TRB

TRANSPORTATION RESEARCH RECORD

Journal of the Transportation Research Board, No. 2017

Sustainability, Energy, and Alternative Fuels 2007

A Peer-Reviewed Publication

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Washington, D.C.
2007

www.TRB.org

Diesel and Hybrids Don't Mix

Perceptions of the Interested Public and Actual Driving Behavior of New Car Owners

David Gerard, Paul S. Fischbeck, and H. Scott Mathews

Hybrid gasoline–electric and fuel-efficient, low-emission diesels are becoming more popular as these technologies improve and fuel prices increase. In Europe, light-duty diesels are the technology of choice for many consumers ("good, clean, green fun"), while in the United States, diesels face significant regulatory certification hurdles. Moreover, U.S. consumers are more interested in hybrids as a solution for improving fuel efficiency and reducing CO_2 emissions. The objective of this paper is to assess U.S. attitudes about hybrid and diesel technologies and behavior of those who purchase these technologies. With survey research, the attitudes of likely diesel and hybrid new car buyers are compared, and the actual driving behavior of new owners of diesels and hybrids is examined. Significant differences were found in both cases. Significant attitudinal differences exist across 20 questions spanning regulatory and environmental issues, with likely hybrid buyers being more environmentally concerned and willing to accept tougher regulatory standards. Hybrid drivers logged fewer annual miles and had a higher percentage of in-city driving. Hybrid buyers generally traded in vehicles that were newer, had better fuel economy, and had smaller engines than did diesel buyers. Both hybrid and diesel drivers saw significant fuel savings with their new vehicles. Because of the bigger improvement from their previous cars and the greater number of miles per year that they drove, however, diesel owners saved more fuel than did new hybrid owners (420 gal per year compared with 275 gal). Acknowledging these differences in public attitudes and behavior is a necessary first step in the development of strategies to reduce mobile source greenhouse gas emissions.

Hybrid gasoline–electric engines and new clean diesels are two of the promising automotive technologies to improve fuel efficiency and reduce (or slow the growth of) greenhouse gas emissions from the transportation sector. The diffusion of these technologies is dependent on many factors, including consumer interest in reducing expenditures at the pump, how advanced technologies affect new vehicle prices, and tax incentives that explicitly target certain technologies. More important, consumers must believe the technology is effective and reliable.

D. Gerard, Center for the Study and Improvement of Regulation, Engineering and Public Policy; P. S. Fischbeck, Departments of Social and Decision Sciences and Engineering and Public Policy; and H. S. Mathews, Departments of Civil and Environmental Engineering and Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213. Corresponding author: D. Gerard, dgerard@cmu.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2017, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 33–40.
DOI: 10.3141/2017-05

Because consumer behavior is ultimately the key to widespread diffusion of new technologies, it is important to understand both consumer beliefs and consumer preferences. Greene, Duleep, and McManus have reviewed evidence on the public attitudes toward hybrids and diesels in the context of projecting likely penetration rates of diesel and hybrid technologies (*1*). Survey results indicated that diesel and hybrid owners tended to have more favorable opinions of these technologies than owners of conventional gasoline vehicles, and that most people associated hybrids with fuel savings (*2, 3*). Overall, potential U.S. customers are far more bullish on hybrids than diesels, with a survey of consumers likely to buy, very likely to buy, or will definitely buy being about twice as high for hybrids (40%) than diesels (22%), whereas the definitely won't buy consumer opinion is nearly twice as high for diesels (39%) as for hybrids (20%) (*4*). In contrast, public attitudes toward the two technologies are nearly reversed in Europe, with diesels enjoying a much larger market share than hybrids, and government incentive programs (i.e., lower fuel taxes) in place in some countries to encourage purchase of diesel vehicles.

More recently, Santini and Vyas examined the possible trajectory of hybrid and diesel diffusion across the U.S. vehicle fleet (*5, 6*). They reviewed some salient economics and social sciences literature on technological innovation and diffusion and applied the basic analytical framework to gasoline–electric hybrid vehicles. Their analyses included survey evidence on consumer preferences for a number of attributes, including fuel efficiency, vehicle acceleration, and towing capacity across several vehicle classes. They found clear differences in the preferences between diesel and hybrid buyers, whereby hybrid buyers preferred small, fuel-efficient vehicles, and diesel buyers were interested in towing and acceleration.

To explore the reasons for the differences in U.S. attitudes toward hybrids and diesels, the authors conducted two sets of surveys. The first took a general sample to gauge public attitudes toward the competing technologies and framed these views in the context of demographic characteristics, driving behavior, and attitudes toward public policy. The authors found that people interested in hybrids are different from those interested in diesels. They owned more fuel-efficient vehicles which they drove less, and they had markedly different ideas about government's role in regulating to protect the environment. For the second set of surveys, the authors polled actual owners of hybrids and diesels to examine a number of questions related to how the vehicles were being driven and how driving behaviors might change with the new technologies. The authors used this information to calculate fuel savings for each individual over his or her previous vehicle. Once again, it was found that diesel and hybrid drivers were different in ways similar to those in the first survey.

SURVEY 1. AUTO SHOW SURVEY OF THE GENERAL PUBLIC

A paper survey was administered at the Pittsburgh, Pennsylvania, International Auto Show in February 2006. People waiting in line for food or tickets were asked to fill out a five-page survey. (The full text of the survey is available from the authors on request.) Candy bars were used as compensation. A total of 237 surveys were collected in 8 h spread over 3 days by six undergraduates. People were eager to participate.

There were six parts to the survey:

1. Questions about making a new car purchase,
2. Agreement with 22 attitudinal statements dealing with regulations and the environment,
3. Opinions about and making comparisons between diesel and hybrid technologies,
4. Willingness-to-pay questions about improving the environment and safety,
5. Assessment of the sensitivity of purchasing diesels and hybrids to changes in the cost of fuel, and
6. Demographics.

The survey took 5 to 10 min to complete.

Results from Survey 1

Results are reported from three of the six sections of the survey: likelihood of purchasing a diesel or hybrid under different fuel prices, stated level of agreement with 22 attitudinal questions dealing with regulatory policy and the environment, and demographics.

Demographics

Survey respondents were biased toward older white males, which was not surprising given, that the survey was conducted at a large automobile show. Sixty-seven percent of the respondents were male, and the average age was 39. The average respondent owned almost seven vehicles, had a current car with 62,000 mi, drove 200 mi per week, and got an oil change every 4,300 mi. Average reported fuel efficiency of the current primary vehicle was 18 mpg in the city and 23 mpg on the highway.

Likelihood of Purchasing Hybrid or Diesel

Respondents were asked to rate the likelihood of purchasing a hybrid or diesel for their next vehicle using a five-point Likert scale (with 1 being very unlikely and 5 being very likely) for different fuel costs ranging from $1.50/gal to $4.00/gal. A weighted average of the responses, with the most weight given to $3.00/gal, was used to place the respondents into four levels of interest for both hybrids and diesels. The first row of Table 1 shows this distribution. Although the respondents were asked to complete both the hybrid and diesel questions, some respondents failed to complete one or both of the sections. Overall, 85% of the respondents completed both sections.

Twenty-eight percent of the respondents stated that it was possible or very likely that they would purchase a hybrid; 20% said the same about diesels. A comparison of these two groups across the demographic variables shows numerous statistical differences (see Table 2).

When compared with people interested in diesels, people interested in hybrids were more likely to be women, drive newer cars with fewer miles, change their oil more often, and drive fewer miles per week in cars that get better fuel economy. Because people interested in diesels drive more miles per week, the difference in miles between oil changes may mean that people change their oil based on the calendar rather than the odometer (20 weeks for hybrid-interested people and 21 weeks for diesel-interested people). The only variable that did not reveal significant differences was age. The descriptive statistics demonstrate that these are very different populations.

Table 3 reveals considerable differences between people interested in hybrids and diesels by showing how respondents answered the questions for the two technologies (only respondents who completed both the hybrid and diesel questions are included). People who were very interested in either technology had little interest in the other. Most respondents had minimal interest in either and by

TABLE 1 Demographics of Likely Hybrid and Diesel Buyers (Survey 1)

	Total Sample	Hybrid Very Likely	Hybrid Possible	Hybrid Not Likely	Hybrid Very Not Likely	Diesel Very Likely	Diesel Possible	Diesel Not Likely	Diesel Very Not Likely
Count	237	17	51	64	63	23	24	56	76
Percentage of women	33	48	39	31	21	25	35	30	34
Average age	39	43	35	40	38	37	36	40	39
Vehicle age	3.5	4.0	3.2	2.6	3.1	4.8	3.3	3.0	3.2
Vehicle mileage (1,000)	62.0	60.5	61.5	60.5	68.4	84.2	71.4	60.1	66.5
Cars owned	6.7	7	7	7	7	4	7	7	6
Miles driven between oil changes	4,300	3,800	3,950	4,000	5,050	5,500	5,800	4,150	3,750
Miles driven per week	200	175	210	185	235	265	250	170	205
Reported city fuel economy	18.2	19	19	18	17	17	19	17	19
Reported highway fuel economy	23.1	24	24	23	22	22	24	22	24
Combined fuel economy	20.5	22	22	21	20	19	21	20	21

TABLE 2 Comparison of Demographic Variables Across Likely and Possible Diesel and Hybrid Buyers (Survey 1)

	Likely or Possible Hybrid	Likely or Possible Diesel	Difference	Significance
Percentage of women	41.2	30.1	0	<.01
Average age	37.0	36.5	0.50	n.s.
Vehicle age	3.4	4.1	−0.70	<.05
Vehicle mileage (1,000)	61.2	77.7	−16.50	<.01
Cars owned	7.0	5.5	1.50	<.05
Miles driven between oil changes	3,900	5,650	−1,750	<.01
Miles driven per week	200	258	−58.00	<.01
Reported city fuel economy	19.00	18.02	0.98	<.10
Reported highway fuel economy	24.00	23.02	0.98	<.10
Combined fuel economy	22.00	20.02	1.98	<.10

default were considering vehicles with conventional gas-powered engines.

Table 4 shows the correlation between the groups with various levels of interest in diesels and hybrids. Once again, it was found that there are significant differences in how people who are interested in diesels and hybrids view the world. The lower left corner shows the correlations among the likely and possible diesel and hybrids respondents. The comparison of very likely categories has the lowest correlation of the table (0.19), which is not statistically different than zero.

Attitude Toward Environmental and Regulatory Issues

Respondents were asked to indicate their level of agreement with 22 statements covering a range of environmental and regulatory issues using a five-point Likert scale (with 1 meaning strong disagreement and 5 meaning strong agreement). Figure 1 plots 16 of the statements. (The other six statements dealt with facts pertaining to diesels and hybrids.) Using the same groups discussed above, the agreement with these attitudinal statements was compared.

The sharp differences indicated by the correlations in Table 4 are reflected in the results presented in Figure 1, which plots the agreement scores for the two groups for 16 of the statements. Several statements fall on or very near the diagonal, indicating similar responses between the two groups [e.g., "Fuel prices will sharply increase in the next 5 years" (#10, high agreement with the statement) and "I am not convinced that climate change is a real problem" (#9, low agreement with the statement)]. Other statements had significant differences between the two groups. Statements with which the hybrid group had much stronger agreement include "I would be willing to drive less to protect the environment" (#1) and "I worry about health effects caused by emissions and pollutants from vehicles" (#2). Statements with which the diesel group had much stronger agreement include "Interstate speed limits should be increased" (#16) and "It is more important to reduce emissions from power plants than from autos" (#14). Table 5 provides a list of the 16 questions and the statistical significance of these comparisons.

TABLE 3 Relationship Between Respondents Stating Interest in Hybrid and Diesel Vehicles (Survey 1)

	Diesel Very Likely	Diesel Possible	Diesel Not Likely	Diesel Very Not Likely	
Hybrid very likely	0	0	5	10	15
Hybrid possible	0	2	17	28	47
Hybrid not likely	4	11	21	14	50
Hybrid very not likely	18	10	12	22	62
	22	23	55	74	174

Discussion of Survey 1

Because the survey was limited to the auto show in Pittsburgh, the results cannot be said to reflect national attitudes; however, the authors believe that the insights gleaned can apply to more than just western Pennsylvania.

When comparing people who are interested in hybrids with those interested in diesel, the authors found significant differences in their demographics, current driving behavior, and attitudes toward regulatory policies and valuation of the environment. In fact, people who are interested in hybrids are not at all interested in diesels. Evidently, consumer demand for fuel efficiency does not mean that consumers are willing to consider either diesels or hybrids; they have a strong preference for one technology. An analysis of the responses to the attitudinal statements shows that the "very not likely in diesel" category and the "very likely in hybrids" category are correlated at .90, and the reverse comparison "very not likely in hybrids" and "very likely in diesels" are correlated at .82 (see Table 4).

On the basis of these results, it appears that people interested in hybrids are much "greener" than are diesel enthusiasts. They are willing to make more make more lifestyle changes to reduce pollution, they are much more worried about the harmful effects of pollution, they want tougher regulations, and they are particularly antidiesel. In contrast, people interested in diesels are more aggressive on the road, want higher speed limits, and feel that power plants should be regulated before vehicles. There was also some surprising agreement between the two groups on topics such as global warming and CO_2

TABLE 4 Correlations of Attitude Questions Across Likelihood of Buying Categories (Survey 1)

	Hybrid Very Likely	Hybrid Possible	Hybrid Not Likely	Hybrid Very Not Likely	Diesel Very Not Likely	Diesel Not Likely	Diesel Possible	Diesel Very Likely
Hybrid very likely	1.00							
Hybrid possible	0.86	1.00						
Hybrid not likely	0.70	0.73	1.00					
Hybrid very not likely	0.49	0.68	0.77	1.00				
Diesel very not likely	0.90	0.95	0.79	0.70	1.00			
Diesel not likely	0.76	0.84	0.92	0.85	0.85	1.00		
Diesel possible	0.39	0.43	0.77	0.78	0.86	0.84	1.00	
Diesel very likely	0.19	0.37	0.51	0.82	0.35	0.60	0.50	1.00

regulation, use of carpool lanes, and vehicle emissions (all either neutral to or in agreement with).

WEB-BASED SURVEY OF HYBRID AND DIESEL OWNERS

The first survey allowed respondents to describe their hypothetical likelihoods of buying either a diesel or hybrid vehicle, given possible future fuel prices. However, accurately estimating the likelihood of future major purchases is extremely difficult. To understand better how these high-efficiency vehicles are actually being used, the authors developed a directed survey aimed a new car owners who had actually made the decision to buy. The authors used the web to identify potential respondents and collect the data. In particular, the authors were interested in how driving behaviors changed with the new vehicles and wanted to estimate the annual savings (or costs). By using the web, the authors were able to collect a large sample without geographic constraints.

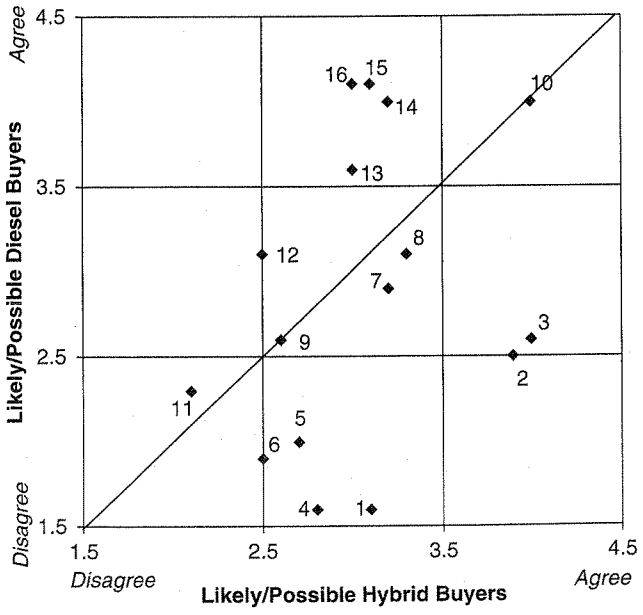

FIGURE 1 Comparison of agreement with attitudinal statements from Survey 1 (see Table 5 for statements).

Methods for Survey 2

A search of Internet message boards dealing with hybrid and diesel topics revealed a number of promising sites. Some are narrow and discuss only one make or model, while others are broad, covering all types of engine technologies. The surveys were housed on 10 message boards (www.slug-lines.com, www.greenhybrid.com, www.mixedpower.com, www.insightcentral.com, www.hybrid.com, www.priuschat.com, www.priusonline.com, www.car-forums.com, www.cartalk.com, and www.tdiclub.com).

The surveys (one for hybrids and one for diesels) were constructed using www.surveymonkey.com, a site specializing in simple online survey construction. SurveyMonkey automatically codes the completed surveys and provides files ready for analysis. The authors had no problems using the website. Pointers to the survey were posted twice on the message boards separated by 1 week. The authors left the survey up for 3 weeks. People seemed very receptive to the survey, with 447 survey respondents.

Each version of the survey contained sections on vehicle descriptions, driving habits, and demographic characteristics. The surveys began with questions to determine details about the respondent's current hybrid or diesel vehicle (i.e., make, model, and year) and his or her previous vehicle (i.e., make, model, year, engine type, and transmission). The previous vehicle information was used to obtain fuel efficiency data from the U.S. Environmental Protection Agency (EPA) database. In the case of the Volkswagen Beetle, Golf, and Jetta TDI models, only one response option was created, since all share the same basic frame and engine and have very similar fuel economy. Internal combustion engines are often offered with a variety of engine types (e.g., four or six cylinders) and with automatic or manual transmission.

The second section dealt with driving habits since obtaining the hybrid or diesel vehicle, including yearly mileage and the percentage of highway miles. Respondents were also asked whether the number of miles had changed since the purchase and by approximately how many thousands of miles. With this information, the authors were able to assess whether owners had reduced fuel consumption and by how much.

The third section of the survey was optional. It asked participants to provide their zip code and contact e-mail address if they were willing to answer further questions or wanted the results of the study. More than 90% of respondents provided their zip codes and e-mail addresses. A text box was provided to allow respondents to add any comments.

TABLE 5 Comparison of Agreement for Likely and Possible Diesel and Hybrid Buyers to Attitudinal Statements Dealing with Regulatory Policies (Survey 1)

Key for Figure 1	Attitude Statement	Likely or Possible Hybrid	Likely or Possible Diesel	Difference	Significance
1	I would be willing to drive less to protect the environment	3.1	1.6	1.5	<.01
2	I worry about health effects caused by emissions and pollutants from vehicles	3.9	2.5	1.4	<.01
3	Diesel vehicles should be required to use "best available" pollution controls	4.0	2.6	1.4	<.01
4	All cars should be required to pass an annual emissions test	2.8	1.6	1.2	<.05
5	The government should mandate an increase in fuel efficiency for all vehicles	2.7	2.0	0.7	<.05
6	I would support a gas tax to help the environment	2.5	1.9	0.6	<.10
7	More car pool lanes should be created	3.2	2.9	0.3	n.s.
8	The government should regulate carbon dioxide as a pollutant	3.3	3.1	0.2	n.s.
9	I am not convinced that climate change is a real problem	2.6	2.6	0.0	n.s.
10	Fuel prices will sharply increase in the next 5 years	4.0	4.0	0.0	n.s.
11	The government should have weaker regulations regarding vehicle pollutants	2.1	2.3	−0.2	n.s.
12	I am an aggressive driver	2.5	3.1	−0.6	<.10
13	Hybrid vehicle batteries hurt the environment	3.0	3.6	−0.6	<.10
14	It is more important to reduce emissions from power plants than from autos	3.2	4.0	−0.8	<.05
15	Diesel engines are more fuel efficient than gasoline engines	3.1	4.1	−1.0	<.05
16	Interstate speed limits should be increased	3.0	4.1	−1.1	<.05

Results for Survey 2

The response to the online surveys exceeded expectations; 447 drivers responded. Of these individuals, 254 were hybrid drivers, while 197 drove diesel vehicles. Respondents came from 45 states. There were heavy responses for hybrid owners in California (20% of respondents) and diesel owners in Pennsylvania (12%). The sections that follow outline the general results of both surveys, as well the statistical analysis performed to examine the differences between hybrids and diesels.

Hybrid Survey

Table 6 shows the distribution of vehicles for the 254 hybrid respondents. The majority, 74%, owned Toyota Priuses. Although initially it seemed that this large proportion of Priuses might be due to a bias in the posting of the survey on multiple Prius discussion boards, an examination of the true distribution of the hybrid fleet according to make and model year yielded similar results, showing about 75% Priuses sold per year.

TABLE 6 Distribution of Hybrid Vehicle Makes and Models Owned by Respondents (Survey 2)

Make and Model	Count	Percentage
Toyota Prius	188	74
Honda Insight	28	11
Honda Civic Hybrid	28	11
Ford Escape Hybrid	5	2
Honda Accord Hybrid	4	1.6
Other	1	0.4
Total	254	100

Fifty percent of the hybrids were model year 2005, 35% were 2004, 15% were 2003, and 5% were 2000–2002. The distribution of the number of miles driven annually was distributed normally, with the median value just below 15,000 mi per year. Eighty-three percent of hybrid drivers said that they have not changed their driving habits (in terms of annual miles) since obtaining their hybrid. Yet multiple open-ended comments provided at the end of the survey discussed how respondents felt that their driving style had changed substantially. One of the key elements is that hybrid drivers can view their current fuel economy on their dashboard screen, and as a result, new hybrid drivers drive in a fashion to maximize fuel economy (for example, by driving more defensively and trying to coast as much as possible). Although hybrid drivers may not be changing the number of miles that they drive, they are changing the way in which they drive those miles. Table 7 provides average results for these questions.

Diesel Survey

The diesel survey was heavily dominated by the TDI Volkswagen Golf platform models (the Volkswagen Beetle, Golf, and Jetta), accounting for 90% of the respondents. Even though there were hundreds of thousands of diesel pick-up trucks on the road, the authors received only a handful of responses, and these were dropped from the data set during the analysis phase.

The survey results indicated that diesel owners drove a lot and that highway miles accounted for a considerable portion of their

TABLE 7 Summary Results Comparing Survey Responses for Hybrid and Diesel Owners

	Diesel	Hybrid	Difference	*t*-Value	Significance
Annual miles per year	18,750	14,445	4,305	6.85	<0.001
Percent highway miles	63	49	14	4.79	<0.001
Change in miles per driven	485	285	200	0.97	n.s.
Fuel economy of previous vehicle	20.3	25.3	−5.0	−6.95	<0.001
Model year of previous vehicle	1995	1997	−2	−3.59	<0.001
Number of cylinders in previous vehicle	5.3	4.9	0.40	2.71	<0.01
Fuel savings	420	275	145	−5.38	<0.001
Population by county (1,000s)	922	1,376	−454	−2.12	<0.05
Population by zip code	22,400	29,306	−6,906	−3.51	<0.001
House value by zip code	$164,890	$190,978	−$26,088	−2.25	<0.05
Household income by zip code	$52,374	$58,457	−$6,084	−2.16	<0.05
% in PM 2.5 nonattainment areas	33.7	31.3	2.3	0.67	n.s.
% in ozone nonattainment areas	35.6	37.1	−1.5	−0.45	n.s.

total miles. Forty percent of the respondents drove 20,000 mi per year or more, and 60% reported that highway driving accounted for 60% to 90% of their total miles. While a majority of drivers did not report changing the number of miles driven annually, 22% stated that they had increased their annual miles driven since the purchase of their diesel vehicle. These results, along with qualitative evidence given in the comments, indicated that current diesel drivers seemed to be driving enthusiasts. These driving habits could certainly influence their preference for the diesel technology, especially given that hybrids tend to get worse fuel economy mileage on the highway than they do in the city. Only five people (3%) decreased their yearly miles driven. Table 7 provides average values for the questions.

Comparison of Hybrids and Diesels

The authors conducted a series of *t*-tests to compare the responses between the two types of vehicles. In addition, the authors calculated, on the basis of the survey answers, an estimate of the number of gallons of fuel saved (or lost) for each respondent. To do this, the authors used the adjusted EPA fuel economy values and combined them using the EPA weighting. (The authors also used the fuel economy values published in *Consumer Reports,* which contained lower values but did not change the significance of the differences. Similarly, the authors used the self-reported weight of city and highway miles but found no difference from the EPA results).

In addition, the authors completed a geographic analysis of the two sets of owners by comparing the demographics of the respondent's home zip code/county and noting whether the respondents lived in a nonattainment area for ozone or particulate matter ($PM_{2.5}$). Results of these statistical tests are shown in Table 7.

There are numerous statistically significant differences. When compared with hybrid owners, diesel owners drove more miles annually and spent more time on the highway. They traded in vehicles with bigger engines that had lower fuel economy. The net result was that the new diesel owners saw a greater fuel savings, even though the fuel economy of their new vehicles was lower. The average diesel owner saved 420 gal per year compared with 275 gal for the typical hybrid owner. Hybrid owners were also found to live in more urban and more wealthy zip codes and counties. Although there was no difference in the air quality of where the owners lived (as measured by nonattainment areas), when compared with national statistics the nonattainment areas were overrepresented.

In addition to the above-mentioned differences in the cars' trade-in, diesel drivers were far more like to have had manual transmissions in their previous vehicle (54% for diesels and 27% for hybrids). There was a significant difference in model year of previous vehicle, but because the TDI diesels have been available longer, when age was used, the difference went away.

Savings can occur for a combination of two reasons: changes in fuel economy and changes in miles driven. The calculations in this research take both into account. Therefore, it is possible for a driver who trades in a gas guzzler for a fuel-efficient hybrid and also drives many more miles in a given year to have increased the fuel consumed. The biggest savings was for a driver who went from driving 25,000 mi a year in a 1988 Toyota Land Cruiser with an automatic transmission to driving 19,000 mi a year in 2003 Volkswagen Golf TDI with a manual transmission. This double change of better fuel economy and fewer annual miles resulted in a fuel savings of more than 1,600 gal per year. The biggest savings for a hybrid was for an owner who traded in a 1993 Jeep Cherokee for a 2005 Prius while maintaining 22,000 per year. The net improvement was more than 850 gal. The biggest increase in fuel consumed was for a driver who traded in a four-cylinder 2000 Volkswagen Jetta with a manual transmission for a 2004 Ford Escape Hybrid and increased his annual miles from 13,000 to 17,000. This resulted in a net increase in annual fuel consumption of over 160 gal. Figure 2 shows the cumulative probability distribution of fuel savings for the two groups.

CONCLUSIONS

Although the two surveys were taken at different times and used different populations and different sampling techniques, a few cross comparisons that are possible. First, in both cases, those interested in hybrids (those who bought hybrids) owned (had owned) vehicles that had much better fuel economy than their corresponding diesel respondents. Second, the two diesel groups were "road warriors"; they drove their cars on average 2,500 (3,000) more miles per year then their hybrid counterparts. Both of these results are remarkably

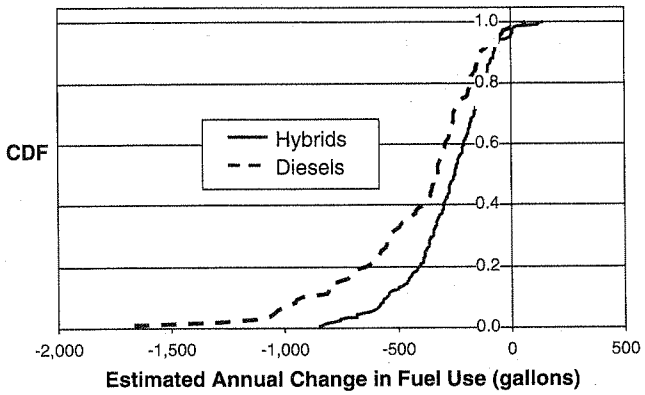

FIGURE 2 Distributions of fuel saved for hybrid and diesel drivers.

consistent across the two surveys. These similarities suggest that the people in first survey who had expressed an interest in hybrids (or diesels) and those who have actually purchased a new vehicle with those technologies were similar in driving habits and car choice. Two different approaches have found the same relationships.

These differences cannot be traced to a simple desire to save fuel (or money), though it is important. Fuel savings were significant for both technologies. However, despite the hybrid owners seeing a greater improvement in their fuel economy with their new vehicle (indeed, the Prius and Insight are 8 to 11 mpg better then diesels), the diesel owners saved more fuel because they drove more miles per year. If the diesel buyers had purchased hybrids, they might have seen even greater savings because of the hybrid's better fuel economy. However, the relative advantage of hybrids is not in highway fuel economy, so diesel owners who logged mainly highway miles might not have improved their savings by driving hybrids. The buying decision appears to be more complicated and involves the attitudinal questions from the first survey.

As this paper has shown, the surveys look at two different but interrelated factors that can influence the buying of hybrids and diesels. First, the authors looked at attitudes to see how people felt about these vehicles, how they reacted to several hypothetical situations, and what they believed would differentiate hybrid and diesel buyers. Second, the authors looked at behavior to see what vehicles consumers were buying, what vehicles were traded in, and what number of vehicles had no trade-in specified. The authors also analyzed the data to discover how much fuel-efficient vehicle owners were driving and, ultimately, how much fuel they were saving with their new vehicle.

Differences in Attitudes

The information on attitudes comes from the first survey. Through multiple methods of analysis, the authors were able to develop a profile of what characterizes people who wanted hybrids or diesels and how each differed from the general population as a whole. Judging from the willingness-to-buy for different fuel costs, it appeared that people in the United States were more interested in hybrids than diesels, all other factors being equal. The authors found that the public generally had a more favorable view of hybrids than of diesels over a variety of areas and that more people were planning to buy or did buy hybrids than diesels.

We can also characterize those who were most interested in conventional gas engines and who could be considered most representative of the general population for the purposes of this analysis, can also be characterized on the basis of survey responses. First, those preferring conventional gas engines did not appear to have significant concerns about the environment—definitely not enough to be willing to buy a more expensive vehicle that pollutes less. But, they did not appear to want the government to loosen regulations for vehicles. Conventional owners did not appear to be sensitive to rising gasoline prices, although rising prices would affect their behavior. At an aggregate level, their total gas mileage was not increasing. There was also a definite dislike of spending extra money on vehicles in general, whether through a tax on gasoline or through higher maintenance costs to reduce emissions. Ultimately, while these people were more disposed to hybrids than to diesels, they seemed quite unwilling to change to either one and replace the tried-and-true conventional gas engine.

People who desired hybrids seemed to be more concerned with the environment in general and the environmental impact of vehicles specifically. This appeared to be a global factor, showing up in a variety of questions dealing with the environment. They also appeared to be more willing to spend money to reduce a vehicle's emissions. Tangential to this, people who wanted hybrids were more receptive to government intervention in issues dealing with vehicles than was the general public. However, such factors appeared to be incidental to why people who wanted hybrids were buying hybrids. Fuel efficiency seemed to take that role. As indicated through regression analysis, a desire for greater fuel analysis was an excellent predictor of willingness to buy a hybrid. This corresponded rather well with a prospective hybrid buyer's increased sensitivity to higher gasoline prices and increased tolerance of possible government-mandated fuel efficiency increases.

People who wanted diesels, in contrast, appeared to have almost the opposite views. They were much less likely to have concerns with the environment as compared with the average consumer, and they believed diesels were much better than hybrids in a variety of areas. They also showed signs of being extremely price-insensitive about to reducing emissions for vehicles and insensitive to increasing gasoline prices. In a predictive sense, it appeared that the people who were most likely to buy a diesel were those who believed that a diesel was generally superior to conventional gas engines or hybrids. While this effect did appear to be global, the predictors found indicated that perceived fuel efficiency superiority over conventional gas engines and perceived reliability superiority over hybrids could indicate who would be interested in a diesel. The "newness" of the hybrid technology and "oldness" of diesels might make those interested such devotees. Because the diesel group was driving 20% to 30% more miles per year, the untested nature of hybrids and the rugged reputation of diesels could have been the deciding factors. For many diesel drivers in the second survey, by logging more than 25,000 mi a year, the hybrid warranty would have expired in 3 to 4 years, leaving significant uncertainty about engine reliability. In comparison, diesel engines had a reputation of lasting several 100,000 mi.

At the same time, people interested in diesels did not seem to want to weaken government regulations. At least in this regard, people who preferred diesel might have been closer to people who preferred hybrids than those who preferred conventional gas engines. Overall, the attitude measures appeared to paint people who wanted hybrids and those who wanted diesels as being on opposite sides of the spectrum,

with those who wanted conventional gas engines in some sort of position in between.

On the basis of the geographic analysis, it is possible to take a different perspective on the results. The hybrid owners in the sample lived in more urban and wealthier zip codes. Their preference for hybrids might have resulted from the type of driving that they experienced every day (i.e., more city driving). Their choice of a hybrid might have been the logical choice for their driving environment. The same could have been true for the diesel owners (the correlation between zip code population and miles driven per year was −0.24 over the entire data set; that is, people drove more in less populated areas). The driving environment directly influences attitudes and, in turn, car purchase decisions.

Policy Implications

This research and its results can have important impacts on policy decisions, marketing decisions, and fleet mix predictions, among other things. The implications for private marketers are obvious: the factors that represent people who like hybrids or diesels can be used for more specific targeting of these vehicles to their most receptive audiences. The results can be important from a policy standpoint, as they can show which policy options would be acceptable to the public, as well as whether such policies would actually have the intended effect (e.g., there might be strong interest if the incentive–rebate programs currently available only for hybrids were expanded to include high-efficiency diesels). It also can act as a sanity check for the many fleet-mix predictions that are being used to model future fuel consumption and emissions by indicating what people would be buying now and how that may change in the near future. In addition, as new models of mobile emissions are developed, they must be sufficiently flexible to allow for differences in driving behavior by technology to be modeled. A mobile emissions model that does not account for a difference of 20% to 30% in annual miles between hybrids and diesels could have significant impact on the results of an air quality model that uses it as an input.

ACKNOWLEDGMENTS

This research grew out of a project research class in the Departments of Engineering and Public Policy and Social and Decision Sciences at Carnegie Mellon University. Todd Wilson, Justin Schantz, Teddy Cleborne, Dana Crook, and Meredith Frey collected and compiled much of the primary data.

REFERENCES

1. Greene, D. L., K. G. Duleep, and W. McManus. *Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market.* Report ORNL/TM-2004/181. U.S. Department of Energy, 2004.
2. McManus, W. Consumer Demand for Alternative Powertrain Vehicles. J. D. Power and Associates, Detroit, Mich., 2003.
3. Duleep, K. G. Analysis of Hybrid Technology. Presented to U.S. Department of Energy, Office of Policy. Energy and Environmental Analysis, Inc., Arlington, Va., Nov. 2003.
4. *Caravan Fuel Efficient Vehicles.* ORC Study 713218. Opinion Research Corp., Princeton, N.J., May 20, 2004.
5. Santini, D. J., and A. D. Vyas. Introduction of Hybrid and Diesel Vehicles: Status Within the Life Cycle of Technology Adoption. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1941,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 18–25.
6. Santini, D. J., and A. D. Vyas. Hybrid and Diesel Powertrains: Further Analysis of Their Status in the Technology Adoption Life Cycle. Presented at 85th Annual Meeting of the Transportation Research Board, Washington, D.C., 2006.

The Alternative Transportation Fuels Committee sponsored publication of this paper.