "work trucks" are composed of compact and standard pickup trucks and standard vans; "passenger trucks" are composed of minivans, compact SUVs and large SUVs. In the unrestricted model, the vehicle attribute coefficients are allowed to vary across the four vehicle body-types. This model provides a point of reference for the restricted model. Both models are multinomial logit share models that were estimated by using a maximum likelihood estimation technique.

The restricted model was developed by inspecting the unrestricted model coefficients and t-values and, when no evidence of statistically significant differences between coefficients was evident, the coefficients were restricted to be identical, regardless of body type. When it was not clear whether coefficients should be restricted or unrestricted, multiple tests were conducted. If theoretically implausible coefficients were obtained, the coefficient was restricted to be zero, regardless of level of significance when not restricted. Restricted models other than the one presented were examined. The one presented was determined to be "best" for OTT spreadsheet market share modeling purposes. In general, it was determined that there were relatively few cases where the NS statistically supported a conclusion that coefficients for key determinants of consumer satisfaction with a vehicle vary by body type.

The restricted model is a more standard conditional logit model [see (5) and (11)]. In this model, most of the vehicle attribute coefficients are held constant across body type. Both of the models presented are statistically significant. Vehicle attributes are defined in Table 6, and estimates for these models are shown in Table 7.

Sixteen vehicle attributes remained in the models presented after preliminary models with more variables had been tested. Note that attributes specific to electric vehicles are not considered for large cars, since by design, survey respondents were not given the choice of large electric vehicles (see Table 4). It was necessary to restrict a number of the coefficients in the pickup truck equation equal to zero because, with the formulation of the independent variables used in the model, and the set of variables included, theoretically unsatisfactory results were obtained for fuel cost, range, and luggage space variables. This is obviously an area for further investigation. However, among the vehicle classes examined, one would expect coefficients for work trucks to be most likely to differ from those for passenger vehicles.

Unrestricted Model

The unrestricted model has a better "goodness of fit" statistic than the restricted model. The unrestricted model is based on the assumption that consumers differentially value vehicle attributes, depending on the type of vehicle. As a result, the estimated coefficients for this model are more difficult to explain theoretically.

Statistically, purchase price is the most important variable in both models. The purchase price coefficient has the expected negative sign and is statistically significant at the 0.005 level in all cases. The relative magnitudes of the estimated coefficients in the unrestricted model seem to make intuitive sense, indicating that consumers who select small cars are more sensitive to the purchase price.

Other variables are less significant in the unrestricted model. The station fuel cost attribute is statistically significant at the 0.01 level for the small car coefficient and, as in the purchase price variable, indicates that consumers who select small cars are more sensitive to cost. Also, the estimated coefficient for the fuel-cost attribute in the work truck equation has a theoretically unacceptable positive sign. It is therefore restricted to be zero in the restricted equation.

The electric off-peak cost variable is significant at the 0.01 level for the work and passenger truck equations. The signs of the estimated coefficients, however, are opposite: positive in the work truck equation and negative in the passenger truck equation. As in the case of the station fuel cost coefficient, a positive sign for the electricity cost coefficient is also theoretically unacceptable, and is therefore restricted to be zero in the restricted equation.

Pending further investigation, these results suggest the interpretation that work truck owners are relatively insensitive to fuel related costs. Since no measure of work truck load carrying capability has been included in the survey, it is not possible to determine whether the desire for larger engines for load carrying capability outweighs the desire for smaller, or more efficient engines to save fuel.

The coefficient estimates for the maximum range variables, crossed with the dedicated-fuel-dummy variable, are statistically significant at the 0.05 level for the small-car and work truck coefficients, indicating that shares for these body types are positively influenced with an increase in vehicle range. For the maximum range variables crossed with the multifuel dummy variable, the estimated coefficients are statistically significant at the 0.025 level for the large car and work truck coefficients and are estimated to positively influence their market shares. Because of coefficient fluctuations in intermediate tests, the coefficients for the range of work trucks were

constrained to be zero in the restricted model. This is true despite obtaining the proper result in the unrestricted model. The range variable uses the actual maximum range of the vehicle up to 300 miles, and then uses 300 miles thereafter, regardless of actual maximum range. Maximum range consists of the sum of ranges for two fuels when a vehicle is a dual fuel vehicle or a hybrid, since the two tanks (or battery and tank) can separately be filled. In the case of the alcohol multifuel vehicles only one tank exists. Range is longer when the tank is filled with gasoline. Numerous experiments were conducted with various formulations for the range variable(s).

Table 6: Description of Variables Included National Survey Models

Variable Name	Description
Body Type Classes:	
Small	Small and compact cars
Large	Midsize and large cars
Work Truck	Compact pickup, standard pickup, and standard van
Passenger Truck	Minivan, compact sport utility vehicle, and standard sport utility vehicle
Purchase Price	Nominal dollar purchase price of vehicle
Operating Cost:	
Station Fuel Cost	Station cost of fuel in cents per mile (on-peak charge for electric vehicles)
Electric Off-Peak Cost	Electric home recharge off-peak cost in cents per mile
Maintenance Cost	Dollars per year ranging between \$300 and \$1,100
EV Battery Cost	Dollars per year to exchange batteries excluded in purchase price--ranging between 0 and \$360 per year
EV Battery: 4-year dummy	Dummy variable for years to exchange battery: 1 = 4+, 0 = less
Performance:	
Max Range--Ded	Maximum range in miles for dedicated fuel vehicles i.e. gasoline, natural gas/propane, and dedicated electric--capped at 300 miles
Max Range--Multi	Maximum range in miles for multifuel vehicles i.e. alcohol (flex fuel), nat gas/propane(dual-fuel--two tanks), and hybrid electric range extender
Acceleration	Seconds, 0 to 30 mph—values range from 2 to 10 seconds
Top Speed	Miles per hour—values range from 40 mph to 125 mph
Luggage Space	Fraction of luggage space versus gasoline vehicle—three values: either 0.0, 0.67 or 1.0
Home Refueling	Dummy variable for home refueling (yes=1)
Multifuel	Dummy variable for multifuel vehicle; see Max Range--Multi
Fuel Availability interacted with home refueling option:	
Station Fuel Avail * no home refuel	Number of alternative fuel stations expressed as a percent of the number of gas stations when home refueling is not specified as an option
Station Fuel Avail * home refuel	Number of alternative fuel stations expressed as a percent of the number of gas stations when home refueling is specified as an option
Number vehicles on road	Thousands of vehicles on the road “in your region”

Table 7: National Survey Model Results

Variable	Body Type	Unrestricted		Restricted		
		Coefficient	T-Stat	Coefficient	\$ Equiv	T-Stat
Purchase Price	Small Car	-0.000107	-4.0	-0.000048	-1.0	-10.5
	Large Car	-0.000046	-6.8	-0.000048	-1.0	-10.5
	Work Truck	-0.000056	-3.6	-0.000048	-1.0	-10.5
	Passenger Truck	-0.000056	-4.7	-0.000048	-1.0	-10.5
Station Fuel Cost	Small Car	-0.161100	-2.4	-0.172000	-3610	-5.7
	Large Car	-0.100800	-1.9	-0.107900	-2264	-5.8
	Work Truck	0.039410	1.3	0.0	0	C
	Passenger Truck	-0.052800	-1.8	-0.107900	-2264	-5.8
Electric Off Peak Cost	Small Car	-0.071880	-0.5	-0.213500	-4481	-5.0
	Large Car	NA		NA		
	Work Truck	0.307100	2.3	0.0	0	C
	Passenger Truck	-0.298500	-2.7	-0.213500	-4481	-5.0
Max Range--Ded	Small Car	0.005018	1.7	0.001727	36	2.3
	Large Car	0.001928	0.7	0.001727	36	2.3
	Work Truck	0.007186	2.1	0.0	0	C
	Passenger Truck	0.001119	0.5	0.001727	36	2.3
Max Range--Multi	Small Car	0.002989	0.6	0.001647	35	2.3
	Large Car	0.005423	2.1	0.001647	35	2.3
	Work Truck	0.005811	2.1	0.0	0	C
	Passenger Truck	-0.001386	-0.5	0.001647	35	2.3
Maintenance Cost	Small Car	-0.000654	-1.2	-0.000569	-12	-3.0
	Large Car	-0.000593	-1.5	-0.000569	-12	-3.0
	Work Truck	-0.000988	-2.4	-0.000569	-12	-3.0
	Passenger Truck	0.000029	0.1	-0.000569	-12	-3.0
EV Battery Cost	Small Car	-0.000108	-0.2	-0.000612	-13	-2.1
	Large Car	NA		NA	NA	
	Work Truck	-0.000595	-0.7	-0.000612	-13	-2.1
	Passenger Truck	0.000078	0.1	-0.000612	-13	-2.1
EV Battery: 4-year dummy	Small Car					
		-0.149900	-0.7	0.251700	5282	1.6
	Large Car	NA		NA	NA	
	Work Truck	0.537700	0.8	0.251700	5282	1.6
	Passenger Truck	0.625100	1.6	0.251700	5282	1.6
Acceleration	Small Car	-0.082320	-1.8	-0.075590	-1586	-3.8
	Large Car	-0.003796	-0.1	0.0	0	C
	Work Truck	-0.110600	-2.2	-0.075590	-1586	-3.8
	Passenger Truck	-0.121200	-2.7	-0.075590	-1586	-3.8
Top Speed	Small Car	-0.002558	-0.5	0.005331	112	3.0
	Large Car	-0.000161	0.0	0.005331	112	3.0
	Work Truck	0.014350	3.3	0.005331	112	3.0
	Passenger Truck	-0.004703	-1.4	0.0	0	C

Table 7: National Survey Model Results (cont.)

Variable	Body Type	Unrestricted		Restricted		
		Coefficient	T-Stat	Coefficient	\$ Equiv	T-Stat
Luggage Space	Small Car	0.005289	1.3	0.006826	143	3.4
	Large Car	0.003777	0.6	0.006826	143	3.4
	Work Truck	-0.034430	-4.9	0.0	0	C
	Passenger Truck	0.011290	2.0	0.014820	311	6.1
Station Fuel Avail * no home refuel	Small Car	0.003604	0.5	0.003938	83	3.0
	Large Car	-0.000139	0.0	0.003938	83	3.0
	Work Truck	0.003130	0.6	0.003938	83	3.0
	Passenger Truck	0.003795	1.2	0.003938	83	3.0
Station Fuel Avail * home refuel	Small Car	0.000543	0.0	0.0	0	C
	Large Car	-0.057160	-1.7	0.0	0	C
	Work Truck	0.019150	0.6	0.0	0	C
	Passenger Truck	-0.024300	-1.3	0.0	0	C
Number vehicles on road	Small Car	0.001390	1.2	0.000814	17	2.3
	Large Car	0.000806	1.2	0.000814	17	2.3
	Work Truck	0.001109	1.5	0.000814	17	2.3
	Passenger Truck	0.000451	0.8	0.000814	17	2.3
Home Refueling	Small Car	0.066620	0.1	0.110400	2317	1.2
	Large Car	0.449200	1.7	0.110400	2317	1.2
	Work Truck	-0.436400	-1.6	0.110400	2317	1.2
	Passenger Truck	0.210600	1.0	0.110400	2317	1.2
Multifuel	Small Car	0.891500	0.8	0.120400	2527	1.0
	Large Car	-0.888300	-1.1	0.120400	2527	1.0
	Work Truck	-0.029610	0.0	0.120400	2527	1.0
	Passenger Truck	0.204600	0.3	0.120400	2527	1.0
Observations			1446	1446		
Final Log Likelihood			-3321.0	-3369.5		
Rho-Squared (0)			0.076	0.062		

The estimated maintenance cost coefficients have the expected negative sign, with the exception of the passenger truck case in which the estimated coefficient is statistically insignificant. The effect of this attribute is estimated to be strongest for the work truck share. The absolute value of the estimated coefficient in the work truck equation is more than 65% larger than that for the large-car equation and more than 50% larger than the estimate for the small car equation. Though it is plausible that maintenance cost is more important to owner of work trucks, the difference in size of the work truck coefficients and the car coefficients is not significant. Similarly the difference between the passenger truck coefficient and the car coefficients is not significant. Accordingly, the coefficients were restricted to be equal in the restricted model, and were estimated to be about the same as the car coefficients in the unrestricted model.

Two variables in the model relate to the cost of replacement batteries for electric vehicles. These are "battery cost", and a dummy variable indicating a statement on the card that the EV battery lasts more than four years. No electric vehicles are offered in the large car class, so only three coefficients are estimated. In each case, two of the three coefficients are of the anticipated sign, but none are statistically significant. Since the OTT sponsors research on electric vehicles, there was considerable interest in determining whether an appropriate battery cost coefficient could be estimated. Sponsorship of the California surveys had included electric utilities, perhaps explaining why there are two questions relating to battery cost characteristics. Both of the battery cost variables were left in the restricted equations due to the level of interest in the coefficients.

The acceleration time attribute (seconds to go from zero to 30 mph) is statistically significant at the 0.05 level, except for the large car. The estimated coefficient has the expected sign in every case. The magnitude of the estimated coefficient is about the same for work and passenger trucks; however, the estimated coefficient for small cars is about 40% smaller.

The top speed variable coefficient is easily significant for work trucks. Otherwise, the coefficients are not significant, and are of the wrong sign in all three cases. An intermediate model reversed the sign of the large car coefficient, though the variable remained insignificant. Given the attributes of minivans (low performance), and the lack of logic for a high value for SUV top speed, the passenger truck top speed coefficient was restricted to be zero in the restricted model, while the coefficients for the remaining three vehicle classes were restricted to be identical.

The coefficient of the luggage space attribute (fraction of luggage space of a gasoline vehicle equals 1.0, 0.67 or 0.0 [for neighborhood vehicle]) is easily statistically significant and (incorrectly) negative in the case of the work truck. For remaining vehicle types it is positive but significant only for passenger trucks. Aside from the work truck, coefficients are statistically indistinguishable and could therefore be restricted to be equal. However, the notion that passenger truck owners place a higher value on luggage space than car owners is intuitively reasonable, so the passenger truck coefficient remains unrestricted relative to the car coefficients, which are restricted to be equal. To the extent that work truck owners value cargo space for work loads instead of luggage space for passenger use, the negative coefficient might be plausible. Here we simply regard it as a theoretically incorrect result and restrict the coefficient to be zero.

The fraction of refueling stations available (as compared to gasoline), when there was no home refueling, was not estimated to have a significant coefficient, but three of the four unrestricted coefficients were nearly identical. As a result, these coefficient were constrained to be equal. When home refueling was indicated to be available, the results were more ambiguous. The coefficient estimates were much less stable than when home refueling was not available, and seemed more likely to be negative than positive. Accordingly, these coefficient estimates were restricted to be zero.

The estimated coefficients for the variable number of similar alternatively fueled vehicles on the road are not significant, but all are positive and statistically indistinguishable from one another. These coefficient estimates are also logical for a restriction that all are equal, and such a restriction was imposed.

The estimated coefficients for the home-refueling attribute in the large-car and work truck equations are statistically significant at the 0.05 level, but have opposite signs. Three of the four

coefficients are positive, as anticipated. These coefficients were also a good candidate for the test that they would be significant if assumed to be identical for each vehicle type.

The estimated coefficients for the multifuel variable are all insignificant. One hypothesis is that multifuel vehicles would represent a good transition strategy from gasoline to alternative fuels. Accordingly, if consumers appeared to like having the flexibility to use both gasoline and another fuel, it would indicate that the strategy would be easier to implement. Due to interest in this hypothesis, and despite the contradictory information in the unrestricted equation, this variable was left in the restricted model, with an assumption that coefficients for all body types are the same.

Restricted Model

The restricted model is more appealing than the unrestricted model from a theoretical point of view. The estimates of this model were subject to restrictions, with the logic for these restrictions discussed in the prior section. The estimated coefficients for each vehicle attribute were required to be equal in most cases. A number of the coefficients were set equal to zero because the estimated coefficients gave implausible results.

In all cases, except for the home refueling, electric vehicle battery 4-year and multifuel variables, the estimated non-zero coefficients were statistically significant at the 0.05 level. Again, the purchase price coefficient has the highest t-value, with the t-value for the coefficient of cost of station fuel a strong second. The performance variables, in particular acceleration, also high a relatively high t-value, as does the passenger truck luggage space coefficient.

The station-fuel-cost and electric-off-peak-cost variables are statistically important with a high degree of certainty in the cases of small and large cars and in passenger trucks. Also, the implied dollar value (dollars of purchase value equivalents per ¢ per mile change in fuel cost) to the vehicle purchaser is substantial, and in excess of expectations that would be obtained by discounting the savings to a net present value. The estimated coefficient for the cost of station fuel for the small-car was allowed to differ from the other body-types. The estimated coefficient for this variable indicates that small-car purchasers are more sensitive to fuel cost. It is also estimated that the electric-off-peak-cost attribute is important for the small-car and also in the passenger-truck case (recall that electric vehicles were not offered in the large car category). It is estimated that a reduction of one penny per mile in fuel cost or electric off peak cost would be equivalent to a \$2,500 to \$4,500 increase in the vehicle purchase price.

The estimated coefficient for the acceleration variable is negative and carries with it substantial value. It is estimated that a one-second reduction in time to reach 30 miles per hour is equivalent to an approximate \$1,600 increase in price.

In this equation, the evolution of experiments had led to separate treatment of maximum range for vehicles "dedicated" to the use of only one fuel vs. those capable of using two fuels. In principle, it was expected that the importance of maximum range would be greater for the former than the latter. However, in this equation the estimated value of range is identical for both, at about \$35 per mile. The implications are that if the range of electric vehicles could be increased from about 80 miles to 300 miles, the value of the vehicle to the purchaser would rise by \$7,700. Recall that any range beyond 300 miles is estimated in this equation to have a value of zero dollars. Thus, providing a large battery pack in a hybrid vehicle, or several tanks in a dual fuel CNG vehicle would not add value related to range if the vehicle were also able to go 300 miles with a full

tank of gasoline. This conclusion is not statistically powerful, but a large number of functional forms were tested for "best fit" for the range variable (test results not included here).

The maintenance cost coefficient, at \$12 of vehicle purchase value increase per annual dollar of maintenance expense reduction, indicates that consumers take into account inconvenience costs as well as "out of pocket" costs when evaluating the maintenance requirements for a vehicle. An alternative explanation is that the respondents evaluated the vehicles on the basis of an assumption that they would keep it 12 years, and applied no rate of discount to the cost stream. The latter explanation is unlikely, but it does illustrate that the coefficient is intuitively reasonable. A similar stream of logic applies to the EV battery cost coefficient, which is \$13 of vehicle purchase value increase per annual dollar of reduction in annualized expense of battery replacement.

The dummy variable indicating that the EV battery lasts more than four years has a large dollar value, but a relatively low t-value. The coefficient implies that consumers do not want to have to replace battery packs very frequently, and would probably be willing to pay thousands extra for an extension of battery life of a couple of years - independent of the annualized cost of replacement, since that is included in the EV Battery Cost coefficient. This coefficient may be indicating that consumers place a high value on "inconvenience costs" involved with having to do major maintenance on a vehicle.

The top speed coefficient of \$112 per mile of top speed capability implies that an increase in top speed capability for an electric vehicle from about 70 mph to 90 mph would be worth \$2,200 to a potential purchaser of the electric vehicle (or any vehicle).

The luggage space variable was tested as a percentage. For passenger cars, it implies that a decrease of 1/3 of the luggage space would reduce the consumer's "willingness to pay" for the vehicle by \$4,700. For Passenger trucks, it implies that a similar percentage reduction would be valued at about \$10,000. Since the luggage space available in a passenger truck is far larger than in a passenger car, these valuations would not be so different if translated to dollar per unit volume of luggage space.

The "station fuel availability variable for vehicles without home refueling" is also expressed as a percentage in the equation. The coefficient of \$83 per percent of gasoline stations implies that consumers would pay \$7,500 dollars less for vehicles that had 10% as many refueling stations (90% less) as gasoline stations. It is important to note that the range of percentages presented to respondents was only from 5% to 15%, so this coefficient should be interpreted with caution. It may only imply that consumers would pay \$830 more for an alternatively fueled vehicle when the number of stations offering the fuel, expressed as a percentage of stations offering gasoline, rises from 10% to 15%. Other research implies that there is a threshold in the neighborhood of 15%, above which additional stations are not particularly important (17).

The variable, number of like alternatively fueled vehicles on the road in your region, was entered into the equation in thousands. Accordingly, the coefficient implies that the knowledge that there were 200,000 vehicles of the type being considered, on the road in the "region" of the purchaser, would make a purchaser willing to pay \$1,700 more than if only 100,000 were on the road in that region. This variable is a difficult one to interpret, since the meaning of region is obviously vague, but it does match intuition and the coefficient is significant, indicating that this is an important consideration to NS respondents.

The home refueling and multifuel dummy variable coefficients are both insignificant, but have the correct sign. The home refueling dummy variable coefficient indicates that a consumer would be willing to pay \$2,300 for the opportunity to refuel at home. The multifuel dummy variable coefficient indicates that a consumer would be willing to pay \$2,500 for an opportunity to own a vehicle capable of using a second fuel aside from gasoline. While these coefficients are insignificant, they may indicate that some subgroups in the population would be willing to pay for these features, and suggest more detailed demographic analysis to search for the existence of such subgroups. On the other hand, the absence of statistical significance indicates that these numbers should be used with caution and regarded skeptically.

POOLING THE NATIONAL AND CALIFORNIA SURVEYS

The estimates presented in Table 7 are provided as a record of work accomplished for DOE/OTT, as an indication of the process of investigation of the survey results, and for information to those interested in the implications of the estimates. Since the California population represents about 12% of the U.S. population, the sponsor had also hoped to obtain pooled estimates which included California - a truly national sample. The NS has been designed to allow the pooling of the two samples, though a few caveats are necessary. Due to other commitments by David Bunch, the UC ITS provided the services of Mark Bradley to complete the NS analysis presented in Table 7, allowing OTT to construct a new spreadsheet model based on the NS. Bunch has since had the opportunity to begin examination of the question of pooling, with less pressure to meet a specific deadline, and with interest expressed by Bunch of UC ITS, by Santini of Argonne, and by David Chien of DOE/EIA in the question of the accuracy of grouping of the vehicle size classes. The inclusion of demographic variables in the tests conducted remains to be done, but Bunch has been conducting numerous tests of the ability to pool the NS and California samples. Bunch was permitted to reexamine the question of grouping of vehicle size classes. He has constructed models which make full use of all of the vehicle body types shown in Table 1.

Before proceeding, we cover a few of the key caveats concerning interpretation and pooling of the two samples. In California, only natural gas vehicles were offered to respondents. Propane was not included. Propane is the leading alternative fuel in the nation, and tends to be used in rural areas. Relative to the NS, the California survey is more geographically confined, tending to sample major urban areas, where the NS is unbiased in this respect. One of the "solutions" to the problem of maintaining the same number of classes of vehicles of various types in the NS and California surveys was to create the "gaseous fuel" category in the NS as a replacement for the natural gas category in CA. Both propane and natural gas are gaseous fuels, and are very similar in terms of how vehicles using the fuels are designed and configured. Propane is more "energy dense", and therefore requires smaller tanks than natural gas. Another difference was that the California survey asked about methanol vehicles. In the midwestern U.S., there is a great deal of interest in ethanol as a vehicle fuel, and the DOE has programs to develop biomass-based ethanol fuels for energy security and greenhouse gas reduction. From a consumer and manufacturer's point of view, however, methanol and ethanol are very similar. The solution was to ask consumers their preference for alcohol vehicles, rather than methanol vehicles in the NS. This categorization recognizes the similarities in the vehicle types, and allows the DOE interest in obtaining information applicable to ethanol to be served. Nationally, ethanol is presently blended into gasoline. Volumes of ethanol that are presently used in U.S. vehicles are far greater than volumes of methanol. Grouping of the gaseous fuels (natural gas and propane (also called LPG)) and the alcohol fuels (ethanol and methanol) allowed the same experimental design and methods to

be used and the same survey contractor to be employed for both surveys. The California survey also incorporated hybrid vehicles as vehicles that are capable of using both electricity from the grid and gasoline. In the DOE cooperative "Partnership for a New Generation of Vehicles" project with the U.S. "Big 3", a possible vehicle design will be an electric drive hybrid which is designed in such a way that it will not make sense to use electricity from the grid, and the vehicle will not do so. The design should be much like a gasoline vehicle in the consumer's eyes, only much more efficient. The NS and the California surveys do not ask any specific questions about such a vehicle. However, the NS does include a range of fuel costs wider (with a lower low) than in the California sample, to allow testing for consumer valuation of dedicated gasoline fueled vehicles with far greater fuel efficiency than available today. For readers of this paper knowledgeable about hybrid vehicles, it is important to keep in mind that the hybrid vehicle label here is associated with a particular type of vehicle. The hybrid is presented to the consumer as a vehicle with significant all electric range, and an ability to use electricity from the grid.

The California sample size is much larger than the NS, and the sample structure has some geographic bias. One reviewer indicated that it was probably more valid to run an unweighted statistical model of the NS than the California sample. No weighting of the California sample has been done in the model presented here, nor for prior experiments. The same reviewer argued that the sample should include used vehicles. Since the model being developed for OTT is intended to simulate new vehicle purchaser behavior, it was decided that the supposed bias created by deleting the used car buyers would be appropriate. The best approach is subject to analysis of coefficient estimates with and without used cars. This does complicate variable construction and necessitates numerous multiplicative dummy variable tests for differences between used and new vehicle purchasers. Knowing the coefficients for used car purchasers is of no value in the model used by OTT or EIA, present "customers" for this research. Accordingly, focus on new car buyers only was considered satisfactory at this juncture. Note in Table 3 that the new vehicle selectors in the sample much more closely match the sample profile for new vehicle buyers than for the population of vehicle owners as a whole.

As an indication of the possible effect of inclusion of used vehicles, note that some of the early NS investigation done in conjunction with the models in Table 7 included tests with and without respondents who selected used vehicles. For the six variables that have counterparts in Tables 7 and 8 and had t-values of 2.3 or higher (purchase price, station fuel cost, maintenance cost, EV battery cost, acceleration, and number of vehicles on the road), the average absolute change in coefficient size was 13% when selectors of used vehicles were added to the sample. The largest change was a drop in the acceleration coefficient of 27%, indicating that used vehicle buyers are probably less concerned than new vehicle buyers about acceleration.

Several different composite variables have been examined prior to the model presented here. Disaggregation/reaggregation of vehicle types has been examined. In addition, two new variables are used. These are the relative emissions of the alternative fuel vehicle vs. the gasoline vehicle, and an indicator of "prestige". It was anticipated that the rest of the U.S. would place a lower value on emissions reduction than residents of most major California cities, where air quality has been the worst in the nation. The "prestige" variable concept was developed for the California survey by K. G. Duleep of EEA, Inc. In general it is correlated with vehicle price, with prestige vehicles being higher priced than other vehicles. However, the prestige vehicle can be cheaper in a given set of choices that a respondent is offered than other vehicles which are not prestige vehicles. This variable proved to be very important in analyses done by the UC ITS of their California surveys. When excluded from the equation presented, the coefficient of vehicle price dropped

sharply, and the value relationships discussed for the estimates in Table 7 become less plausible. When prestige is included, the vehicle price coefficient is consistent with the values estimated and presented in the second model of Table 7. Accordingly, the prestige variable is included. It is anticipated that the causes of the importance of the prestige variable will be investigated further.

Having stated our caveats, we turn to the latest estimates. The variables used in the pooled model are described in Table 8 and estimates presented in Table 9. Note that this model is a result of numerous preliminary investigations of the statistical validity of pooling the NS and California respondent values for a particular variable, in order to develop an appropriate, truly national coefficient.

Core variables

A large number of the variables of fundamental importance to consumer choice in the prior estimates proved to have coefficients statistically indistinguishable between California and the NS. These variables were pooled, and are presented in the upper portion of Table 9. These include purchase price, station cost, home refueling cost, maintenance cost, acceleration, EV battery cost. All four reconfigured range variables were also estimated to be poolable. The maximum range variable was estimated for four subgroups of vehicles. Standard trucks, minivans, and standard vans were grouped together. The value of range for these body types was determined to be greater than for "other" body types, whether the vehicle was dedicated to a particular fuel or multifuel. Range coefficient estimates were also separately constructed for dedicated vehicles or multifuel vehicles. As one would expect, the value of range was consistently less for vehicles capable of running on multiple fuels, than for vehicles dedicated to only one fuel. The estimates suggest that, for an electric minivan, if the range were increased from 80 to 300 miles, the dollar value of the vehicle to the purchaser would rise by \$17,500. For an electric car or SUV, the same increase in range would be worth about \$11,100. For other coefficients of interest for electric vehicles, the cost of refueling coefficient dropped by 38%, toward a more plausible value, while the battery cost coefficient rose by 35%, becoming more unreasonable. The good news for electric vehicles is imbedded in the coefficient for the dummy variable for electric vehicles, but the bad news is that consumers are indicating that they regard a dollar saved on annualized battery cost or on fuel cost per mile to be more important than similar savings for a gasoline vehicle, and to be higher than standard net present value calculations would indicate to be appropriate for a typical gasoline vehicle. Some electric vehicle advocates argue that electric vehicles will last much longer than gasoline vehicles. If this is what respondents selecting electric vehicles expect, it could partly explain the higher value placed on annual savings for an electric vehicle than a gasoline vehicle.

For vehicles other than those using electricity from the grid and batteries, the reestimated coefficients are, except for range, lower or about the same. The value of a one cent per mile saving in fuel cost is now estimated to be about \$1,800. Our estimate of the net present value of these savings for a typical gasoline vehicle, assuming a 4% real discount rate, is about \$1,200. Perhaps respondents are factoring in fear of an increase in gasoline prices during the life of the vehicle. Maintenance cost is now estimated to be worth about \$10 per dollar per year of savings, a reasonable value. The value of acceleration is down from \$1,600 per one second reduction in time to reach 30 miles per hour to \$1,400. The preference for top speed proved to be higher in California than in the rest of the U.S. but the size of the coefficient also dropped relative to the value estimated in Table 7. The NS sample value becomes 74 per mile of top speed, so the estimated value of increasing top speed from 70 mph to 90 becomes about \$1,500 instead of \$2,200. The California estimate is about \$2,300 for the same 20 mph top speed gain.

Table 8: Description of Variables in the Pooled Model

Variable Name	Description
Purchase Price ¹	Nominal dollar purchase price of vehicle
NonEV Station Fuel Op. Cost (cpm)	Non-electric station fuel cost in cents per mile
Home-Ref. Elec Fuel Op Cost (cpm) ¹	Electric off-peak home refuel cost in cents per mile
Maintenance Cost (\$ per year) ¹	Dollars per year ranging between \$300 and \$1,000
EV Battery Cost (\$ per year) ¹	Dollars per year to exchange batteries excluded in purchase; values between 0 and \$360 per year
Acc_0-30 (seconds) ¹	0 to 30 miles per hour in seconds —values ranging from 2 to 10 seconds
"Prestige" factor (1, 0)	Dummy variable indicating higher price tier
MaxRange*Ded-Fuel*(LrgTruck/Van)	Maximum range in miles for dedicated fuel vehicles in the large truck or van size class i.e. fuel types: gasoline, natural gas/propane, and dedicated electric—capped at 300 miles
MaxRange*Multifuel*(LrgTruck/Van)	Maximum range in miles for multifuel vehicles in the large truck or van size class i.e. fuel types: alcohol (flex fuel), nat gas/propane (dual-fuel—two tanks), and hybrid electric range extender
MaxRange*Ded-Fuel*(Other)	Maximum range in miles for dedicated fuel vehicles other than large trucks and vans
MaxRange*Multifuel*(Other)	Maximum range in miles for multifuel vehicles other than large trucks and vans
Work Truck (Trucks, Large Vans) ¹	Compact pickup, standard pickup, and standard van
Dedicated Electric	Dummy for dedicated electric vehicle
No.of Vehicles on Road*AFV ¹	Thousands of vehicles on the road “in your region”
Small Van ("Minivan")	Dummy for minivan
Multiple Fuel ¹	Dummy for multifuel vehicle
TopSpeed (MPH) ¹	Miles per hour—values ranging from 40 mph to 125 mph
RelEmiss(100=gasoline)	Relative emissions of AFVs to gasoline vehicles
Neighborhood Vehicle	Size class dummy for neighborhood vehicle
Dedicated Natural Gas	Dummy for dedicated natural gas vehicle
Small Car	Dummy for small car —compact, subcompact, sport
Large Car	Dummy for large and midsize cars
Small Sport Utility Vehicle	Dummy for small SUV
Large Sport Utility Vehicle	Dummy for large SUV

¹ / Same variable appeared in the National Survey models from previous section

Table 9: Pooled National and California Model

Table 9: Pooled National and California Models

Variable Name	Pooled Coefficients	T-Stat		
Purchase Price	-0.000045	-12.15		
NonEV Station Fuel Op. Cost (cpm)	-0.080155	-7.00		
Home-Ref. Elec Fuel Op Cost (cpm)	-0.131782	-5.74		
Maintenance Cost (\$ per year)	-0.000469	-4.23		
EV Battery Cost (\$ per year)	-0.000830	-5.15		
Acc_0-30 (seconds)	-0.061988	-5.11		
"Prestige" factor (1, 0)	0.561182	9.46		
MaxRange*Ded-Fuel*(LrgTruck/Van)	0.003573	4.55		
MaxRange*Multifuel*(LrgTruck/Van)	0.002823	4.45		
MaxRange*Ded-Fuel*(Other)	0.002269	3.16		
MaxRange*Multifuel*(Other)	0.001581	2.66		
Work Truck (Trucks, Large Vans)	-0.642400	-8.92		
Dedicated Electric	0.341787	2.23		
	National	T-Stat	California	T-Stat
No.of Vehicles on Road*AFV	0.000915	2.56	0.000096	0.38
Small Van ("Minivan")	-0.609868	-4.81	-0.337855	-3.10
Multiple Fuel	-0.127597	-0.48	0.317561	1.28
TopSpeed (MPH)	0.003333	2.02	0.005179	4.59
RelEmiss(100=gasoline)	0.001574	1.26	-0.004315	-4.48
Neighborhood Vehicle	-0.807957	-4.41	-0.300663	-2.13
Dedicated Natural Gas	-0.413657	-3.14	0.146379	1.48
Small Car (Sub, Compact, Sport)	-0.640111	-6.64	-0.109414	-1.81
Large Car	-0.169724	-1.25	0.379010	3.74
Small Sport Utility Vehicle	0.325259	3.48	0.735045	7.97
Large Sport Utility Vehicle	0.119526	0.97	0.441867	4.22
Number of observations	4660			
Log-Likelihood (est.)	-10962.20			
Log-Likelihood (0)	-11449.60			
-2[L(0) - L(EST)]	974.91			
1 - L(EST)/L(0):	0.0426			
1 - (L(EST)-No. parameters)/L(0)	0.0395			

The coefficient for number of vehicles on the road in your region is not significant in California, while it is estimated to be a bit higher in the NS than in Table 7. The value of an additional 100,000 vehicles of the specified type "in your region" is now about \$2,000.

On the whole the estimates of the coefficients for core determinants of vehicle choice remain about the same whether California is included with the NS or not. The evidence is that many of the coefficients are statistically indistinguishable between California and the rest of the nation.

Variables Deleted

The variables which were in the model in Table 7 which did not "make the cut" in this model (Table 9) are station fuel availability variables, the home refueling variable, luggage space, and the dummy variable designating that an EV battery lasts more than four years.

New variables

For the two new variables, it was determined that the "prestige" dummy variable is statistically significant, and the values for the NS and California surveys are statistically indistinguishable from one another, allowing pooling. For the relative emissions variable, expectations were confirmed. Californians care about emissions, the rest of the U.S. (on average) does not. The coefficients could not be pooled. The California coefficient implies that a vehicle which has 50% of the emissions of a gasoline vehicle could be sold for \$4,800 more to a Californian. A zero emissions vehicle should, according to the coefficients, be marketable at a price of \$9,600 more than an average gasoline vehicle. Recognizing that this is a "stated" preference, one might expect the reality to be different. Nevertheless, it does help explain how a costly zero emissions vehicle standard could be politically maintained in California. Based on stated preferences in the rest of the U.S., one would expect such a regulatory mandate to be vehemently opposed.

Vehicle Type

For the vehicle body size and type, ten of the eleven vehicle types had tests for dummy variable (1 = type named, 0 = other) coefficients conducted for that type. The base vehicle was the midsize passenger car. Accordingly, a significant dummy variable coefficient would indicate that average consumers regarded the specified vehicle type as different in desirability from a midsize car. Tests were conducted to determine whether the body types could be merged (within samples) and/or pooled (across samples). Dummy variables for the vehicle types classed as "work trucks" proved to be mergeable, and poolable. By mergeable, it is meant that, within the NS, and within the California sample, the coefficients for the dummy variables for compact pickup, standard pickup and standard van were statistically indistinguishable from one another, within both the NS and California samples. They were therefore merged into the "work truck" class. Once those dummy variables were merged to recreate the work truck class, then the work truck coefficients for the NS and California sample were tested and also found to be poolable. No other vehicle body types were determined to be poolable. For all other body types, it was determined that Californians have different preferences than the rest of the U.S.

It was determined that the subcompact car and the compact car could be merged, but not pooled, into a small car class. In the California sample, sports cars had been offered, but these were not included in the NS. It was determined that they could be merged into the small car class in California. The "passenger truck" classification used in Table 7 estimates did not hold up too well. Recall that category includes minivans, compact SUVs and standard SUVs. The estimates in Table 9 indicate that consumers prefer SUVs to midsize cars, while midsize cars are preferred compared to minivans. Based on its coefficient values, the neighborhood electric vehicle, a small, low performance vehicle, is the least preferable of car body types in both the NS and California, although Californians are considerably more receptive to it. The neighborhood electric vehicle should not be grouped with other small cars. As far as the large car class in Table 7 is concerned (combining midsize and large cars), the combination does not appear to be refuted for the NS. The

NS coefficient for the large car is insignificantly different from the midsize vehicle. However, this is not the case in California, where the large car is preferred to the midsize car. Generally speaking, these results indicate that the subject of grouping vehicle types into smaller subgroups should be done carefully. Aside from the "passenger truck" category, however, the results do not indicate that the NS grouping in Table 7 is unacceptable. The results, both for the NS and California, suggest a disaggregation of the passenger truck class at least into SUVs and minivans.

Fuel Type

The merging of the three types of vehicles capable of operating on two fuels into a multifuel category was supported, while pooling was not. When the coefficients of multifuel are statistically compared to one another the statistical tests implied that the NS respondents are significantly different from one another. Given the nature of the statistical tests applied, this means that the two cannot be pooled. The results indicate that Californians are considerably more receptive to multifuel vehicles than the rest of the country. This raises the question of the influence of publicity and state programs on consumers in California vs. the rest of the U.S. However, the results, looked at individually, indicate that the estimated coefficients are not distinguishable from zero. The sign of the NS coefficient reversed from Table 7, indicating that the estimate is not "robust". For the California coefficient, if correct, the dollar value of a multifuel capability is estimated to be about \$7,000. If there is a significant subset of consumers receptive to multiple fuel vehicles, automakers might like to determine exactly who those consumers are. The coefficient for a dedicated electric vehicle can be pooled. This estimate implies that consumers throughout the U.S. (not just CA) are highly interested in electric vehicles, and are willing to pay about \$7,600 more to own a dedicated electric vehicle which is identical in all the estimated respects to a gasoline vehicle. The difference in results for the neighborhood electric vehicle and the dedicated electric vehicle probably require further investigation. Both are dedicated electric vehicles, but the neighborhood vehicle has considerably lower performance and smaller size. Perhaps the cause of the differences could be interpreted as "threshold" effects for some variables such as range, acceleration, top speed, and size. Perhaps, below a certain threshold, consumers find the sacrifice of too much of these desirable characteristics to be unacceptable. The natural gas/propane vehicle in the NS is regarded negatively relative to a base gasoline vehicle, while in California, the natural gas vehicle is regarded positively. This difference might be due to an aversion to propane, but, note that the difference between the California and NS coefficient for the gaseous fueled vehicles is only 26% greater than the difference for multifuel vehicles, and the signs in the California and NS samples are the same. It remains possible that positive publicity about alternative fuels, combined with and created by California state programs, has made Californians generally more receptive to alternatively fueled vehicles. Nationally, the publicity has often been negative. In the NS, the results in Table 9 clearly indicate that respondents are more receptive to dedicated electric vehicles than to dedicated gaseous fueled vehicles.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Dr. Phil Patterson in the Office of Transportation Technologies. We would also like to acknowledge the contribution of Dr. Tom Golob at the Institute of Transpiration Studies, University of California, Irvine and Margaret Clemmons, the technical editor. This work was conducted under Contract W-31-109-Eng-38 for the United States Department of Energy.

REFERENCES

- (1) Automotive News 1995, *Market Data Book 1995*, Automotive News, Detroit, MI (May).
- (2) Brownstone, D., D.S. Bunch, T.F. Golob, and W. Ren. "A Transactions Choice Model for Forecasting Demand for Alternative-Fuel Vehicles," University of California, Irvine (forthcoming, *Transportation Economics*, 1996).
- (3) Bunch, D.S., M. Bradley, T.F. Golob, R. Kitamura, and G.P. Occhiuzzo. "Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Study," *Transportation Research*, Vol. 27A, pp. 237-253, 1993.
- (4) Bunch, D.S., D. Brownstone, and T.F. Golob. "A Dynamic Forecasting System for Vehicle Markets with Clean-Fuel Vehicles," *Selected Proceedings of the Seventh World Conference on Transport Research, Sydney, 1995*. Amsterdam: Elsevier Science (in press).
- (5) Cowing, T.G. and D. McFadden, *Microeconomic Modeling and Policy Analysis*, Academic Press, Inc., Florida, 1984.
- (6) Energy Information Administration, *National Energy Modeling System: An Overview*, DOE/EIA-0581 (96), Washington, DC, March 1996.
- (7) Fulton, L. 1991, Alternative Vehicle Sales Module: Design of the Modeling Framework and Prototype Module Description, Energy Information Administration, U.S. Department of Energy, Washington, D. C. (September).
- (8) Golob, T., D. Bunch and D. Brownstone, "A Vehicle Usage Forecasting Model Based on Revealed and Stated Vehicle Type Choice and Utilization Data." Presented at Seventh World Congress on Transport Research, Sydney, Australia, July 16-21, 1995.
- (9) Lave, C., and K. Train, "A Disaggregate Model of Auto-Type Choice, *Transportation Research*, 13A: 1-9, 1979.
- (10) Maddala, G.S., *Limited-Dependent and Qualitative Variables in Econometrics*, Cambridge, New York, N.Y., 1983.
- (11) McFadden D., (1974). Conditional logit analysis of qualitative choice behavior. In "Frontiers in Econometrics (P. Zarembka, ed.), Academic Press, New York.
- (12) Moore, J., et al., *Program Analysis Methodology: Office of Transportation Technologies. Final Report - Quality Metrics 98*. April 16, 1997. TA Engineering, Inc. Baltimore, Md. for the U.S. Department of Energy Office of Transportation Technologies.
- (13) Newsweek, (1990). *1990 Buyers of New Cars: A Research Report from Newsweek*. New York, NY.

- (14) NPTS, (1991). *1990 Nationwide Personal Transportation Survey: User's Guide for the Public Use Tapes*, Federal Highway Administration, U. S. Department of Transportation, Washington, D.C..
- (15) OTT (1994), *Five-Year Transportation Program Plan*, Office of Transportation Technologies, U. S. Department of Energy, Washington, D. C. (August)
- (16) Ren, W., D. Brownstone, D.S., Bunch and T.F. Golob, "A Vehicle Transactions Choice Model for Use in Forecasting Demand for Alternative-Fuel Vehicles." Presented at the Annual Meeting of the Transportation Research Board, Jan. 23-28, Washington. *Research in Transportation Economics* (in press), 1995.
- (17) Sperling, D. and K. S. Kurani, "Refueling and the Vehicle Purchase Decision: The Diesel Car Case," *SAE Technical Paper Series No. 870644*, Society of Automotive Engineers, Warrendale, PA, 1987.
- (18) Train, K., *Qualitative Choice Analysis*, MIT Press, Cambridge, MA., 1986.
- (19) U.S. Bureau of the Census, *Statistical Abstract of the United States: 1996*, (116th edition.) Washington, DC, 1996.
- (20) Ward's (1993), *1993 Automotive Yearbook*, Ward's Communications, Detroit, MI.