Rise and Fall of Diesel Cars: A Consumer Choice Analysis

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The search for alternative transportation fuels must be undertaken with an understanding of the retail markets for vehicles and fuels. The authors examine the history of the diesel car, as the only important alternative to gasoline in the U.S. household vehicle market, with the specific intent of exploring the conditions under which individuals would purchase a nongasoline vehicle. Diesel car sales rose from less than 1 percent of new car sales in 1976 to 6 percent by 1981, and then collapsed to less than 1 percent by 1985. A survey of diesel car owners was conducted in California to determine why diesel car sales rose and fell so sharply. The rise of diesel car sales was fueled by expected fuel cost savings. However, it was found that consumers relied on per gallon fuel prices, not per mile fuel costs or fully allocated total costs as the indicator of whether diesel cars were economically superior. The fall of diesel car sales was fueled by the declining per gallon price advantage of diesel fuel and specific perceived and actual problems with General Motor's (GM's) early 5.7-liter diesel engine. It was found that non-GM diesel car owners were no less likely to buy another diesel car of any make because of the public perception of the 5.7-liter GM engine, but that GM diesel owners and the general car-buying public believed diesel cars to be of lower quality than gasoline cars. It is concluded that fuel price and vehicle quality will be important determinants of the success of alternative transportation fuels and vehicles in the marketplace.

The rise and fall of light-duty diesel vehicle sales in the United States was meteoric. Sales of these vehicles increased from less than 1 percent of new motor vehicle sales in 1976 to approximately 6 percent nationwide (*1*) and 9 percent in California (*2*) in 1981, then collapsed to less than 1 percent by 1985. The time period from 1977 to 1985 defines the diesel passenger car era that will be examined here. [Most of the light-duty diesel vehicles sold were passenger cars; for simplicity the term "diesel cars" will be used here with the understanding that it encompasses light-duty diesel trucks.]

Why and how diesel car sales collapsed so quickly is the subject of this paper. The authors take the point of view of the consumer because the failure of the diesel car market was ultimately the result of consumer behavior. The objective is to analyze why the diesel car market collapsed and to generalize these findings to the introduction of new vehicle technologies and vehicular fuels. The diesel car was chosen for study because it is the only modern example in the United States of a nongasoline vehicle and fuel offered in the retail passenger car market. The paper is based on a survey of diesel car owners in California.

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This study differs from past works in that the perceptions and decisions of consumers who have actually chosen an engine/fuel innovation, in this case light-duty diesel engines and diesel fuel, are examined. Past studies have relied on hypothetical choices (*3, 4*) or on data bases not specifically designed to analyze consumer reactions to new vehicle technologies [e.g., Train (*5*) and Greene (*6*)]. Only one study has specifically addressed the market for diesel cars (*7*).

The importance consumers placed on vehicle attributes and the fundamental relationships between their perceptions and their behavior are analyzed. Specifically, in this case of a collapsing diesel car market, the authors analyze the role played by actual and perceived costs of diesel fuel, actual and perceived engine quality, and unfavorable publicity. How the perceptions and behavior of early buyers of diesel cars differed from those of later buyers and how diesel car buyers differed from the general car-buying public are investigated.

As background and context for the consumer analysis, a brief history of the rise and fall of diesel cars, an overview of the attributes of diesel cars relative to their gasoline counterparts, and a brief analysis of actual costs of owning and operating diesel cars are provided next.

HISTORICAL BACKGROUND

Mercedes-Benz had been selling small numbers of diesel cars in the United States since the 1930s, and Peugeot since the early 1970s. The market began to expand rapidly in the late 1970s as a result of a new emphasis on fuel efficiency. In 1977 Volkswagen (VW) and the Oldsmobile division of General Motors (GM) began selling diesel cars, followed shortly thereafter by a number of other domestic and foreign manufacturers.

Two stimuli for increased fuel efficiency were the Corporate Average Fuel Economy (CAFE) standards and the requirement that fuel efficiency estimates be posted on all new cars. The CAFE standards required automakers to increase the efficiency of their new cars from an average of less than 14 mpg in 1975 to 27.5 mpg in 1985. Because diesel-powered vehicles typically achieved 10 to 50 percent greater fuel efficiency than their gasoline-powered counterparts, automakers saw diesel cars as an attractive strategy for achieving the CAFE standards and for favorably positioning themselves in a market in which fuel efficiency was of growing importance to consumers.

Inhibiting the movement toward diesel cars were proposed standards for reducing nitrogen oxide (NO_x) and particulate emissions. During the early 1980s GM and other diesel car manufacturers claimed the standards proposed for 1985 were not technically feasible for diesel cars, although Mercedes-

Benz argued to the contrary (*8*). The emissions controversy created some uncertainty for vehicle manufacturers and tarnished the attractiveness of the vehicles to those concerned with air pollution, but ultimately this controversy played only a minor role in the demise of the diesel car.

A more important factor in the downfall of diesel car sales was the question of engine quality—a question that was initially related to consumer complaints about GM's 5.7-liter diesel engine. GM diesel car owners complained of the need for frequent oil changes, faulty fuel pumps, inadequate systems to separate water from the fuel (which clogged injectors and corroded fuel system components), inadequate main bearings, an engine block not designed for the additional stresses of a diesel engine, and a transmission poorly matched to the power characteristics of the motor. These complaints were volunteered by survey respondents, publicized in the trade literature (*9–12*), and documented by long-term tests of GM diesel-equipped light-duty trucks and cars by the California Department of Transportation (*13, 14*).

Consumer groups and the federal government settled various claims with GM regarding the 5.7-liter engine. GM paid $22.5 million to original owners of 1978 to 1980 diesel cars to settle one class action suit and settled another case, which involved the diesel fuel injectors, with the Federal Trade Commission. The latter settlement was estimated to have cost GM in excess of $30 million in the first 10 months of 1984 (*11*). Owners of vehicles equipped with the fuel injectors in question are eligible to apply for compensation until 1991.

Evidence that GM's diesel engines were not fulfilling owners' expectations regarding maintenance and durability did not go unheeded by the manufacturer. GM took several remedial actions to improve the 5.7-liter diesel engine. Even so, many owners of later model (1981 through 1985) 5.7-liter engines were also dissatisfied with this particular engine. One hundred such owners filed a class action suit in October 1986 seeking damages for repair costs and loss of resale value (*12*). Later GM diesel engines, the 4.3-, 5.0-, and 6.2-liter engines, were not the object of lawsuits, presumably because GM had benefited from the knowledge gained with the 5.7-liter engine.

The diesel car market in California, where the survey was conducted, varies somewhat from the national market. First, as was stated earlier, diesel car sales in California were greater than the national average (Table 1). This greater market penetration may be explained in part by California's moderate climate in which the cold-starting difficulty of diesel engines is not a disadvantage. Second, Mercedes-Benz held a disproportionately large share of the diesel passenger car market in California—20 to 25 percent of Mercedes-Benz sales in the United States during the heyday of the diesel car (Mercedes-Benz of North America, unpublished data).

Diesel cars had some attributes that were superior to those of comparable gasoline cars and others that were inferior. The most important superior attribute was lower fuel costs as a result of diesel engines' higher fuel efficiency and, until about 1982, diesel fuel's lower price per gallon. In practice, fuel efficiency differences between gasoline and diesel cars varied from model to model and are difficult to specify precisely from a consumer perspective.

Complicating the fuel efficiency comparison is the fact that diesel engines have much lower horsepower than do gasoline engines of similar displacement, even if the diesel engines are turbocharged. Test comparisons of diesel and gasoline engines of equal horsepower indicate that diesels have an 11 to 25 percent advantage (*17*). Because diesel fuel contains about 11 percent more energy per unit volume than does gasoline, diesel car engines of equal horsepower are 0 to 14 percent more energy efficient. But, because diesel cars tend to have similar displacement not similar horsepower engines, a consumer perceives an overstated fuel efficiency benefit for diesel engines. On the basis of the Environmental Protection Agency's city and highway mileage estimates, the perceived energy efficiency advantage of diesel cars relative to their gasoline counterparts, not correcting for differences in horsepower, was 10 to 50 percent.

A critical factor in the demise of diesel cars was the relative increase in diesel fuel prices. As the data in Table 2 indicate, the per gallon price of diesel fuel was less than that of unleaded regular gasoline until 1982. However, diesel car owners could still achieve lower per mile fuel costs even after 1982 because of the fuel efficiency advantage of diesel engines. As will be demonstrated later, consumers did not necessarily recognize these per mile fuel cost benefits.

TABLE 1 LIGHT-DUTY VEHICLE SALES IN CALIFORNIA AND THE UNITED STATES, 1977 TO 1985

	California			United States (*13*)		
Year	Total Vehicle Sales (*14*) (×1000)	Diesel Vehicle Sales[a] (×1000)	Diesels as Percentage of Total New Vehicle Sales	Total Vehicle Sales (*14*) (×1000)	Diesel Vehicle Sales[a] (×1000)	Diesels as Percentage of Total New Vehicle Sales
1977	1,083	9.0	1	11,183	37.5	0.4
1978	1,134	20.5	2	11,314	114.9	1.1
1979	1,094	33.1	3	10,673	271.0	2.6
1980	708	44.4	6	8,979	387.0	4.3
1981	692	60.0	9	8,536	520.8	6.1
1982	646	48.0	7	7,982	354.7	4.4
1983	780	34.4	4	9,182	191.7	2.1
1984	880	18.0	2	10,391	150.5	1.5
1985	1,041	15.1	1	11,042	91.1	0.8

NOTE: All figures in this table refer only to automotive and light-duty truck sales.

[a]From personal communications with A. Schuman, Mercedes-Benz of North America, Montvale, N.J., Feb. 10, 1987, and E. Folz, Volkswagen of North America, Detroit, Mich., Feb. 11, 1987.

TABLE 2 AVERAGE RETAIL PRICES FOR UNLEADED REGULAR GASOLINE AND DIESEL FUELS IN CALIFORNIA, 1977 TO 1985

Year	Unleaded Regular	Diesel	Difference Between Unleaded Regular and Diesel
1977	64.7	59	5.7
1978	65.3	59	6.3
1979	89.6	84	5.6
1980	122.8	116	6.8
1981	134.6	131	3.6
1982	124.6	129	−4.4
1983	116.0	117	−1.0
1984	112.9	117	−4.1
1985	111.5	120	−8.5

NOTE: Prices for unleaded regular gasoline are averages for the San Francisco and Los Angeles metropolitan areas. Values are current cents per gallon.
SOURCES: Unleaded regular gasoline: 1977, *Platts Oilgram*; 1978–1985, Bureau of Labor Statistics, U.S. Department of Labor. Diesel fuel: 1977–1983, U.S. Department of Energy (*18*); 1984–1985, *Lundberg Survey*.

The other principal advantage, at least as initially perceived, was diesel engines' reputation for long engine life and less frequent and less expensive maintenance. This perceived advantage was later tarnished, as suggested previously, by widely publicized stories of problems with GM's 5.7-liter engine.

Diesel cars also had several disadvantages. The vehicle was generally more expensive to purchase, noisier, did not start as well in cold weather (which, as was stated earlier, was not generally a problem in California), had less power than a comparable gasoline car, and had visible emissions (especially during acceleration). Also, diesel fuel was available at far fewer stations than was gasoline.

One factor that cannot be characterized as either an advantage or a disadvantage is the economics of diesel car ownership. The following analysis of actual costs is presented as background for the later analysis of consumer perceptions of cost. The fuel cost savings diesel car buyers expected must be weighed against the premium charged for the diesel engine. Several specific cases are presented here.

According to data published by Oldsmobile engineers regarding the 1978 5.7-liter engine, assuming vehicles are driven 15,000 mi/year, owners of 1978 model year Olds 88s and 98s could expect to wait 47 to 54 months for their fuel cost savings to pay back the additional cost of the diesel engine (*19*).

A shortcoming of this analysis is the implicit assumption that consumers have a zero time value of money; that is, their implied discount rate for future fuel cost savings is zero. However, various analyses have demonstrated that consumers use implicit interest rates ranging from 5 to 40 percent in valuing energy savings associated with automobile purchases (*20, 21*).

An analysis of the difference between vehicle purchase price and annual fuel costs for the 1981 model year Volkswagen Rabbit and the Peugeot 505 is given in Table 3. It is assumed that the vehicles were driven 15,000 mi/year, diesel fuel was priced 3.6 cents less than gasoline, and fuel price differences remained constant. The results are presented for a range of annual percentage rates (APR). At 0 percent APR (as assumed in the Oldsmobile analysis), it would have taken 23 months for fuel cost savings to pay back the higher purchase price of the Volkswagen Rabbit, and 40 months for the Peugeot 505. As future fuel cost savings are increasingly discounted by higher implied interest rates, the payback periods increase—dramatically so in the case of the Peugeot for which annual fuel cost savings were a smaller percentage of the difference in purchase price.

TABLE 3 PAYBACK PERIODS FOR 1981 DIESEL VW RABBIT AND PEUGEOT 505

	VW Rabbit	Peugeot 505
Diesel model mpg	40	28
Gasoline model mpg	28	20
Percent difference	43	40
Difference in purchase price	$425	$1,000
Difference in fuel cost per year	−$230	−$307
Months for fuel savings to pay back purchase price difference at		
0% APR	23	40
6% APR	24	44
17% APR	27	58
30% APR	33	154

NOTE: This analysis is an extension of a similar 1986 analysis by COMSIS Corp. (*22*).
SOURCES: Mileage estimates, EPA (*23*); fuel prices, Table 1; purchase prices, COMSIS Corp. (*22*).

In still another analysis, which compared 1983 model year diesel and gasoline vehicles, it was found that although the operating cost for diesel-powered models was lower than for gasoline-powered models, neither diesel nor gasoline models offered a consistent advantage in total annual costs (*24*). In that study diesel fuel was assumed to cost 10 cents less per gallon than unleaded regular gasoline. However, as the data in Table 2 indicate, in 1983 diesel fuel cost on average 1 cent per gallon more than regular unleaded gasoline in California (and about 1 cent less nationwide). Thus, by 1983, diesel cars generally cost more to own and operate than gasoline cars.

In summary, diesel fuel prices were less than gasoline prices through 1981, and fuel costs per mile were less with diesel fuel throughout the diesel car era. However, by 1983 the full cost of owning and operating diesel cars had increased relative to gasoline cars to the extent that annualized costs were similar for both types of cars. When, if ever, diesel cars' operating cost savings would pay back the higher vehicle purchase price depended on when the diesel vehicle was purchased, relative fuel prices, the number of miles driven per year, and the make and model purchased. It will be shown, however, that diesel car owners used relative fuel prices, not strictly rational analyses of fuel and vehicle costs, as the key deciding factor in evaluating the economics of diesel cars.

HYPOTHESES EXPLAINING THE RISE AND FALL OF DIESEL CAR SALES

On the basis of an analysis of the recent history of diesel cars in the United States, two hypotheses were identified that explain the rise and fall of diesel car sales. The first is that expected per mile fuel cost savings drove the rising sales until 1981, whereas diminishing actual per mile fuel cost savings fed the decline

after 1981. The second is that dissatisfaction with early GM diesel engines damaged the image of diesel engines as reliable, low-maintenance alternatives to gasoline engines, thus undermining the market for diesel cars among not only GM diesel owners but the general car-buying public as well. These hypotheses were tested, and the relevance of fuel cost savings, engine quality, and other vehicle and fuel attributes to diesel car owners was established.

RESEARCH APPROACH

The mail survey was directed only at diesel car owners and not at gasoline car owners. Thus this is primarily a study of early adopters of a new passenger vehicle technology. The survey sample was drawn from the population of California residents who had registered a diesel automobile, van, or light-duty truck with the Department of Motor Vehicles before July 1985. A list of 3,000 names (and addresses) randomly selected from this population of light-duty diesel vehicle owners was purchased from R. L. Polk Co., Inc. A mail survey was sent in early 1986 to 980 people selected at random from this list. The questionnaire elicited information on refueling behavior, consumers' prepurchase perceptions and postpurchase experiences with their diesel vehicles, and socioeconomic and demographic characteristics of individuals and their households. The return rate of usable questionnaires was 58 percent.

The researchers tested for self-selection bias—the tendency for one type of person to be more likely to respond to the survey than another—by comparing the percentages of makes and model years of vehicles in the data set with those for the remaining (unsampled) 2,020 diesel car owners. (Make and model year data were included on the purchased list.) It was found that differences between the two samples were not statistically significant at the 5 percent level. To the extent that year of purchase and make of vehicle are correlated with other variables of interest, the researchers are reasonably certain that the survey data are representative of light-duty diesel vehicle owners in California.

To test the hypotheses about fuel prices and vehicle quality, various statistical tests were conducted and both a log-linear and a logit model of how likely a current (early 1986) diesel car owner is to buy another such vehicle were created. The log-linear model estimates the effects of the independent variables—year vehicle was purchased, make of vehicle, income, and satisfaction with fuel prices and vehicle maintenance—on the likelihood of buying another diesel vehicle of any make. The model also allows estimates of specific interactions among the independent variables to be made. For example, it is possible to estimate the three-way interaction among income, make of vehicle, and maintenance satisfaction.

The log-linear model attempts to reproduce a table of observed data. In this case there is a six-dimensional table, each dimension of which is defined by one variable. Every cell in the table is uniquely identified by specific values of the variables. For instance, one cell in the table is defined by the following characteristics: high income, vehicle purchased before 1982, GM owner, satisfied with both fuel prices and maintenance, and would buy another diesel car. The cell is filled with the number of respondents who have those characteristics. The output of the log-linear model is a set of parameters that estimates, on the basis of a limited set of all possible interactions among the variables, the expected number of respondents in any particular cell of the table. The parameters are estimated by the maximum likelihood method. The estimated log-linear model is shown in Figure 1, and the parameter estimates are presented in the Appendix.

FIGURE 1 Model of relationships among income, make of vehicle, year of purchase, and satisfaction with fuel prices and maintenance and likelihood of purchasing another diesel car.

The functional form of the model expresses the logarithm of the probability of a respondent being in any given cell as a linear sum of the parameters. For example, all other things held constant, the negative parameter for dissatisfaction with maintenance (–0.453) indicates that fewer people were dissatisfied with their maintenance experience than were satisfied. However, when maintenance satisfaction is allowed to vary with make of vehicle, the large positive parameter for dissatisfied GM owners (0.701) increases the probability that a GM owner was dissatisfied with her or his maintenance experience to the extent she or he was more likely overall to have been dissatisfied than satisfied.

Note here that satisfaction with fuel price, not fuel economy, was used as the measure of diesel car buyers' satisfaction with their fuel costs. As will be shown in the section on fuel cost savings, satisfaction with fuel prices was correlated to willingness to buy another diesel car. Satisfaction with fuel efficiency was not statistically related to willingness to buy another diesel because virtually all diesel car owners were satisfied with the fuel efficiency of their car.

RESULTS

Likeliness To Buy Another Diesel Car of Any Make

The dependent variable in the analysis was likeliness to buy another diesel car of any make. This variable served not only as a measure of diesel car owners' overall satisfaction but also as a direct measure of whether diesel car sales fostered repeat sales. If it can be shown why current (early 1986) diesel car owners would not buy another diesel car, then clues about why the diesel car market collapsed will have been found.

The results of the model estimation show that make of vehicle, satisfaction with maintenance of that vehicle, and satisfaction with current diesel fuel prices all affect the likelihood of a current diesel owner buying another diesel car. The magnitude of the effects of fuel price and maintenance satisfaction on likeliness to buy another diesel car are similar.

The parameters of the log-linear model do not directly indicate how many current diesel owners would buy another diesel car of any make. To determine the ratio of current diesel owners who would buy another to those who would not, the

logit model associated with the log-linear model was estimated. The logit model provides a summary of the effects found in the log-linear model and a measure of overall likelihood that current owners of such vehicles will buy another diesel car.

A majority of diesel car owners were not inclined to buy another. When respondents were asked to rate how likely they were to buy another diesel vehicle of any make on a scale of 0 (not at all likely) to 10 (very likely), 53.6 percent rated themselves a 5 or below. Thus, more than half the sample of current diesel vehicle owners were at least undecided about, and at most adamantly opposed to, the purchase of another diesel vehicle.

The proportion of current diesel car owners who were likely to buy another diesel car, estimated using the logit model, is given in Table 4. The data in this table indicate that GM diesel car owners (in early 1986) were much less likely to purchase another diesel car of any make than were owners of all other makes. For instance, of those owners satisfied with both fuel prices and maintenance experience, 1.67 times more GM owners were willing to buy another diesel car than were not. In contrast, for Mercedes-Benz and VW owners satisfied with fuel prices and maintenance, the ratios were 3.33 and 3.46, respectively. These relationships did not vary across income or year of vehicle purchase.

TABLE 4 EXPECTED RATIO OF CURRENT DIESEL CAR OWNERS WHO WOULD PURCHASE ANOTHER DIESEL CAR TO THOSE WHO WOULD NOT

Make	Fuel Price	Maintenance	Expected Ratio
General Motors	Dissatisfied	Dissatisfied	0.18
		Satisfied	0.61
	Satisfied	Dissatisfied	0.47
		Satisfied	1.67
Mercedes-Benz	Dissatisfied	Dissatisfied	0.37
		Satisfied	1.30
	Satisfied	Dissatisfied	0.94
		Satisfied	3.33
Volkswagen	Dissatisfied	Dissatisfied	0.38
		Satisfied	1.35
	Satisfied	Dissatisfied	0.97
		Satisfied	3.46

The purposes of presenting these model results on likelihood of buying another diesel vehicle were, first, to demonstrate that a large number of diesel car owners did not intend to purchase another diesel vehicle and, second, to motivate more specific analyses of the role of fuel price, vehicle quality, and other factors in the vehicle purchase decision.

Fuel Cost Savings and Fuel Prices

It was hypothesized that expected fuel cost savings were the principal motivation for purchasing diesel cars. Indeed, this appears to be true. It was also true that fuel price was the key indicator owners used to determine the magnitude of those savings. A corollary of the fuel cost savings hypothesis is that the year in which the diesel vehicle was purchased should affect satisfaction with current (early 1986) fuel prices. People who bought their diesel cars during or after 1982, when diesel fuel cost more per gallon than gasoline, should be less dissatisfied with current fuel prices than people who bought their diesel cars before 1982, when diesel fuel had a per gallon price advantage.

When respondents were asked to list the three most important reasons why they had chosen to purchase a diesel vehicle instead of a gasoline vehicle, half the sample listed fuel economy first and another 11.8 percent listed fuel price first as the most important reason (Table 5). A cross tabulation of make of vehicle by first reason (for buying a diesel instead of a gasoline vehicle) reveals that fuel economy was the most common response for buyers of all makes. Thus fuel economy and fuel price were the principal motivations for purchasing diesel cars.

TABLE 5 WHY CALIFORNIA DIESEL CAR OWNERS PURCHASED THEIR DIESEL CARS

First Reason		Second Reason		Third Reason	
Attribute	%	Attribute	%	Attribute	%
Fuel economy	49.8	Fuel economy	26.1	Dependability	17.8
Fuel price	11.8	Maintenance	20.7	Maintenance	17.2
Dependability	8.4	Dependability	14.5	Fuel economy	11.9
Maintenance	7.3	Fuel price	14.0	Fuel price	9.0
Purchase price	5.4	Make/model	2.8	Purchase price	7.6

NOTE: *n*, Reason 1 = 498; *n*, Reason 2 = 449; *n*, Reason 3 = 354. The percentages presented under First Reason are the percentages of the 498 people who gave a first most important reason, those under Second Reason are of the 449 people who gave a second most important reason, and so forth.

The data in Table 5 indicate that diesel car buyers expected fuel economy benefits; the data in Table 6 show that they were not disappointed. Table 6 presents a complete ranking of responses by diesel car owners about what aspects of their diesel cars they found most satisfying. Nearly 55 percent of the respondents listed fuel economy as the characteristic of their diesel vehicle with which they were most satisfied. (Driving range per tankful of fuel, which is dependent in part on fuel economy, was also among the top five most satisfying attributes.)

TABLE 6 ATTRIBUTES WITH WHICH DIESEL VEHICLE OWNERS ARE MOST SATISFIED

First Reason		Second Reason		Third Reason	
Attribute	%	Attribute	%	Attribute	%
Fuel economy	54.4	Maintenance	32.9	Dependability	16.3
Maintenance	14.1	Fuel economy	21.5	Maintenance	14.3
Dependability	9.5	Dependability	13.1	Fuel economy	13.6
Driving range	6.4	Driving range	7.6	Driving range	9.9
Comfort	2.4	Comfort	3.7	Comfort	8.8

NOTE: *n*, Reason 1 = 482; *n*, Reason 2 = 410; *n*, Reason 3 = 294. The percentages in this table are interpreted as are those in Table 5.

At the same time, however, in response to another question, a large number of diesel car owners reported that they were dissatisfied with current (early 1986) fuel prices (Table 7). This dissatisfaction with fuel prices was due mostly to the rising price of diesel fuel relative to gasoline throughout the diesel car era. Thus per mile fuel cost and per gallon fuel price played key roles in the rise and fall of diesel car sales.

TABLE 7 ATTRIBUTES WITH WHICH DIESEL VEHICLE OWNERS ARE MOST DISSATISFIED

First Reason		Second Reason		Third Reason	
Attribute	%	Attribute	%	Attribute	%
Performance	24.0	Performance	19.3	Performance	17.8
Noise	18.3	Noise	14.9	Noise	11.5
Maintenance	9.8	Smoke, emissions	8.8	Fuel availability	10.5
Fuel price	9.1	Maintenance	7.6	Maintenance	8.2
Engine, transmission	8.5	Fuel price	7.3	Fuel price	8.2

NOTE: *n*, Reason 1 = 470; *n*, Reason 2 = 409; *n*, Reason 3 = 304. The percentages in this table are interpreted as are those in Table 5.

The results of the log-linear model establish that fuel price satisfaction determined, in part, current diesel car owners' willingness to buy another diesel vehicle of any make and provide insight into the corollary between year of vehicle and fuel price satisfaction. The most important result of the log-linear model with respect to fuel price satisfaction was that owners who were more satisfied with diesel fuel prices in early 1986 were more likely to buy another diesel vehicle. Although this result may appear to be a truism, the model clearly establishes that per gallon fuel price is an important determinant—as important as satisfaction with the quality of the vehicle itself—of diesel car owners' likeliness to buy another diesel vehicle.

The modeling results also indicate that although more people were dissatisfied with current diesel fuel prices than were satisfied, only among higher-income buyers does year of vehicle purchase result in significant differences in fuel price satisfaction: early, high-income diesel owners were more dissatisfied than later, high-income buyers. High-income diesel car owners who bought their cars before 1982 may not have believed that their fuel cost savings had as yet paid back the higher vehicle purchase price. Thus these people would be sensitive to the loss of the fuel price advantage of diesel fuel. High-income owners (indeed all owners) who did not buy their diesel cars until 1982 or after must have been less sensitive to fuel price differences to have purchased a diesel in the first place. These people may have been from one of two groups: previous owners of luxury diesel automobiles who by their own experience were already convinced they could achieve maintenance and durability benefits, and were therefore less concerned with the magnitude of fuel cost savings, or first-time luxury diesel car buyers who had been convinced of the same results by the reputation of the high-priced European imports.

Vehicle Quality

The authors hypothesized that another factor in the demise of diesel cars was a generalized perception that diesel cars were of inferior quality. It was hypothesized that consumers would not distinguish between the early, trouble-plagued 5.7-liter GM engine and all others—that they would note the criticisms and reported problems of the GM engine and assume that all diesel car engines had the same inherent flaws.

As the data in Table 5 indicate, two of the reasons cited for buying a diesel instead of a gasoline car were expectations of dependability and reduced maintenance costs. The data in Table 6 would appear to indicate that the expectations of dependability and low maintenance costs were realized by many diesel owners. These two attributes were consistently rated among the three most satisfying. However, responses to the question "what attributes are you most dissatisfied with?" (Table 7) indicate that nearly 10 percent of the respondents listed maintenance as the most dissatisfying attribute of their diesel car. An additional 8.5 percent of the respondents stated that specific, acute engine, fuel system, or transmission failures were their primary source of dissatisfaction.

That some people listed maintenance as the most satisfying attribute while others listed it as the most dissatisfying indicates two quite different experiences with diesel cars. Table 8 gives the relationship between make of vehicle and satisfaction with maintenance. The data indicate that owners of Oldsmobile and other GM vehicles are more likely to be dissatisfied with their maintenance experience than are owners of Mercedes-Benz, VW, and all other diesel vehicles. GM is the only manufacturer for which the number of persons dissatisfied with their maintenance experience exceeds the number who were satisfied. The chi-square test for the relationship between make and satisfaction is highly significant.

TABLE 8 MAKE OF VEHICLE VERSUS SATISFACTION WITH MAINTENANCE

Satisfaction with Maintenance[a]	Make of Vehicle				
	Olds-mobile	Other GM	Mercedes-Benz	VW	All others
1	36	25	14	4	8
2	20	10	8	5	3
3	10	8	11	6	4
4	25	15	30	33	16
5	16	18	89	41	43

NOTE: $n = 498$; calculated chi-square = 110.4; chi-square ($df = 16$, $p = 0.01$) = 32.1.

[a]Least satisfied = 1; most satisfied = 5.

The log-linear model was used to test whether income affected the relationship between vehicle make and maintenance satisfaction. The model indicates that an interaction among income, make of vehicle, and maintenance satisfaction does exist. Although both high- and low-income GM owners were more likely to be dissatisfied with maintenance than owners of all imports, high-income GM owners were much more likely to be dissatisfied. The increased likelihood that higher-income GM owners were dissatisfied may have been due to comparisons of the maintenance records of their vehicles with those of the higher-priced imports, which had good maintenance reputations.

The model also indicates that maintenance satisfaction had a strong effect on likeliness to buy another diesel car of any make. However, the interaction between make and maintenance satisfaction makes it clear that maintenance satisfaction, and thus its effect on likeliness to buy another diesel car, were make specific. GM owners were much more likely to be dissatisfied with their maintenance experience and thus much less likely to buy another diesel. It was equally true that owners of Mercedes-Benz, VW, and other makes of diesel cars were not dissuaded by the experience of the GM diesel owners.

In conclusion, it appears that the actual and perceived problems with the GM 5.7-liter engine did not greatly influence non-GM diesel owners' perceptions of diesel vehicles.

Minor Factors in the Decline of Diesel Car Sales

Several other attributes of diesel cars played minor roles in determining owner satisfaction, and thus in explaining the rise and fall of diesel car sales. These factors are diesel fuel availability and the performance, noise, and emissions characteristics of diesel cars.

The role of fuel availability was addressed in a previous paper based on the same survey of diesel car owners (2). It was found that fuel availability was not an overwhelming concern among those consumers who actually purchased a diesel car. However, this lack of concern was due to an advantage not available to other alternative fuels: the already widespread availability of diesel fuel. As the data in Table 9 indicate,

TABLE 9 NUMBER OF RETAIL DIESEL STATIONS IN CALIFORNIA (2)

Year	Hammond's Estimate[a]	Authors' Estimate	Percentage of Retail Stations[b] (based on authors' estimate)
1976	395	1,200	9
1977	524	1,300	10
1978	697	1,440	12
1979	827	1,650	15
1980	999	2,000	19
1981	na	2,250	22
1982	1,326	2,500	24
1983	na	2,500	23
1984	na	2,500	25
1985	1,327	2,500	25

[a]Estimates from a published directory. The full reference is in the source document for this table.

[b]The total number of retail fuel outlets in California decreased from 13,066 in 1976 to 10,771 in 1980, and remained at about that level through 1985. Retail fuel outlets are defined as establishments that derive at least half of their retail sales from motor fuel sales.

during most of the diesel car era diesel fuel was available at more than 15 percent of all retail fuel outlets.

Concern about fuel availability does not appear to have diminished among later buyers of diesel cars, even though the number of retail outlets increased substantially over time. Indeed, later buyers of diesel vehicles expressed levels of concern similar to those expressed by earlier buyers. This apparent anomaly is explained by later diesel car buyers' higher expectations regarding fuel availability; real increased fuel availability, measured as number of fuel outlets, did not translate into lower levels of concern. In any case, it was concluded (2) that if 10 percent or more of fuel outlets supply the alternative fuel and if there is certainty that the alternative fuel will continue to be available, fuel availability will not be a major concern for buyers of alternative fuel vehicles.

The lower performance and higher noise levels of diesel cars relative to gasoline cars were also not critical to the fall of diesel car sales. Although performance and noise were rated as the most dissatisfying attributes of diesel cars (Table 7), these concerns had small associations with willingness to buy another diesel vehicle. Few people rated either performance or noise as important in response to a question that asked what their perceptions had been at the time they originally purchased their diesel vehicle. Only 22 percent rated performance, and only 14 percent rated noise, as 6 or higher on a scale of 0 (not important) to 10 (very important), indicating that performance and noise did not weigh heavily in most people's initial decision to buy a diesel car.

Neither do diesel emissions appear to have been a central concern of diesel car buyers. Emissions did not enter consumers' prepurchase perceptions. And though nearly 9 percent of respondents indicated that smoke and visible emissions were the second most dissatisfying attribute (Table 7), this dissatisfaction was not associated with the likelihood of buying another diesel car.

The high rating for comfort in the list of most satisfying attributes (Table 6) was an artifact of the high number of luxury vehicles in the sample; diesel cars are no more comfortable than their gasoline counterparts.

Early Adopters and Market Expansion

These insights into the behavior of diesel car owners inspire two follow-up questions: How do these individuals differ from the general car-buying public, and why didn't more people buy diesel cars? The survey of diesel car buyers, combined with information from surveys of the general car-buying public, provide insight into these questions.

First, the sample of diesel car owners is not typical of the general car-buying public. Of the sample of diesel car owners, 81.8 percent indicated that they had at least some college education, and the median total household pretax income was $55,000. For comparison, a survey of owners of light-duty (gasoline and diesel) passenger vehicles in California in 1985 found that the average car owner was less educated (64.4 percent had some college education) and less affluent (average household income was $27,960) (25). The high education and high income of diesel car owners are characteristic of innovators—people who tend to be among the first to adopt new technologies.

Furthermore, the reported motivations for purchasing a diesel car (Table 5) are quite different from the motivations of gasoline-car purchasers. A nationwide survey conducted by J. D. Powers, Inc., for their September 1984 Automotive Consumer Profile [reported by COMSIS Corp. (22)] indicates that the general population (including diesel car buyers) rated dependability and quality higher, and fuel economy and maintenance much lower, than did diesel car buyers in the sample:

Rating	*Factor*
1	Dependability
2	Quality
3	Parts availability
4	Safety
5	Manufacturer reputation
6	Purchase price
7	Maintenance
8	Fuel economy
9	Warranty
10	Acceleration
11	Resale value

For this survey n = 4,500 including 78 diesel owners. Clearly, then, diesel car buyers differed from the general car-buying public in that they were more interested in reducing fuel costs and maintenance requirements.

The greater concern about fuel efficiency among diesel car owners may be explained in part by the fact they drove more miles than did the general motoring public. Dividing the total number of miles driven since the diesel vehicle was purchased by the time the vehicle had been owned yielded an average 14,533 mi/year averaged over the life of the vehicle for the sample of diesel car owners. The average number of miles driven per year by all light-duty vehicles in California between 1977 and 1985 was 10,397 (California Department of Transportation, unpublished data). Though the data are not precisely comparable, it appears likely that diesel car owners drove their cars many more miles than did the general motoring public and for this reason were more attracted by the fuel efficiency and initial fuel price advantages of the diesel option.

In summary, diesel car owners differed from other car buyers in that they were wealthier, better educated, and more sensitive to fuel costs.

This latter attribute of diesel car owners changed over time. It would be expected that because buyers of diesel vehicles during and after 1982 faced higher relative diesel fuel prices, these later buyers would be less sensitive to fuel price than were earlier purchasers of diesel vehicles. Cross tabulations of year of vehicle purchase with importance of fuel price (in the initial vehicle purchase decision) indicate that later buyers considered fuel price less important in their vehicle purchase decision than did earlier buyers. In addition, cross tabulations of year of vehicle purchase and satisfaction with current fuel prices indicate that later diesel car buyers were less dissatisfied with current (early 1986) diesel fuel prices (though the log-linear model reveals that this difference in fuel price satisfaction is found predominantly among higher-income persons).

This phenomenon is important. Consider first that the decline in the fuel cost advantage of diesel cars was due not only to changes in relative fuel prices but also to the decreased relative efficiency of diesel versus gasoline cars. Wade and Jones cite a decline in the fuel economy advantage of diesel cars relative to other light-duty vehicles from 29 percent in 1979 to 20 percent in 1983 (*17*). Later buyers of diesel cars could not achieve fuel savings as great as earlier buyers, and the fuel savings of all owners were eroded by the rise in diesel fuel prices.

Because some later buyers of diesel vehicles did not value the diesel cars' most outstanding attribute, fuel economy, as highly as earlier buyers, and because these later buyers bought their vehicles at a time when the relative advantage of the diesel car was declining, it would appear that, just at the time diesel car sales peaked, such sales may have begun to move beyond an initial group who had placed a particularly high premium on fuel cost savings. But it is difficult to determine whether this signaled an expansion of diesel car sales beyond a particular segment of the population to the general car-buying public, or whether many of the later buyers were previous owners who were already convinced of the benefit of diesel fuels and engines by their prior ownership.

If it is hypothesized that diesel car sales were moving beyond some initial core group and into the general car-buying public, then the expectation is that later buyers were less likely to have previously owned another diesel vehicle. However, cross classifying the year in which the diesel vehicle was purchased by whether the respondent had previously owned any diesel vehicles indicates that more people who had bought their current diesel vehicle during or after 1982 had previously owned another diesel vehicle than would have been expected (under the hypothesis of no relationship between year of purchase and prior ownership). This result is at least indirect evidence that the diesel car market remained dependent on repeat sales to previous owners and was not rapidly expanding into the general populace.

This limited expansion of the diesel car market suggests that perceived and actual problems with the 5.7-liter GM diesel engine probably played a critical role. Earlier it was determined that these quality problems had a large impact on GM diesel owners, but not on owners of other diesel cars. The question remains whether the perceptions of poor quality and unreliability spread to nondiesel car owners. A 1985 survey conducted by J. D. Powers, Inc., an automotive market research company, indicates that among the general car-owning public diesel cars were perceived to be less reliable than their gasoline counterparts, and that GM diesel cars were perceived to be the least reliable of all (*22*). It would appear that the negative image of the GM 5.7-liter diesel engine had spread to the general public, and perhaps diminished sales of diesel vehicles to people who had not previously owned a (non-GM) diesel car.

CONCLUSIONS

The rise of diesel car sales was fueled by the perception that diesel cars would cost less to operate than their gasoline counterparts. The initial buyers of diesel passenger vehicles, those who bought their cars before 1982, placed a higher value on fuel efficiency than did the general car-buying public (and later buyers of diesel cars), in part because they drove more miles.

The fall of the passenger diesel vehicle was a result primarily of fuel prices and selective problems with diesel engine technology. Thus the primary perceived and actual advantages of diesel vehicles were reduced, diminishing the attractiveness of any diesel car to potential and previous owners alike. The result was a failure of the market to move beyond an initial core of buyers. Furthermore, in a market heavily dependent on repeat purchases, the refusal of a large segment of current owners to buy another diesel car of any make could only spell the continued decline in sales of light-duty diesel vehicles.

The collapse of the diesel car market indicates that gasoline car owners rightly saw little or no economic advantage to diesel cars and, because of negative publicity about diesel cars, determined that such vehicles offered no significant quality or performance advantage.

These results, based on the analysis of the perceptions and behavior of people who actually chose the diesel option,

confirm and extend the inferences, based on aggregate data, of a previous study of diesel car sales (*7*). The previous study inferred that declining relative fuel cost savings were partly responsible for the decline of diesel car sales. The present analysis at the consumer level confirms that finding, but it determines that consumers relied on relative per gallon fuel prices as the indicator of overall fuel cost savings. Also, instead of assigning hedonic values to different makes, without a discussion of the reasons for differences between makes, the authors conclude that the response of diesel car owners to the GM 5.7-liter diesel engine was the result of specific complaints about the quality of that engine.

The implications for alcohol, natural gas, electric, and other non-petroleum-fueled vehicles are clear. First, any new fuel must promise not only some significant performance advantage, such as per mile fuel savings, it must also be priced less than gasoline, in some easily understood units (e.g., cents per gasoline-equivalent gallon). Government and fuel industries will have to guarantee that the new fuel will retain its price advantage in the future. Note that diesel car sales began to collapse when per gallon diesel fuel prices began to approach gasoline prices, even though diesel cars still offered significant per mile fuel cost savings as a result of diesel fuel's greater energy content per gallon and the greater efficiency of diesel engines.

Second, a reputation for inferior quality can be devastating. Alternative fuel vehicles must be high-quality products from the moment they are introduced into the retail market. Further, manufacturers must be prepared to support those vehicles with adequate service facilities and personnel.

Third, other factors such as noise, performance, and emissions play a minor role compared with vehicle quality and price/cost factors.

Presumably there are some buyers who for various personal, environmental, or social reasons will choose nonpetroleum fuels if given the choice (i.e., electric vehicles because of emissions or methanol for performance). But that group is likely to be small, especially during the initial introductory years.

In conclusion, the initial introduction of a new vehicle technology and fuel is highly vulnerable to changing economic conditions and public perceptions. Only strong and consistent support from government and the fuels and automobile industries can assure the car-buying public that quality vehicles, service, and fuels will be available to the consumer and that alternatives will maintain their private as well as public cost advantage.

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APPENDIX: Parameter Estimates for the Log-Linear Model

FIRST ORDER TERMS

Fuel Price Satisfaction

Dissatisfied	0.565 (9.835)
Satisfied	-0.565 (-9.835)

Maintenance Satisfaction

Dissatisfied	-0.453 (-5.676)
Satisfied	0.453 (5.676)

Likely to Buy Another

No or undecided	0.043 (0.635)
Yes	-0.043 (-0.635)

SECOND ORDER TERMS

Maintenance by Income

	Dissatisfied	Satisfied
Low	0.048 (0.597)	-0.048
High	-0.048 (-0.597)	0.048

Maintenance by Make

	Dissatisfied	Satisfied
GM	0.701 (7.278)	-0.701
MB	-0.081 (-0.849)	0.081
VW	-0.619 (-4.413)	0.619

Fuel Price by Year

	Dissatisfied	Satisfied
Prior 1982	0.159 (2.770)	-0.159
1982 After	-0.159 (-2.770)	0.159

Fuel Price by Income

	Dissatisfied	Satisfied
Low	-0.034 (-0.585)	0.585
High	0.034 (0.585)	-0.585

SECOND ORDER TERMS, continued

Likely to Buy Another by Make

	No	Yes
GM	0.279 (3.464)	-0.279
MB	-0.123 (-1.752)	0.123
VW	-0.156 (-1.935)	0.156

Likely to Buy Another by Maintenance

	No	Yes
Dissatisfied	0.299 (4.905)	-0.299
Satisfied	-0.299 (-4.905)	0.299

Likely to Buy Another by Fuel Price

	No	Yes
Dissatisfied	0.250 (4.066)	-0.250
Satisfied	-0.250 (-4.066)	0.250

THIRD ORDER TERMS

Maintenance by Make by Income

	Dissatisfied	Satisfied
Low income		
GM	-0.213 (-2.211)	0.213
MB	0.111 (1.161)	-0.111
VW	0.102 (0.723)	-0.102
High income		
GM	0.213	-0.213
MB	-0.111	0.111
VW	-0.102	0.102

Fuel Price by Year by Income

	Dissatisfied	Satisfied
Low income		
Prior 1982	-0.100 (-1.748)	0.100
1982 After	0.100 (1.748)	-0.100
High income		
Prior 1982	0.100	-0.100
1982 After	-0.100	0.100

NOTE: Figures in parentheses are ratios of parameter estimates to their standard errors.