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Publication Date
1996-12-01

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Transpn Res.-D, Vol. 1, No. 2, pp. 131–150, 1996
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1361-9209/96 $15.00 + 0.00

PII:S1361-9209(96)00007-7

TESTING ELECTRIC VEHICLE DEMAND IN 'HYBRID HOUSEHOLDS' USING A REFLEXIVE SURVEY

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(Received 8 February 1996; in revised form 4 May 1996)

Abstract—The debate over electric vehicles (EVs) pivots largely on issues of market demand: will consumers purchase a vehicle that provides substantially less driving range, yet can be refueled at home, than an otherwise comparable gasoline vehicle? Also, what role do other unique attributes of EVs play in the purchase decision? Most previous studies find that limited driving range is a serious market barrier; many of those same studies ignore or under-value other novel attributes. To probe these future consumer decision processes deeply and robustly, we first devised and conducted detailed, interactive and experiment-oriented interviews. Then, incorporating what we learned, we designed an innovative mail survey and administered it to 454 multi-car households in California. The four-stage mail survey included a video of EV use and recharging and other informational material, completion of a 3-day trip diary and map of activity locations, and vehicle choice experiments. In addition to propulsion systems, respondents made choices of body styles, driving ranges, and other features. We formalized and tested what we call the *hybrid household hypothesis*: households who choose EVs will be purposefully diversifying their vehicle holdings to achieve the unique advantages of different propulsion systems. The hypothesis is supported, given the assumptions in our experimental design. In fact, a significantly larger number of EVs are chosen than the minimum number that would support our hypothesis. We find that purchases of battery-powered EVs by hybrid households would account for between 7 and 18% of annual light duty vehicle sales in California. EVs sold to fleets and other households would be in addition to those identified by this study. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Electric vehicles, markets and mandates

In the fall of 1990, the California Air Resources Board (CARB) adopted its Low Emission Vehicle (LEV) program. Among other requirements, it stated that 2% of all light duty vehicles sold by each major manufacturer in 1998 must be zero emitting, with the percentage increasing to 5% in 2001 and 10% in 2003.* The only practical technology for meeting the mandate in the initial years is battery-powered electric vehicles. On 29 March 1996, the CARB board adopted a modified plan that rescinded the mandated sales levels for all years prior to 2003 (replacing it with far more modest demonstration-scale production requirements), but maintaining the 10% sales requirement for 2003 and thereafter. CARB's adoption of the ZEV mandate spawned similar requirements in New York and Massachusetts and sparked intense debate between air quality regulators, the automobile and petroleum industries, electric power suppliers, environmentalists and others. These arguments revolved around forms of governance (e.g. state vs federal regulation, mandates vs incentives vs *laissez-faire*), the relevance and ability of EVs to solve the problem of urban air pollution, technological readiness and marketability.

The issues of technological readiness, cost effectiveness and marketability are closely related. Central to the EV debate is the fact that, for now, EVs have limited driving ranges and typically require a few hours to recharge a largely discharged battery.† Questions

*Throughout this article we use the terms 'car', 'automobile,' 'light-duty vehicle' and 'vehicle' interchangeably. In each case, unless expressly defined otherwise, we mean light-duty passenger cars and trucks, including minivans, full-size vans, pick-up trucks and sport utility vehicles.

†The Advanced Lead-Acid Battery Consortium has demonstrated that vehicle-size packs of lead-acid batteries can be recharged from a 20% state of charge back to 80% in a matter of minutes. However, the electrical service required (typically 440 V at 100 A or more) would only be available to EV drivers at the equivalent of a gasoline station, not at homes, public parking garages, businesses or the variety of other places that EVs might be charged.

remain as to the value of home recharging, quiet operation, zero tail-pipe emissions and ease of use; minimum driving ranges that drivers will accept in order to obtain these positive attributes; and prices at which these attributes can be provided. While all credible analyses conclude that EVs will reduce emissions under almost all circumstances, their cost effectiveness is linked to the cost of the vehicles, which, in turn, is linked to consumer demand for range, recharging and other characteristics of EVs.* It is widely believed that few people would purchase a limited-range electric vehicle. This belief is driven, in large part, by the perception that consumers will demand such long driving ranges that the cost of EVs will be prohibitively high. Several automobile industry and academic studies concur. We do not. Based on our studies of alternative fuel vehicle demand conducted over the past 10 years and the results we report here of a recently completed 4-year, multi-staged study of electric vehicle demand, we conclude that a large number of consumers would purchase a competitively-priced electric vehicle, even when driving ranges are well under 100 miles.

Previous EV market studies

In the absence of data on actual sales, researchers have previously tried three methods to develop estimates of EV market potential—attitude studies, travel behavior analyses and stated preference surveys. A meta-analysis of these three research streams presents an apparent paradox. Attitude studies show EVs to be an almost universally admired technology; travel behavior studies show that many households could use at least one limited range vehicle; but stated preference studies typically conclude that virtually no consumers are willing to buy EVs. As summarized below, we see that this paradox called for close scrutiny of the methods and findings in these studies (Kurani *et al.*, 1994).

The problem with attitude surveys is that they represent consumers' ideals and not their full decision processes (Buist, 1993; Kirchman, 1993; Fairbanks *et al.*, 1993; The Dohring Company 1994). These studies tend to overstate the demand for EVs because of the vehicles' clean, progressive image. Travel behavior studies that address the role of limited range also overstate the demand. These studies identify households with daily driving patterns that match the range capabilities of EVs (Deshpande, 1984; Kiselewich & Hamilton, 1982; Nesbitt *el al.*, 1992; Dables, 1992). The problem is that consumer preferences and vehicle purchases are not measured.

Most stated preference studies, in contrast, have produced very low estimates of EV demand, from 0 to 2%, primarily because they estimate huge average price penalties for a limited range (e.g. Morton *et al.*, 1978; Beggs & Cardell, 1980; Calfee, 1985; Bunch *et al.*, 1993). A more recent stated preference study enhances the realism of its respondents decision context by incorporating elements of their revealed and expected vehicle purchase behavior (Bunch *et al.*, 1995; Golob *et al.*, 1995). While also estimating very large penalties for limited range, this study forecasts initial EV market penetration rates of 4–5% within California's South Coast Air Basin.† We have previously expressed our scepticism about such results from stated preference studies. We have presented theoretical arguments (Turrentine & Sperling, 1991; Turrentine, 1994) and empirical results (Turrentine *et al.*, 1992; Kurani & Turrentine, 1994; Kurani *et al.*, 1994, 1996) to support our contention that the application of econometric models to stated preference data on EV choices is premature. New technologies can enable fundamental changes in established consumer practices and preferences. Consumers may be unable to envision how they

*In California, EVs reduce emissions of all the criteria pollutants. Given the current and expected mix of electricity sources in some other regions of the country, EVs reduce all criteria pollutants, except SO_x and particulates. Compared to gasoline-powered light duty vehicles, EVs are likely to result in a percentage increase in SO_x and particulates per vehicle mile. However, because total SO_x and particulate emissions from light duty vehicles are small to start with, even a large percentage increase translates into a small absolute increase. Decisions by states, such as Massachusetts and New York, to actively promote EVs indicate a belief that the reductions of emissions of all other criteria pollutants outweigh these small increases in SO_x and particulates.

†Because Bunch *et al.* (1995) and Golob *et al.* (1995) are constructing a multi-year forecasting tool, comparisons to other, single point estimates (including those in this study) are not straightforward. The 4–5% market penetration estimate is based on the first few years of their base case model. In no year do they forecast greater than 8% EV market penetration.

would use a new technology and therefore why they would buy it. New technologies may have few analogous attributes to conventional technologies. This can cause people, confronted with new technology, to overestimate or underestimate the value of novel attributes. In the case of EVs, consumers cannot have preferences for such attributes as limited range, home recharging, zero tail-pipe emissions and other unique attributes of EVs because they have no experience with them and therefore have not constructed preferences for them.

Compounding the difficulty, researchers, dependent on high survey response rates and large sample sizes to validate their statistical procedures, are likely to create surveys that are as brief and easy as possible. Simplified survey response processes stand in stark contrast with the complex decision processes of considering new alternatives. Survey respondents are likely to offer initial impressions or biases in place of actual consideration of the options. This is a particular problem for products that embody socially desirable values, such as environmental benefits—researchers run the risk of eliciting either hasty 'feel good' responses or equally hasty backlashes of anti-environmental sentiment in place of considered evaluations. Further, participants may 'see through' over-simplified survey instruments, viewing them as pointless. Finally, surveys may query only one person from a household, when, in fact, major purchases, like vehicles, are often made jointly by household members.

RESEARCH APPROACH

A process-oriented view

Research into potential markets for novel products, especially those that embody new values or possess new performance attributes, must be attentive to processes. It is not sufficient to capture a snapshot of current preferences of consumers; rather we need to record the processes of preference formation and lifestyle evaluation that are put into motion by the new technology. Slovic *et al.* (1990) argue that preferences are often constructed—not merely revealed—in responding to a choice. Payne *et al.* (1993) state that this constructivist approach to preferences "means more than simply that observed choices and judgments are not the result of a reference to a master list of values in memory,' but that the process by which preferences are constructed may change from task to task (Tversky *et al.*, 1988). Payne *et al.* (1993) also point out that "constructed preferences are consistent with the 'philosophy of basic values', which holds that people lack well-differentiated values for all but the most familiar of evaluation tasks" (Fischoff, 1991).

We examine household consideration of EVs within the context of several processes. First, households move through developmental phases called life cycles. These life cycles are defined primarily by the presence or absence of children, age of children, age of heads of household, number of heads of household, and employment or retirement status of household members. Second, people build self images and self-identity through reflexive processes (discussed further below). The expression of such processes is lifestyle choices, many of which are manifested as consumption and activity participation choices. Third, living within a socio-economic, land-use and transportation milieu that places a premium on mobility and flexibility, many households engage in an ongoing process of managing a fleet of household vehicles.

To investigate these processes and their impact on households' evaluation of EVs, it is essential to intensify the intellectual tasks of participants in order to engage them in these processes. Before we ask survey participants if they would buy a novel technology, we first explain the technology in some detail, and we intentionally design complex gaming simulations in which household members must (if appropriate) jointly solve problems from their own daily life. In the case of EVs, they must determine whether they must, whether they can, and whether they are willing, to allocate household travel according to driving range limits and home recharging.

Methodological foundations

Our approach to experimental designs is built upon three areas of active research in transportation: activity-based approaches, gaming simulations, and interactive stated response methods, and a fourth new area we call reflexive design, which is not unique to our work, but which is previously not identified in the literature.

Jones *et al.* (1990) define *activity analysis* as "[a] framework in which travel is analyzed as daily or multi-day patterns of behavior, related to and derived from differences in life styles and activity participation among the population." Several reviews trace the development of activity analysis (e.g. Damm, 1983; Jones, 1983; Kitamura, 1989; Jones *et al.*, 1990; Jones, 1995).

Previously, automobile marketing studies have not given much attention to how activity patterns, in particular the geographic distribution of daily activities, influence car purchases. In fact, it is one of the themes of American automotive mythology that automobiles liberate us from any constraints on travel (Dettelbach, 1974). However, home recharging, longer refueling time and limited range make an activity approach essential to understanding potential EV markets. Within the context of multi-vehicle households, driving range choices are formed around the travel routines of households and the subsequent allocation of driving tasks. We incorporate into our survey design three elements that are central to household response to a limited range vehicle which we learned in previous research: *emergency range buffer*, *routine activity space* and *critical destinations* (see Kurani *et al.*, 1994).

Games and simulations. These are experimental contexts which allow researchers to observe individuals or households as they make complex decisions. Gredler (1992) defines *simulations* as learning activities in which: participants seek solutions to, or resolutions of, a particular task, issue or problem; activities do not have straightforward or transparent settings, contexts or solutions (in fact there may be no single correct solution); and participants must conscientiously fulfil specific roles (what Gredler cites as Jones (1984) "reality of functions"). We address reality of function by asking participants to fulfil a familiar role—their real life roles within their household. We aid their conscientious fulfilment of this role by providing them with materials to recall a specific week of their lives (e.g. travel diaries) and by conducting the study in their household setting.

In a preliminary study, we designed simulations to observe household responses to home recharging and limited range (Kurani *et al.*, 1994). In our Purchase Intention and Range Estimation Games (PIREG) interviews, households relive the events of their diary week—that is, they fill the same activity space—while we repeatedly fix one of the constraints (the range limit of one household vehicle) to increasingly lower levels in order to 'defeat' the household's ability to solve problems created by that constraint. The household determines whether that constraint, or any other, prevents them from filling their activity space. In a later stage of the game, we change the consequences of the household's solution to the range limit (by changing the relative fuel costs of electricity and gasoline). The household must then resolve those new consequences.

The third element of our research approach is *Interactive Stated Response* (ISR) methods. Lee-Gosselin (1995) distinguishes "stated response" methods from "stated preference" methods and develops a taxonomy of the former which subsumes the latter. The taxonomy is based on the degree to which constraints and behavioral outcomes are either provided by researchers or elicited from participants. Traditional stated preference work specifies both constraints and behavioral responses (choice sets). Other classes of stated response techniques include "stated tolerance" (behavioral outcomes given, constraints elicited), "stated adaptation" (behavioral outcomes elicited, constraints given) and "stated prospects" (both behavioral outcomes and constraints elicited).

We used ISR methods in PIREG to develop the hybrid household hypothesis and to explore the learning and decision processes of households as they considered the implications of a new travel technology for their lifestyle needs and wants. Our PIREG interviews fall within Lee-Gosselin's stated adaptation class. We supplied constraints (driving range limits and recharge times of EVs), and the households provided solutions to any problems created by those constraints.

Reflexive designs: translating interactive methods to non-interactive surveys. One of the most important goals of our mail survey design was to transfer the requisite gaming-simulation elements from the highly interactive PIREG interviews to a non-interactive mail survey. Although ISR methods offer several advantages, they are often forgone because of the demands imposed by requirements for larger samples—demands that are difficult to fulfil with the open-ended and time-consuming nature of ISR methods. In a mail survey, it is not possible to enact a dialog between the interviewer and subject. The real-time gaming aspects of interactive stated response problems cannot be anticipated and designed into rigid survey forms. The data from dialogs and games with hundreds or thousands of participants could not be systematically coded devoid of the context in which each respondent offered their data.

However, some elements of ISR may be effectively combined with large-scale surveys to produce valid, generalizable results. In particular, there are certain elements of PIREG which we were able to incorporate into this mail survey to enhance the engagement of participants and heighten their reality of function. We call these elements *reflexive designs* (Turrentine, 1995).* Reflexive designs depend on first identifying features of the gaming-simulations used in interactive research that explain or shape the observed outcomes of the gaming-simulation, then establishing whether those features can be constructed by respondents without interaction with the researcher. If those features can be constructed solely by the respondent, we have a basis for expanding sample sizes to levels that allow statistical tests of hypotheses.

The reflexive designs in this survey included visual diaries, activity maps and reflexive questions. Visual diaries are timelines of activities and travel that respondents draw for themselves as their days unfold (rather than recording activity start and end times as numerical text). The near unanimous acceptance and understanding of the timelines we used in PIREG lead us to believe that households could construct and comprehend such timelines without the intervention of the researcher. The activity maps are used by households to record both locations actually visited during the diary period, as well as other activity locations that are regularly accessed or otherwise important to the respondents' lifestyle. Reflexive questions ask respondents to summarize aspects of the timelines and maps and to solve a variety of travel related problems derived from their own travel. Reflexive questions also serve as a context for the vehicle choice situations.

Identifying and sampling hybrid households

We assume, in this study, that households are the fundamental unit for decisions of vehicle purchase and use.† A household that combines electric and gasoline vehicles in its stock of vehicles is one example of a *hybrid household.* In contrast to a hybrid vehicle which combines multiple propulsion systems in one vehicle, a hybrid household chooses two or more vehicles with different types of propulsion systems and then allocates household travel according to the different operational characteristics of those vehicles. A household that chooses a hybrid electric and a gasoline vehicle is another example of a hybrid household. Thus, it is not a specific vehicle technology that defines a hybrid household, but rather the behavior of choosing vehicles with different propulsion systems to create a fleet of specialized transportation services and lifestyle expressions.

We defined and sampled a group of *potential hybrid households* whose existing vehicle purchase behavior and vehicle stocks indicate that they may be more amenable to hybridizing their vehicle holdings. Our sample of potential hybrid households met the following criteria: own two or more vehicles; buy new vehicles; own one 1989 or newer vehicle *and* one 1986 or newer vehicle; and at least one of their vehicles was not a full sized sedan,

*In describing games and simulations (and learning environments more generally), Greenblat (1981) uses the term "reflexive" to describe feedback on successes and errors that allows participants to assess their own progress. Our usage includes such feedback, but is more general. We use "reflexive" to describe techniques that reflect back to a household its own behavioral reality and a sociological system in which individuals are conscious about the social construction of reality (Turrentine, 1995). There is a direct connection from our use of the phrase to recent use of reflexive techniques in sociological studies, for example those of Pierre Bourdieu (Bourdieu & Wacquant, 1992) and Anthony Giddens (Giddens, 1991).

†This conclusion is supported by a national study by Newsweek magazine (1991) of 32,000 new car buyers. That study reported that only 8% of respondents said that they were not influenced by their spouse. It found further that the presence of children played a role in vehicle choices in most households; only 27% of households reported not being influenced by children.

van, sport-utility vehicle or pick-up truck. The ages of recruited participants were matched to the age distribution in the California new car market. We filled quotas for minivans, sports utility vehicles and sedans, based on the recent proportions of those vehicles in the California new vehicle market. Also, we matched the split of foreign and domestic makes (50/50 in California) of the most recently purchased vehicle.

Possible EV buyers that we did not sample (and do not include in our potential hybrid household definition) include those households that do not now buy new cars, but would in order to buy an EV; households that do not now own vehicles of the likely EV body-styles, but would buy one to get an EV; and single car households that would become two-car households by purchasing an EV.

A total of 740 households were recruited by eight market research firms in six metropolitan areas of California: the San Francisco Bay Area, Sacramento, Fresno, Santa Barbara, Los Angeles and San Diego. Participants were selected by each market research firm from their own databases to fill our survey quotas. Each firm then contacted the households to see if they would be willing to participate in the study. Participants were offered an incentive of $50 because of the time demands of the survey and to keep the study from being biased toward those interested in the subject. Of the 740 households recruited, 454 completed the study, yielding a response rate of 61%. The relatively high rate of completion in this study gives a higher confidence that the sample was not biased to those interested in alternative fueled vehicles.

The hybrid household hypothesis

In this study, we designed experiments to test what we call the *hybrid household hypothesis:*

> *'Assuming the vehicle can start each day with its full range, a driving range limit on that vehicle will not be an important barrier to its purchase by a potential hybrid household'.*

If the hypothesis is true, then we expect, over a long period of time, (relative to the period of time between new car purchases within a household) that hybrid households will actually choose to buy an EV at least once every n times they buy a new car, where n is the number of vehicles each household owns. Thus, if a household maintains ownership of two vehicles over a long period of time, we assume that, on half the occasions they buy a new car, it will be an EV. This is based on the assumption that hybrid households maintain ownership of at least one long-range vehicle.

Based on our PIREG interviews, we know that not all potential hybrid households will find a limited range to which they can adapt (Kurani *et al.*, 1994). In that study, four of the 51 households were unable to find a limited range to which they could adapt.* As an initial extension of that result, we hypothesize that 8% of the sample of potential hybrid households in this study will also be unable to adapt to any of the EVs offered in this study. This study does not cover a long period of time. We do not observe repeated choices by households across time; we ask only about the next new vehicle purchase decision. Therefore, we make the following assumption: all the factors that determine whether the next vehicle purchased by each of these households is a limited range EV or an 'unlimited' range gasoline vehicle are distributed throughout our sample such that $1/\mu$ of our households choose to buy an EV for their next new vehicle, where μ is the average number of vehicles owned by all households. In our sample, $\mu = 2.43$.

We can now state the hybrid household hypothesis in a manner that can be empirically tested. If the hypothesis and the assumptions above are true, then:

> *'The proportion of our original sample of potential hybrid households who choose a limited range, home refuelable vehicle will be at least 38% (1/2.43 × (100% − 8%))'.*

*Actually, it was the combination of limited range and long recharge times to which these four households could not adapt. We note that we did not include hybrid EVs in that study and all four of those households might have overcome any of their range/recharge problems through the use of a hybrid EV of the type we included in this study.

SURVEY INSTRUMENT DESIGN

The survey instrument was divided into four parts and was designed to be completed over several days to encourage critical evaluation of the options. The four parts are summarized below.

Part 1: Initial survey of household vehicle holdings, purchase intentions for next new vehicle, demographics, and environmental attitudes.

Part 2: Three-day travel diary for two primary household vehicles, a map on which the household plotted their activity locations, and a survey of the travel and refueling behavior of the two primary drivers.

Part 3: Informational video and reprinted articles from major media that explain and demonstrate distinct refueling and recharging routines, emissions and other new features of compressed natural gas, battery powered electric, hybrid electric and neighborhood electric vehicles.

Part 4: Choice experiments related to their next vehicle purchase. We explain this section in greater detail immediately below.

Vehicle choices in the survey

Part 4 of the questionnaire consisted of two vehicle choice scenarios in which respondents were asked about their next expected new vehicle transaction. Each scenario was a distinct experiment. Situation 1 was a test of the hybrid household hypothesis. It involved a choice between conventional, gasoline-fueled vehicles and limited-ranged, home-recharged, electric vehicles. Situation 2 was designed as one plausible future market scenario, designed primarily to test a corollary of the hybrid household hypothesis—that the demand for EVs can be segmented by the demand for driving range—and to explore the lower boundary on the demand for range. Six vehicle types were offered: reformulated gasoline, compressed natural gas, hybrid electric, two types of freeway-capable battery electric and a neighborhood battery electric.

Summary descriptions of the range, speed and price features of the vehicles offered in the choice situations are shown in Table 1. These attribute values and recharging or refueling were chosen to reflect the needs of our hypothesis tests, as well as technological realities and possibilities. All vehicle features not discussed below were generic to all vehicle propulsion types. The names we chose for different range classes of EVs reflect the activity analysis framework underlying our analysis of vehicle purchases. 'Neighborhood' EVs provide access to local activities that can be accessed without travel on freeways or expressways. 'Community' EVs fill a geographically larger *routine activity space*. 'Regional' EVs are intended for even wider-ranging daily travel.

Our choices of limits on EV driving range were important for the validity of our test of the hybrid household hypothesis. We could have chosen ranges so high that any household could have chosen an EV, yielding an uninformative 'validation' of the hypothesis. Our choices of driving ranges were determined by the *minimum* and *comfortable* ranges to which households (who matched the same selection criteria as those in this study) could adapt in our PIREG interviews (Kurani *et al.*, 1994). The upper driving range limit of 120 miles in Situation 1 was the highest value of the minimum range to which any household could adapt; the lower and upper limits of 40 and 150 miles (for battery-only EVs) in Situation 2 were the shortest and longest comfortable ranges.*

The driving range for EVs in Situations 1 and 2 depended on the body style of the vehicle, battery options and charging options. The lower energy storage requirements associated with shorter ranges and smaller body styles could be met with lead-acid batteries commercially available at the time of the survey. Higher energy storage requirements associated with larger body styles and longer ranges would typically require more advanced batteries. The prices that we stipulated for the periodic replacement of battery packs and for longer range battery options were based on consultations with battery manufacturers, regarding expected mass production prices.

*Excluding those four households that could not adapt to any limit.

Table 1. Range, speed and sample price characteristics of vehicles in the choice situations

Situations and vehicle type:	Driving range (miles)	Top speed (mph)	Comparative* prices ($×1000) (includes incentives where applicable)
Situation 1:			
Electric vehicle†	80 or 100; 100 or 120	80	10.0–19.9
Gasoline vehicle	—¶	—¶	10.0–18.9
Situation 2:			
Neighborhood electric vehicle (NEV)	40	40	3.5–7.1
Community electric vehicle (CEV)†	60 or 80	75	8.0–16.8
Regional electric vehicle (REV)†	120 or 140; 130 or 150	85	11.5–22.1
Hybrid electric vehicle (HEV)†‡	140 or 180	85	14.0–24.9
Natural gas vehicle (NGV)§	80 or 120	—¶	9.5–19.9
Reformulated gasoline vehicle (RGV)	—¶	—¶	10.0–18.9

*Comparative prices in this table are calculated for a sub-compact sedan—other body styles have higher prices. The lower price limit is for the lowest trim level and no other options added. The upper limit is for the luxury trim level plus all applicable engine, transmission and energy storage options, except four wheel drive. Both limits include the varying purchase incentives for the different vehicle types. The sub-compact sedan is used for comparison because it is most similar in body style to the Neighborhood electric vehicle, which is only offered in one body style. In Situation 1, the purchase incentive for an EV is $4000. In Situation 2, the purchase incentives are: $1000 for NGVs and HEVs; $2000 for NEVs: and $4000 for CEVs and REVs.
†Vehicle range depends on body style and choice of battery options.
‡The battery-only driving range options are either 40 or 80 miles.
§Range depends on choice of one or two fuel cylinders.
¶Comparable to existing gasoline vehicles.

The driving range options we offered for natural gas and hybrid EVs were shorter than has already been demonstrated. However, our primary objective was to construct tests of household response to driving range and refueling/recharging options, not to guess exact specifications of possible future vehicles. By choosing the ranges we did for these vehicles, we created vehicles that could offer fast, ubiquitous away-from-home refueling, but had ranges similar to the battery EVs. The top speed limits on EVs are consistent with vehicle designs pursued by every major EV manufacturer. Operating at high speeds requires sustained high power discharges. By electronically limiting top speeds, driving range can be extended, and batteries can be protected from damage caused by too high power discharge. Top speed was also used to distinguish a class of non-freeway capable electric vehicles known as 'Neighborhood electric vehicles'.

In Table 1, we also provide an example of how prices were used in the study (see table notes for details). The prices include purchase incentives. As an example, in Situation 2, participants were offered a price of $15,500 for a basic trim level, regional electric, sub-compact sedan (130-mile range)—for which they had to do the calculations themselves to calculate that the final cost to them would be $11,500. Accordingly, such an EV is priced at $5500 more ($15,500–10,000) before incentives, and $1500 more ($11,500–10,000) after incentives than its gasoline-powered counterpart. The actual price 'paid' by our respondents is a function of their choice of vehicle propulsion type, body style, trim level and other options.

Some reviewers have criticized these EV prices for being too low. We chose these prices for several reasons. First, our intention was to maximize the information about household response to driving range limits and home recharging, while incorporating elements of realism. We intentionally designed the overall vehicle price structure to reduce the importance of up-front purchase price in the choice between different vehicle types.

This seemed reasonable, given the likelihood that most EVs will be leased, at least initially, thereby spreading the cost over several months or years. Moreover, actual purchase prices will likely be reduced by government incentives worth thousands of dollars. Such incentives are already available, reflecting the social value placed on private decisions to reduce environmental and energy security costs. Also, if buyers will accept lower ranges than has been widely acknowledged in the public debate, as we find they will, the size and therefore cost of battery packs and EVs can be greatly reduced. If the hybrid household hypothesis is supported, then we will have established that households are willing to specialize their vehicle holdings according to the unique performance of different propulsion systems. If that fact is established first, then reasoned arguments can be made as to whether our price assumptions represent attainable vehicle development targets.

Recharging and refueling options varied by vehicle type. We stipulated that some electric vehicles, such as neighborhood and community EVs in Situation 2, could only be recharged at home. Other EVs, notably the longer range regional and hybrid EVs, could be purchased with optional 'fast charging'. We described fast charging as requiring 20 min to restore 80% of a full charge and being available at the equivalent of a gasoline station. As one example of reflexive questioning, households had to select one location on their activity map where they would like such a station to be located if they chose the fast charging option. A final EV recharging option available for all EVs was solar charging. This was described as adding a range of 10 miles or completely supplying electricity demand for air conditioning on sunny days. Natural gas vehicles were offered with the option of buying or leasing a home refueling appliance—a small compressor that refuels a natural gas vehicle at home overnight. They could either buy the compressor for $2500 or lease it for $60 per month. This home refueling capability would be in addition to refueling at fuel stations. As a final note on differences in vehicle offerings, in both choice situations, we offered electric vehicles only in the body styles in which we expect them to be offered during the next few years. These *EV body styles* include sports cars, small sport-utility vehicles, small (sub-compact) sedans, compact sedans, mid-size sedans and minivans. Gasoline and natural gas vehicles were offered in the full range of body styles, including full sized sedans, pick-ups, vans and sports utility vehicles.

RESULTS

The hybrid household hypothesis is supported

We found strong support for the hybrid household hypothesis—that a driving range limit on one household vehicle will not be an important barrier to the purchase of an EV by a potential hybrid household. Choice Situation 1 was designed specifically to test this hypothesis. The scenario allowed participants to choose either a limited—80–120 miles—range, home rechargeable electric vehicle or a conventional gasoline fueled vehicle.* We reasoned above that in excess of 38% of our sample would have to choose an EV in Situation 1 in order for the hybrid household hypothesis to be supported. In fact, 46% of respondents said they would purchase an electric vehicle as their next new vehicle. This finding suggests that multi-vehicle households who buy new vehicles and own at least one vehicle of the body styles in which EVs are likely to be offered, will seriously consider owning at least one limited range vehicle (assuming that the vehicle is home-rechargeable and is priced within a few thousand dollars of comparable body-style and trim level gasoline cars).

How could this response to EVs be so high? The answer, as we discuss below, has two parts: once they have thought about how they might use an EV within their stock of vehicles, many multi-vehicle households discover that a range limit (somewhere within the range options offered) on one household vehicle is simply not a binding constraint on their travel, and some attributes unique to EVs become more attractive, once a household has made this determination.

*In Situation One, "electric vehicle" is synonymous with "limited range vehicle" and so we use the terms interchangeably. In Situation Two, hybrid electric and natural gas vehicles are also limited range vehicles and we will use the phrase "limited range vehicle" to refer to them as well as battery-powered electric vehicles.

Demand for driving range

Clearly, more range implies greater value than less range, but how much greater? Based on the proviso that additional increments of range are expensive, and on the results from our PIREG interviews and those reported below, we believe that, once households discover a reduced range with which they are comfortable, they will not pay significantly higher prices to acquire more. In the more detailed choice scenario of Situation 2, consumers were provided with an expanded variety of vehicle propulsion types and driving ranges. Respondents selecting EVs (except neighborhood EVs) were offered a choice of either a base (Type 1) battery or an optional, longer range, more expensive (Type 2) battery. Those interested in still more range could select a 140 or 180 mile hybrid electric vehicle. Natural gas vehicles (NGVs) were available with one or two compressed gas storage cylinders, providing a driving range per fueling of 80–120 miles, depending upon their choice of storage and body style.

The results were striking. As shown in Table 2, a total of 37% of our sample chose a vehicle, be it electric or natural gas, with a range of 130 miles or less. Even more dramatically, 65% chose vehicles with ranges of 180 miles or less. Many households chose vehicles with very low ranges, when the vehicles were offered at lower prices. For instance, 4% chose inexpensive neighborhood EVs, and another 12% chose relatively inexpensive community EVs with ranges of 60–80 miles. We see a market segmented by ranges acceptable to different households, with some ranges much lower than previously reported.

These results stand in stark contrast to stated-preference studies. We ascribe the difference, as indicated earlier, primarily to our use of complex tasks that require households to explore travel and lifestyle implications of EVs and provide opportunities for households to begin to construct preferences for driving range and home recharging. The difference is also explained by our efforts to forego representations of average consumers, and to target a segment of the market whose vehicle purchase behavior is more amenable to the process of hybridizing their vehicle holdings.

The willingness of some drivers to buy lower ranges is further demonstrated by examining those who changed their range choices between Situations 1 and 2. As shown in Table 3, many who had chosen a gasoline vehicle in Situation 1, chose electric vehicles with ranges of only 40–60 miles in Situation 2. More dramatically, 46% of the households who had chosen a gasoline vehicle in Situation 1, chose a shorter range electric, hybrid electric or natural gas vehicle in Situation 2. Across all vehicle types, 32% of households chose a shorter range vehicle in Situation 2 than they had chosen in Situation 1. They did so, presumably because additional range had little value to them. We note that these choices of shorter ranges cannot be explained solely by the low prices of neighborhood and community EVs. Half the households who chose a shorter range vehicle in Situation 2 than they had in Situation 1, also chose a vehicle that cost more. We conclude that households will make choices from across a spectrum of range possibilities; so long as

Table 2. Range choices in Situation 2

Vehicle type	Range (miles)	Number of households choosing type and range	Percentage of households choosing type and range
Neighborhood EV	40	19	4
Community EV with Type I batteries	60	10	2
Community EV with Type II batteries	80	18	4
Natural gas vehicle with single tank	80	28	6
Natural gas vehicle with double tank	120	60	13
Regional EV with Type I batteries*	120/130	52	12
Regional EV with Type II batteries*	140/150	63	14
Hybrid EV with Type I batteries	140	6	1
Hybrid EV with Type II batteries	180	37	8
Reformulated gas vehicle	300	154	34
Total		447	100

*Range of regional EV is also dependent on body style.

Table 3. Transition in range choices from Situation 1 to Situation 2

Driving range in Choice 2 (miles)	Driving range in Choice 1 (miles)				
	80	100	120	Conventional range	Total
40	2	6	1	10	19
60	8	4	0	0	12
80	1	15	3	16	35
120	17	30	3	45	95
130	0	10	5	2	17
140	4	37	0	8	49
150	1	1	12	7	21
180	3	16	3	15	37
Conventional range	5	12	9	128	154
Total	41	131	36	231	439

Note: differences in range due to body style and battery choices are suppressed in this table.

additional increments of range are expensive, demand for EVs and other limited range vehicles will be segmented by demand for driving range.

The value of novel EV attributes: home recharging

The single most valuable attribute of EVs is, for many households, home recharging. When choosing a vehicle in Situation 2, households made choices of refueling/recharging capabilities and locations. Their choices are summarized in Table 4. Over half the households (54%) chose vehicles which refuel or recharge at home (EVs plus NGVs with home refueling) and only 46% of households chose vehicles that refuel only away from home (NGVs without a home refueling appliance and gasoline vehicles). Among households that chose an NGV, 27% chose to purchase the capability to recharge at home, despite the fact this option was priced at $2500; another 13% chose to lease this capability for $60 per month. These 'point' values do not allow us to calculate elasticities, but they do indicate that some households place a high value on avoiding retail fueling stations. Prior studies have documented a dislike of gasoline stations (Kurani *et al.*, 1994). This suggests to us that home recharging and refueling are highly valued attributes of electric (and possibly natural gas) vehicles.

Environmentalism in electric vehicle purchase decisions

It has been assumed by many that the market for EVs, at least initially, would be largely environmentally motivated 'green' consumers; that is, early buyers of EVs would place a very high value on, and therefore pay a premium price for, the green attributes of EVs. We find that this is not a necessary condition of the early market. We relate two measures of environmentalism to choices between electric and gasoline vehicles in Situation 1. Questions regarding environmental attitudes were asked in Part 1 of the survey, prior to any information or questions about EVs.

One question measured the importance people place on environmental problems, compared to other problems. Rather than a simple scale of 'importance,' we asked people to indicate the degree of lifestyle change that they believe they must make to solve environmental

Table 4. Number of households choosing home and away-from-home refueling options in Situation 2

Home and away-from-home refueling	Count	Away-from-home refueling only	Count
Neighborhood EVs	19		
Community EVs	28		
Regional EVs without fast charging	27		
Regional EVs with fast charging	92		
Hybrid EVs	44	Reformulated gasoline	154
Natural gas with home refueling	36	Natural gas without home refueling	52
Totals	246		206

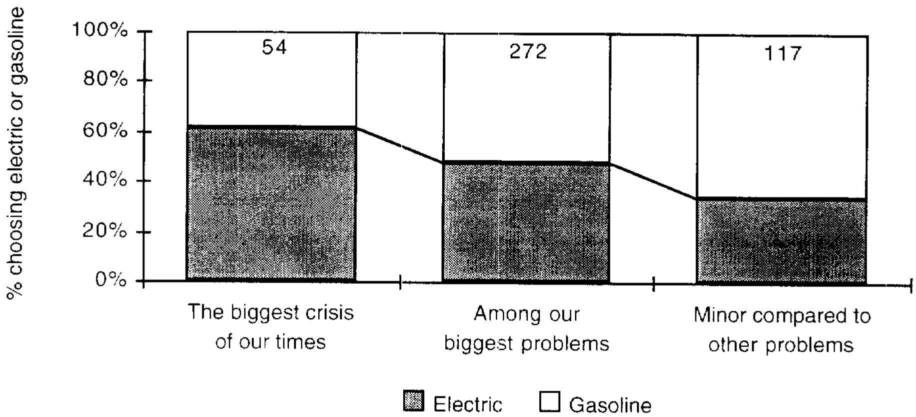

Fig. 1. Vehicle choices in Situation 1 by the perceived seriousness of environmental problems. Note that only three households indicated that they believed that environmental problems simply are not important (response 4); these households are not shown in the figure. The number of households in each category is given at the top of each column.

problems. Choices of vehicle type in Situation 1 are cross-tabulated by responses to this question in Fig. 1. The question and possible responses were:

"*How would you characterize your feelings about the world's environmental problems?*

(1) The biggest crisis and challenge of our times. The solutions require immediate international effort and major changes in our economies and lifestyles.

(2) Among our biggest problems. The solutions require co-operation of government and citizens. Time to reconsider our lifestyles and make changes.

(3) Environmental problems exist, and need some attention, but are minor compared to other problems in our world.

(4) Environmental problems are not important problems. There is no need to change the way we live."

By focusing on EVs as one transportation option within a hybrid fleet of vehicles, we observe that even those households disinterested in environmental issues choose EVs at very nearly the rate our central hypothesis predicts. Three-quarters of the households responded that environmental problems are either the greatest crises of our time or are among our biggest problems. A strong belief that lifestyle changes are warranted to solve environmental problems was associated with a greater likeliness of choosing an EV. However, even among people who do not believe that environmental problems are particularly pressing, more than a third chose an EV as their next new vehicle. This latter group also forms the only group who chose fewer EVs than the hybrid household hypothesis predicts, and then only slightly fewer (34% compared to the 38% threshold).

The second measure of environmental attitudes we consider here is the willingness to pay for less polluting products. The responses to the following question are cross-classified by vehicle-type choice in Situation 1 in Fig. 2:

"*How much* more *are you willing to pay for products which don't pollute compared to products which do pollute?*

0% 3% 5% 10% 20% 30% 50% 100%".

There is neither a particularly well-ordered nor a statistically significant relationship between the willingness to pay more for goods that are less polluting and the choice between an EV or gasoline vehicle in Situation 1. Even among those relatively few people willing to pay virtually nothing more for non-polluting products, a substantial number chose EVs.

Who chooses EVs and why? A lifestyle perspective

Households' activity spaces and vehicle purchases are not simply travel choices; they are also lifestyle expressions. We have just concluded that, while EVs will allow the expression of pro-environmental values and lifestyle choices, such values are not a necessary pre-

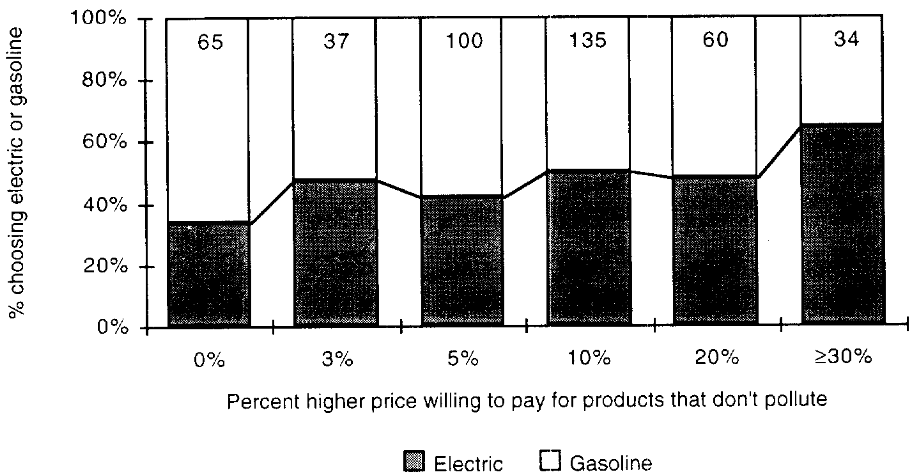

Fig. 2. Vehicle choices in Situation 1 by willingness to pay for less polluting products. Note: the number of households in each category is given at the top of each column.

condition in the initial market. We examine here whether differences in activity spaces are related to choices of propulsion systems and how EVs are incorporated into household vehicle purchase processes.

Given the limited range of EVs, one would expect that households with particular travel routines would be more likely to purchase an EV. However, given the complexity of households' activity spaces, we do not necessarily expect any one simple measure of activity space to be associated with propulsion system choices. In fact, we found that differences in simple measures of travel routines between households have only a minimal effect on vehicle propulsion type choices. The reason for this (as found in many travel behavior studies) is that seldom do any multi-vehicle households encounter situations in which they could not access their activity space using their fleet of household vehicles—even if that fleet contains a reduced range vehicle. When viewed in terms of the travel needs of households in our study, a range limit of 40–180 miles on one household vehicle simply is not a binding constraint on their ability to access their desired activities.

Providing a complete assessment of the households' routine activity spaces is beyond the scope of this paper. However, we do provide a few summary indicators of the geographical extent of routine activity spaces in Table 5. We find no statistically significant relationships between vehicle choices and households' commute trip distances, longest weekly trips, or distances to critical destinations. Neither the independent nor the joint distributions of these distance measures within a household are correlated to choice of propulsion systems. To test the joint household distributions, we used cluster analysis to create three clusters of households—those in which both household drivers reported

Table 5. Summary distance measures of respondents' household activity locations (miles)

	Shorter distance within households	Longer distance within households
One-way commute distance: median	8	15
90th percentile	30	45
97.5th percentile	53	80
Longest one-way trip made weekly: median	10	20
90th percentile	26	55
97.5th percentile	54	113
One-way distance to critical destination*: median	7	15
90th percentile	44	66
97.5th percentile	99	125

**Critical destination* is defined as the furthest destination that the household members feel they must be able to reach, even when the 'unlimited' range gasoline vehicle is not available (Kurani *et al.*, 1994).

short distances, those in which both reported long distances, and those in which the distance reported by one household member was much longer than the other. We then used membership in these clusters to attempt to explain choices of limited range vehicles.

We cannot report all the observations in this paragraph with statistical confidence because only a few households belong to the clusters in which both drivers report long distances—the statistical tests indicate significant differences based on the clustering, but the tests themselves are not strictly valid. We observe that, if one household member reported a much longer distance for their longest weekly trip, the household is more likely to have chosen a Regional EV or a gasoline vehicle. Only households in which both drivers report short distances to their critical destinations chose neighborhood EVs (cluster mean distances for both household members less than 20 miles). We do not find any significant relationship between vehicle type and clusters of commute distances.

The general absence of significant relationships between vehicle type choice and simple measures of activity space obscures the fact that, in those households in which at least one person consistently has shorter travel, we observe the full variety of vehicle choices. Also, if the household can allocate the limited range vehicle to the shorter trips, regardless of the driver, then these distance measures suggests that the majority of households in our sample have routine and *critical* destinations well within the range of the EVs offered. Ultimately, part of a household's limited range vehicle purchase decision will involve imagining whether a sufficiently large repertoire of trips can be assigned to the vehicle that it enters into the choice set of vehicles considered for purchase.

Next, we examine how households incorporated EVs into their on-going management of multiple vehicle purchases over time. One way by which they do so is through changes in the staging of vehicle choices by changing the 'defining purpose' of the next new vehicle. As we demonstrate below, we found a relationship between propulsion type choice, and the defining purpose for the vehicle as well as household life cycle.

The concept of defining purpose is as follows. Consider that a household may use a vehicle for all types of travel, but that the decision to buy a vehicle of a particular body style may be determined by the desire to access one particular type of activity. For example, while one household member might commute to work every weekday in a sport-utility vehicle (SUV), the reason the household bought an SUV rather than any other body style may have been to enable, or at least symbolize, access to certain recreation activities. In this case, the defining purpose for the household's choice to buy an SUV is weekend recreation travel. When vehicle propulsion types are offered with unfamiliar range and recharging/refueling characteristics, households alter their choices of vehicles based on the changes they make to the defining purpose of their next new vehicle.

We define these seven categories of defining purposes:

(1) Commute to work or school on a regular basis;
(2) Chauffeur children or other non-drivers;
(3) Chauffeur business clients and associates;
(4) Run business-related errands;
(5) Take weekend and vacation trips;
(6) Haul large loads;
(7) Vehicle styling and other.

We recognize that not all vehicle purchase decisions are made for purely practical reasons. As seen in the list of defining purposes, we did allow households to indicate that vehicle styling or some other non-travel related reason defined their choice of a particular body style and propulsion type. We asked them to identify the defining purpose of the vehicle they initially expected to buy next (that is, prior to us sending them the survey) in Part 1 and again for the vehicles they chose in Situations 1 and 2.

We estimated a log-linear model that includes household life cycle, and the vehicle defining purpose and propulsion type from Situation 2.* The analysis is restricted to

*We use the same household life cycle classification scheme as does the Nationwide Personal Transportation Study (Office of Highway Information Management, 1993).

households with the four most common defining purposes (commute, chauffeur children, weekend and vacation, and styling) in the four most common life cycle categories (all households with two or more adults, with or without children of any age). We do so to eliminate sparse and empty cells from the data table. We lose the ability to generalize about our entire sample, but gain statistical confidence about our conclusions regarding the sub-sample. About 60% of our entire sample is in this sub-sample. Further, we collapsed all four EV types into one super-category of electric vehicles while retaining the distinction between reformulated gasoline and natural gas vehicles.

The model that best reproduces the vehicle choices within this sub-sample includes interactions between life cycle and defining purpose, and between defining purpose and vehicle type. The likelihood ratio chi-square is 24.63, with 24 degrees of freedom. Thus, we do not reject the null hypothesis that the distribution generated by the model is the same as the observed distribution (i.e. we accept the model as a plausible explanation of the data).

The decision-making process that this model represents assumes that a household's life cycle is determined by choices that it makes either prior, or external, to vehicle purchase decisions. Given that a household is in a particular life cycle, one step in its vehicle purchase process is to choose a body style for the vehicle it will purchase next, based on the defining purposes of both the vehicles being considered for purchase and the vehicles in the fleet which the household imagines it will own after the vehicle transaction. Once a defining purpose is chosen for the next new vehicle, the household then chooses the propulsion type of the vehicle—electric, natural gas, or reformulated gasoline.

We also observe that the introduction of new propulsion types produces changes in most households' expectations of their next new vehicle. Across the whole sample, only 45% of households retain the same defining purpose for the vehicle that they chose in Situation 2 as they had stated in Part 1 for the (conventional gasoline) vehicle they next intended to buy. If we again examine only the four most frequently stated defining purposes, we obtain the data on defining purposes shown in Table 6.

While we show the statistics for the test of independence below Table 6, this hypothesis is of little interest in this case. We expect to reject the null hypothesis of independence; thus such a test does little to inform us about the nature of the changes in defining the purpose which we do observe. Two other hypotheses provide greater insight. The first is a test for *marginal homogeneity*. If Table 6 displays marginal homogeneity, then the defining purposes of the chosen body styles in Situation 2 are distributed the same as the defining purposes of the vehicles that households were contemplating buying before they received our survey. The second hypothesis is one of *symmetry*. In a symmetrical table, many households will change *to* a particular defining purpose as a change *from* that purpose. The null hypotheses are that *symmetry* and *marginal homogeneity* exist in Table 6. We reject both these null hypotheses. The marginal distributions (the row and column totals) are significantly different. (likelihood ratio chi-square = 24.29; degrees of freedom = 3) and the transitions between defining purposes are not symmetrical (likelihood ratio chi-square = 26.72; degrees of freedom = 6).

Table 6. Defining purposes for the chosen body style in Situation 2 by defining purpose for the expected body style in Part 1

Defining purpose of chosen body style in Situation 2	Expected defining purpose from Part 1				
Observed count	Commute	Chauffeur	Weekend	Styling	Total
Commute	90	19	25	27	161
Chauffeur children	6	26	8	2	42
Weekend/vacation	19	15	31	12	77
Styling	8	0	5	17	30
Total	123	60	69	58	310

Test	*Chi.square*	*Probability chi-square*
Likelihood ratio:	102.15	0.0000
Pearson:	116.29	0.0000

Based on this analysis, we are more than 95% certain that the changes which we observe in households' defining purposes for their next new vehicles did not occur by chance alone. Further, these results indicate that a household's vehicle purchases are not independent across time. The choice set of vehicles which a household forms during any given vehicle transaction is dependent on the vehicles that the household already owns, and on those it expects to own immediately following that transaction. Faced with a new choice set of vehicles in our experiments, many households changed the defining use of their next new vehicle to allow incorporation of a novel vehicle into their vehicle holdings. Table 6 shows a strong shift toward commuting as the defining purpose of the vehicle chosen in Situation 2 and a lesser shift to weekend and vacation travel, with a shift away from chauffeuring children and vehicle styling. In a separate analysis (Turrentine & Kurani, 1995), we show that these changes in defining purpose are significantly related to choices of vehicle propulsion type. Households that chose any of the electric vehicles in Situation 2 were more likely to say that the defining purpose of the body style they chose was commuting. A disproportionately large number of households that chose gasoline and natural gas vehicles stated that weekend and vacation travel or hauling large loads defined their vehicle propulsion system choice.

QUANTIFYING THE HYBRID HOUSEHOLD MARKET

The hybrid household hypothesis is supported strongly by the evidence in this study. We conclude that across the variety of range choices offered in our study, many *potential hybrid households* find a range that represents an inconsequential drawback. Further, any disadvantage is more than offset, in their minds, by the positive attributes of home recharging and 'greenness' (and possibly other attributes that we have not yet explored).

To establish the relevance of this conclusion from our choice experiments to the real world of markets and mandates, we must translate our findings into estimates of new car market shares for the state of California. To do so, we must determine what proportion of light duty vehicle sales is represented by potential hybrid households. We divide annual light duty vehicle sales into four segments: commercial and government fleets; single vehicle households; potential hybrid households; and multi-vehicle, non-potential hybrid households. This last segment includes a number of multi-car households that fit our hybrid household definition but are unable or unwilling to adapt to a limited-range vehicle. They include households whose vehicle use patterns require long distance capabilities for all their vehicles; households that own only full-sized vehicle body styles; and households that demand that the newest vehicle always be a long range vehicle (because the other vehicle is either not new or not maintained well enough to serve as a long distance vehicle).

As shown in Fig. 3, we estimate that *potential hybrid households* buy between 35 and 40% of all new light-duty vehicles sold in California every year. If, as was the case in our

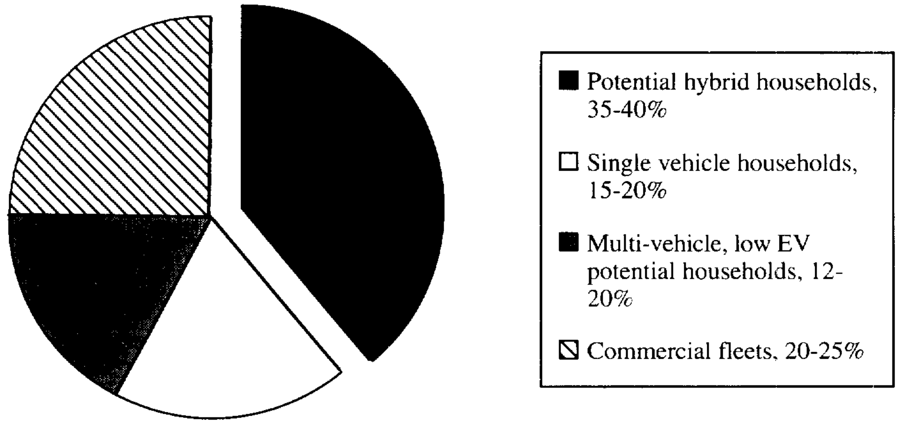

Fig. 3. Existing California light duty vehicle market shares, 1992. Percent of vehicles sold to each market segment.

first choice situation, 46% of potential hybrid households choose an EV, then we expect that 16–18% of annual light-duty vehicle sales would be limited-range electric vehicles sold to potential hybrid households. If a wider variety of range options and propulsion types were offered, the results of our second choice situation translate into combined annual markets shares of 23–26%.

Not all the types of EVs chosen by households in Situation 2 have been demonstrated. The mid-size body style, longer range regional EVs were based on battery technologies not yet commercially available, but expected to be available by the year 2000 (Kalhammer *et al.*, 1995). Limiting our market estimates to currently demonstrated EV technologies, the results of our choice experiments indicate that there are still more than adequate potential markets for electric vehicles to have exceeded the former 1998 CARB mandate for sales of ZEVs in California (with the price assumption which we imposed). These vehicles include small (sub-compact) and compact sedans, wagons, sport-utility vehicles, pick-up trucks and sports cars with driving ranges of 60–150 miles and mid-size body styles with ranges of 60–80 miles. The market potential for these vehicles would be 7% of the total light-duty vehicle market. This estimate does not include any sales to commercial or government fleets, nor does it include any sales to households who lie outside our sample of *potential hybrid households*.

CONCLUSIONS

We identified a substantial market for reduced-range, home-recharged electric vehicles among a particular group of multi-car households. Though we provide a quantitative estimate of sales to this market segment—18% of the annual new light-duty vehicle market in California for battery-powered EVs with ranges of 40–150 miles—these numbers should be viewed as being illustrative of market responses, not as forecasts. Actual EV purchases could be far more or less, depending on prices, vehicle performance, marketing strategies, government incentives and rules, and ultimately, on whether consumers regard the EVs offered to them as affordable, viable options within a variety of transportation services.

What we can say, with confidence, is the following. The vehicle choices made by our respondents support our central hypothesis. The fundamental differences between electric and gasoline vehicles in our choice experiments were driving range, home recharging and emissions—purchase prices in particular were designed to overlap between vehicle types. Since many more households chose EVs than even our hypothesis predicts, we conclude that any disutility of reduced range is more than offset by the value of home recharging (as explicitly stated in the hypothesis) and possibly zero emissions. We break down the responses to these three attributes of EVs as follows.

First, we believe that the progressive environmental image of EVs will have a greater impact on information search and choice set formation than on choices between vehicles within that choice set. While we find, along with others (e.g. Kempton *et al.*, 1995), strong concern for the environment, the role of motor vehicles in degrading the environment, and the need to make some corresponding lifestyle changes, we do not find that those concerns and commitments translate into a willingness to pay thousands of dollars more for clean vehicles. However, environmental factors will play an important role in the search process for new vehicles. In testimony to the California Air Resources Board, a respected auto industry analyst points out that "the current car buyer is confronted with more than 900 available models of new cars and light trucks...the typical buyer will actively consider only 6 vehicles and actually shop to compare only 3" (Power, 1995). Our research suggests that the positive environmental image of EVs will put them on the short list of a large number of buyers.

Second, home recharging is probably the most valued novel attribute of EVs. The willingness of many buyers to spend many thousands of extra dollars for an EV, given their reduced range and our belief that environmental attributes have more to do with choice set formation than with choices from that set, can be best attributed to the attraction of home recharging.

Third, any disutility of reduced driving range in one (and possibly more) household vehicle is small for most multi-car households. Many critics would contend that electric vehicles must achieve ranges higher than 150 miles to be commercially viable, but we find evidence in our studies that the marginal utility of range beyond 150 miles for home rechargeable vehicles will be small—within our studies, any household that can adapt to any reduced range, adapts to a range of 150 miles or less. We argue that the utility of short range, home-rechargeable EVs lies primarily in their complementary, not competitive, relation to vehicles that have a range of over 300 miles and quick, ubiquitous refueling—that is, in their ability to diversify transportation services and lifestyle expressions in hybrid households.

Further, so long as any additional range is relatively expensive, the market for EVs will be segmented by the demand for driving range, with some households preferring vehicles with ranges as low as 40–80 miles. A large number of households in our sample opted for shorter range electric vehicles when longer range EVs were available. A large number of households opted for a short-range EV when familiar long range gasoline vehicles were available. It is precisely this willingness of households to choose shorter range vehicles that opens up the market to electric vehicles that can be built and sold based on a technology which is not too different from what is available as this paper is being written in 1996.

A successful market launch depends on designing EVs that do respond to consumer preferences for the novel attributes of EVs, and do not attempt to duplicate all the performance attributes of gasoline vehicles. Likewise, research should focus less on new batteries that provide a longer range (i.e. higher specific energy and energy density), and more on improved battery cycle life, energy management and manufacturing costs. So long as the belief persists that EVs must mimic the long range and short refueling times of gasoline cars, the EV market will be stalled, at least until the commercialization of fuel cell electric vehicles. Failure to recognize the market for truly reduced range EVs will unnecessarily delay the introduction of EVs and possibly lock us into an unnecessarily expensive future.

In closing, marketing textbooks are full of examples of new technologies from microwave ovens to copy machines to computers, for which researchers initially found no market, but which eventually established large markets. Studies often fail to identify markets for new technologies because researchers search among the existing inventory of consumer preferences and market segments. When potential buyers have not yet constructed preferences for the attributes of novel technologies, attempting to identify and measure market segments will surely mis-estimate future demand. We believe that, in order to avoid the pitfalls that we found in previous EV market studies, market research into many new transportation technologies, especially technologies with social costs and benefits, would be improved by a multi-stage, experimental and process-oriented approach such as that which we designed for this study of electric vehicles. Study participants must be given adequate information and decision-making contexts based on their own daily life and lifestyle goals to evaluate the practical and symbolic values of new technologies. The answer may be a solid market, as we found here for EVs.

Acknowledgements—We would like to acknowledge support for this work from the California Air Resources Board, the California Institute of Energy Efficiency and CALSTART. We would also like to thank the University of California Transportation Center, The University Energy Research Center, Nissan, Exxon and other supporters who funded previous studies in which we developed many of the methods and much of the knowledge underlying this work. Also, special thanks are due to Prof. Martin Lee-Gosselin of Université Laval, Québec. Finally, many thanks to the 454 participants in this study who completed a unique and time consuming survey.

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