1. BACKGROUND

Introduction

This report investigates the application of Federal feebate programs to achieve increased fuel economy in the U.S. fleet of private light-duty vehicles. A feebate (the term is a combination of "fee" and "rebate") is a sliding-scale financial incentive that is added to, or subtracted from, the purchase price of a good, as a function of some attribute of that good. In theory, feebates can be applied to any good, on any attribute. In this study the application is to vehicles and fuel economy—the magnitude of the feebate applied to the purchase price of a vehicle is determined by the relative fuel economy of the vehicle. If (in the most straightforward of feebate programs) the vehicle has a higher fuel economy than average, it receives a rebate; if the fuel economy is lower than average, a fee is assessed.

Feebates can be designed to vary in different manners with fuel consumption. The most direct is a feebate that varies in direct proportion to fuel consumption. In several legislated feebate proposals, the feebate has been calculated in proportion to fuel economy (that is, miles per gallon, or mpg), which is the inverse of fuel consumption (gallons per mile, or gpm). There have been proposals, most notably from the American Council for an Energy-Efficient Economy (Geller and DeCicco, 1991; DeCicco, Geller, and Morrill, 1993), to base a feebate on a size-indexed fuel-economy rating, proportional to relative fuel consumption per cubic foot of interior volume or some other measure of vehicle size. This study examines all these feebate variants, as well as a new approach designed to evoke a larger impact without having excessive feebates for vehicles with very high or very low fuel economy. This study does not examine emissions- (for example, California DRIVE+) or safety-based proposals. Only revenue-neutral feebates are examined—in all cases, the fees collected and the rebates disbursed are equal or nearly so. No changes in net fees are analyzed.

For each feebate approach that is examined, this study provides quantitative estimates of the effects on fuel economy, fuel consumption, carbon dioxide (CO_2) emissions, and consumer surplus. The estimates of the relative effects of feebates are intended to inform policy discussions and the design of feebate programs. The report does not attempt to compare feebates with other policies, such as corporate average fuel economy (CAFE) standards or gasoline taxes, that have similar goals.

The remainder of this chapter provides the definitions and terminology necessary for an indepth discussion of feebates, a summary of previous feebate proposals, and a survey of existing literature on the subject. Chapter 2 describes the models and methodologies used in the study. Chapter 3 provides an indepth description of the baseline forecast, against which the policy scenarios are compared. Chapter 4 describes the six policy scenarios and discusses their effects relative to the baseline and to each other. Chapter 5 summarizes the findings of this study. Finally, a variety of technical details are provided in Appendices A through E, and detailed descriptions of U.S. feebate proposals to date are provided in Appendix F.

Feebate Concepts

To understand and analyze the differences among specific feebate approaches, it is useful to understand some concepts and terms that apply to feebates in general.

Changes in Sales and Product Mix

Feebate incentives encourage both the purchase and the manufacture of more fuel-efficient vehicles. Consumers respond directly to these incentives by purchasing more fuel-efficient vehicles. This is the short-run, demand-side response to feebates, having an immediate influence on the composition of total vehicle sales. The consumers are still choosing from the same set of vehicle offerings, but the fact that vehicles with high fuel economy become cheaper and gas-guzzlers become more expensive causes the composition of the fleet of new vehicles sold, or the *sales mix*, to shift in favor of greater fuel economy. This type of effect is reflected in changes in the sales-weights component of fleet average fuel economy—the fuel economy of the individual vehicles remains unchanged.

Producers are also expected to respond to the feebates by making their vehicles more fuel efficient. This is the long-run, supply-side response to feebates. If a fuel-economy technology costs less to install than the change in

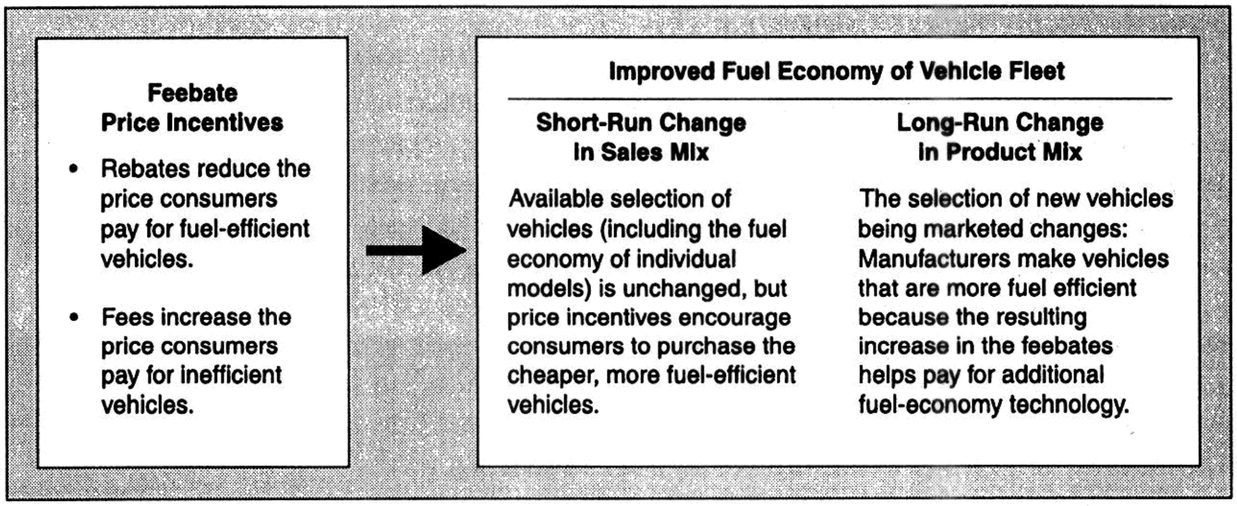

Figure 1–1. How Feebates Result in a More Fuel-Efficient Fleet of Vehicles

feebate resulting from its installation, then manufacturers can profit by installing the technology, increasing the vehicle price by more than the cost of the technology, but less than the amount of the change in feebate. The consumer still perceives a net reduction in purchase price, and the manufacturers perceive a net increase in sales price. Feebates therefore encourage the introduction of all fuel-economy technologies that earn a larger feebate increase than they cost. Manufacturers might also choose to install technologies that still increase the cost of the vehicle slightly, even with the feebate. Because the price would rise less than without the feebate, the technology may be deemed worth the now-smaller increase in price. Manufacturers will be induced to change their *product mix*, the composition of technologies in the fleet of vehicles they offer, providing a more fuel-efficient set of vehicle alternatives from which consumers can choose. This type of effect on fleet average fuel economy is reflected in changes in the fuel economy of individual vehicles.

These feebate-induced changes in product mix and sales mix both achieve the objective of improving the fuel economy of the vehicle fleet (Figure 1–1). Together, the effects are termed mix shifts or mix shifting. The sales-mix shift and product-mix shift are also referred to as the demand (consumer) response and supply (manufacturer) response, respectively.

Manufacturer Versus Consumer Feebates

Theoretically, there is no difference between a feebate that is assessed on the consumer and one that is assessed on the manufacturer. If product-mix shifts are deemed more important, and if there is any doubt about whether the incidence of the feebate would be shifted backwards from the consumer, then it may seem sensible to provide the manufacturers the incentive directly to better elicit these product-mix shifts. In theory, however, the share of the feebate incident on the manufacturers is independent of whether it is directly assessed on them or on the consumers. Furthermore, the incentive to shift the product mix is independent of this share, and depends only on the size of the total feebate. The incidence of a tax or a subsidy (a fee or a rebate) depends only on the relative elasticities of supply and demand of the good that is taxed. The formula for the share of the feebate incident on the manufacturers is:

$$s_m = \frac{\varepsilon_D}{\varepsilon_S - \varepsilon_D}$$

where the ε_S and ε_D are the price elasticities of supply and demand. Similarly, the share of the feebate incident on the consumer is:

$$s_c = \frac{\varepsilon_D}{\varepsilon_S - \varepsilon_D}$$

The tax (fee) drives the same wedge between the price paid by the consumer and the price received by the supplier no matter on whom it is imposed. The subsidy (rebate) case is analogous. Because the effective price outcome is the same, the effect of feebates on sales-mix shifting is the same whether the feebates are assessed on the manufacturer or on the consumers (Nicholson, 1989).

The effect on product-mix shifting is also unaffected by the choice of how to assess the feebates. The installation of a fuel-economy technology will occur as long as the change in feebate provided by the technology exceeds its cost. In this case, the producer can always raise prices enough to cover costs without losing market share, because the higher feebate will always allow a net decrease in the price facing the consumer. Automakers' pricing practices are, however, more complex than a simple cost-plus rule. Insofar as the net sum of feebates on a large manufacturer will usually be smaller than the sum of the magnitudes of the individual feebates, manufacturers may adjust their fleet prices as a whole in response to the net feebates, which could reduce the feebates incident on the consumers. The incentive to introduce new fuel-economy technologies, however, is unaffected. For these reasons, the sales- and product-mix shifts are, in the long run, forecast to be the same for both consumer and manufacturer incentives, and no further distinction between them is made in this report.

Feebate Schedule

The *feebate schedule* is simply an enumeration of the fees and rebates over the range of possible fuel consumption. It provides the prospective sales tax adjustment in dollars for all vehicles. The feebate schedule can be plotted with dollars on the vertical axis and fuel consumption (or fuel economy) on the horizontal axis. The feebate schedules applied in this analysis are provided in parametric form, in the feebate formula, and therefore can be graphed as a continuous curve. Figure 1–2 shows the curves for two of the feebate scenarios examined in this study.

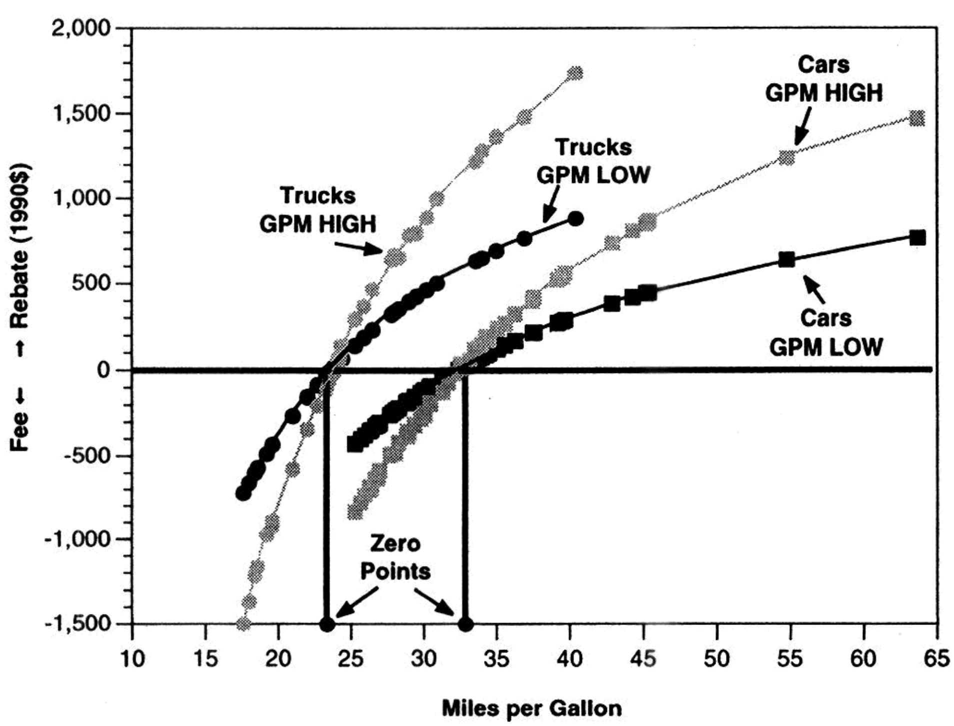

Figure 1–2. Example of Feebate Schedule

Feebate Rates

The *nominal feebate rate* is the dollar value assigned to some measure of change in fuel economy or fuel consumption. The nominal feebate rate is the multiplier that appears in the feebate formula (provided in Chapter 4). It is less important than, and named primarily to clearly distinguish it from, the *effective feebate rate*, which is the change in the feebate given a change in fuel consumption. The effective feebate rate is the slope of the feebate schedule. It determines the dollar amount that the introduction of a fuel-economy technology will capture. It is, therefore, the quantity that most closely determines whether a fuel-economy technology becomes cost-effective with the introduction of a feebate. It is the quantity that determines the net incentive to the vehicle purchaser for switching to a more fuel-efficient vehicle. It is also the quantity that determines the net incentive to the manufacturer for introducing a fuel-economy technology. In short, the effective feebate rate is the quantity that most directly influences consumer and manufacturer response.

Zero Point, Revenue Neutrality, and Leverage

The *zero point* is the fuel consumption, fuel consumption per unit of size, or fuel-economy rating at which the feebate is set to equal zero—that is, the point at which no fee is levied and no rebate is provided. A feebate is *revenue-neutral* if the zero point is set such that the fees collected exactly equal the rebates paid out, resulting in no net taxes. For a simple consumption-based feebate, the zero point is set to the sales-weighted fleet average for revenue neutrality. Other feebates require more complicated rules for determining the revenue-neutral zero point.

The *leverage* of a feebate is the sales-weighted average absolute value of all feebates actually applied. (For example, the absolute value of a $100 fee is the same as that of a $100 rebate, and the average of their absolute values is $100.) A simple average is inappropriate for a revenue-neutral feebate, because the fees and rebates are intended to cancel each other out, summing to zero. Using the absolute value of the feebate to determine this summary measure is therefore necessary.

Feebate Proposals

Feebates have been proposed in a variety of legislative bodies. In Maryland, a State feebate program has been enacted, though it is currently facing a legal challenge on the grounds that it is preempted by Federal CAFE legislation. California was the first State to propose feebates, with its DRIVE+ bill. Massachusetts, Maine, and Arizona also have or have had feebate legislation before their lawmakers. At the Federal level, there have been four feebate bills, two in the House of Representatives and two in the Senate. These bills are summarized in Table 1–1.

Table 1–1. Summary of Legislative Proposals for Automobile Feebates

	Revenue-Neutral?	Only New or All Vehicles Affected?	Across or Within Size Classes?	Consumer Incentive Type[a]	Vehicle Attributes Included[b]	Window Sticker?
State Policies						
California SB 378	Yes	New	Across	C	TCO_2/UE	Yes
Maryland SB 3	No	All	Across	ST	MPG	No
Massachusetts HB 2086	Yes	All	Within	ST	MPG	Yes
Maine HB 1709	No	New	Within	ST	MPG	Yes
Arizona HB 2425	Yes	New	Within	C	MPG/UE	Yes
Federal Policies						
Scheuer HR 1583	Yes	New	Within	C	TCO_2/VS	Yes
Gore S 201	No	New	Within	IT	MPG	No
Wirth S 741	Yes	New	Across	C	TCO_2/S	Yes
Synar HR 2960	Yes	New	Across	C	LCO_2/AF, VS	Yes

Source: Union of Concerned Scientists, Berkeley Office.

[a]Consumer incentives include: C—cash; ST—sales tax adjustments; IT—investment tax credits.
[b]Vehicle attributes include: TCO_2—tailpipe carbon dioxide emissions; UE—urban tailpipe emissions (from certification test procedures) of hydrocarbons, oxides of nitrogen, carbon monoxide (and, in some cases, particulates); MPG—fuel economy; S—vehicle safety index; LCO_2—life-cycle (fuel production, transmission, and combustion) carbon dioxide emissions; AF—use of alternative fuels; VS—vehicle size.

Several important design elements are summarized in Table 1–1. More than half the feebates proposed have been revenue-neutral. The remaining are intended to be sources of revenue for the State or Federal governments. (Again, this study only examines revenue-neutral feebate programs.) Several of the feebate proposals apply to used, as well as new, vehicle transactions. This study examines only new-vehicle feebates. Finally, several feebate proposals determine the feebates by comparing vehicles only with others in the same size class. This study compares all cars with all other cars, and all light-duty trucks with all other light-duty trucks. (All references to trucks in this report are to private light-duty trucks.)

The manner in which the consumer incentive is implemented is also shown in the table. Tax credits tend to benefit consumers at a reduced rate, and they also benefit higher income households (with higher tax rates) more.

Feebates can apply to a variety of vehicle attributes. As the table indicates, proposals thus far have included feebates based on pollutant emissions, incentives for alternative-fuel vehicles, and life-cycle costing, as well as fuel consumption (or carbon dioxide emissions), fuel efficiency, or fuel consumption per unit of size. Finally, feebate legislation often explicitly includes a labeling requirement.

Details of each of these feebate proposals can be found in Appendix F.

Previous Research on Feebate Impacts

Most of the existing literature on feebates to improve fleet average fuel economy makes little headway in actually estimating the effects of feebates on fuel consumption. Two studies (described below) identify target levels for (sales-weighted) fleet average fuel economy and then make an attempt to estimate the necessary feebates to achieve these targets. Another estimates the costs of using price adjustments to achieve such target levels. Other studies (also described below) use price elasticities to estimate the demand response to different feebate proposals, a relatively rough approach. None of the studies survey different feebate proposals and estimate their relative effects. Only one makes any attempt to quantify the long-run manufacturer response to feebates. This section reviews these studies and summarizes the current state of empirical knowledge of the estimated effects of feebates.

The original feebate proposal (called DRIVE+) was developed at Lawrence Berkeley Laboratory by Gordon and Levenson (1989). These authors applied a simple sales-mix model, using price and sales data, along with price elasticities of demand, to estimate the demand response to fuel-efficiency and emissions feebates. They do not report estimated fuel savings or emissions reductions due to DRIVE+. The authors also published a shorter, more qualitative piece describing this work (Levenson and Gordon, 1990).

Gordon and Levenson find fuel-economy improvements (and emissions reductions) of a few percent are possible because of the demand response to feebates. The most uncertain aspect of Gordon and Levenson's sales-mix model is their use of elasticities. Price changes are calculated from national emissions and fuel-economy data, and the demand response is determined by applying one of six price elasticities of demand estimated in the late 1970s. To use this methodology to accurately estimate marketwide effects, a more extensive cross-price elasticity matrix should be applied—own-price elasticities are intended to apply to a single good, while the prices of all other substitutes and complements are held constant. This method still provides a useful first cut at estimating the magnitude of the demand response to a feebate. The authors, however, undertake no examination of the supply response. There is no attempt to account for the increased rate of penetration of fuel-economy and emissions-reduction technologies into the vehicle fleet, so projected changes in fleet average fuel economy and emissions cannot be forecast.

Davis (1991) applies much of the same methodology in an analysis of the California DRIVE+ proposal. This study uses California emissions data, and although it devotes more attention to the estimation of the demand response to feebates, including sensitivity analysis, the sales-mix model is still subject to the same criticism regarding the elasticity estimates. Davis' study finds that the sales-mix effects of the proposed California feebates improve new-vehicle fleet average fuel economy a few percent.

Greene (1991) provides a thorough empirical treatment of the demand response to pricing policies to improve average fuel economy. Although he does not examine a feebate *per se*, his analysis is relevant to feebates. He applies a logit model, the same general specification used in this analysis, to calculate the effects of the price changes on consumer surplus. The pricing policies he examines are designed to be efficient and to hold the net effect on consumer surplus to zero, placing the entire burden of the price changes on the manufacturer. While the resulting price changes are not precisely proportional to differences in fuel consumption, they do provide estimates of the magnitude of the price changes necessary to achieve 1-, 2-, and 3-mpg improvements in fleet average fuel economy in the 1986 vehicle fleet. Greene finds that there is limited latitude for sales-mix shifting to achieve large average fuel-economy gains in the short run because of the fairly narrow distribution of fuel economies of individual vehicles in the 1986 vehicle fleet. While small (1- to 2-mpg) improvements in fleet average fuel economy are relatively easy to achieve using price incentives (with a leverage of $150 to $300 per vehicle), larger gains become increasingly difficult. Greene finds that a 4-mpg gain would require an incentive that averages close to $1,500. The majority of vehicles sold are within a fairly narrow range of fuel economies; thus, even if the sales weights are shifted radically, the fuel economy to which they are shifted would not be high enough to make a large difference in the fleet average. Greene concludes that manufacturers can use price incentives to eke out compliance with CAFE limits without imposing undue burdens only if small changes in average fuel economy are required. For gains of more than 0.2 mpg, it would be cheaper for manufacturers to incorporate engineering and design changes into their vehicles, or simply to pay the CAFE fine of $5 per vehicle per 0.1 mpg.

DRI/McGraw-Hill undertook a study for the Environmental Protection Agency's (EPA) Office of Policy, Planning, and Evaluation (DRI/McGraw-Hill, 1991), comparing feebates with a gas tax and an oil import fee as alternative means to achieve CO_2 emissions-reduction targets in vehicles (equivalent to fuel-consumption-reduction targets). DRI's approach was to take fleet fuel-consumption targets (constant and 20 percent reduction) and impose feebates high enough to achieve them. Because all vehicles are grouped into only seven classes (only cars are examined, to the exclusion of light trucks, minivans, and other private passenger vehicles), only interclass mix shifting results in improvements in fleet average fuel economy. Demand response is very roughly modeled by assuming that consumer budgets for vehicle purchases are fixed and that "to the extent that drivers spend more [because of feebates] . . . [they will] spend less at the time of purchase, ending up with a less expensive, smaller, and more fuel efficient vehicle." This implies that a more fuel-efficient vehicle is necessarily smaller and less expensive. Consumers in the DRI study do not substitute any other expenditures for those for cars when car prices change. DRI believes that this highly approximate characterization of consumer choice does not introduce a large error in results because the sales-mix response accounts for only a small portion (4 to 18 percent by their estimates) of fleet average fuel-economy improvements. Product-mix shifts are judged to be much more important in determining the fuel efficiency of the auto fleet.

DRI's modeling of the product-mix response to feebates is based on cost curves for fuel-economy technologies provided by Energy and Environmental Analysis (EEA). It is assumed that all fuel-economy technologies that cost less than the increase in feebate that they capture are introduced. This is essentially the same methodology applied in this Department of Energy study, although the DRI study applies the method in a more simplified manner.

The DRI study finds that, for fleetwide fuel efficiency to continue to increase over time (to meet constant fuel-consumption targets in the face of growth in travel demand), it is necessary to continue to increase the feebates. The feebate schedules developed by DRI have increasing effective feebate rates. The change in feebate that an improvement in fuel consumption captures increases both as fuel economy increases and over time. (The resulting feebate lies somewhere between the GPM and MPG feebate scenarios examined in this analysis.) DRI finds that a feebate with an average effective feebate rate of about $100,000 per gpm (between 30 and 50 mpg) is necessary to stabilize greenhouse gas emissions (the zero point is 43 mpg in the year 2000, and a 30-mpg vehicle pays a fee of about $1,000). For a 20-percent reduction in emissions, a feebate of about $350,000 per gpm is necessary (the zero point is 47 mpg, and a 30-mpg vehicle pays a fee of $5,000). DRI has 20 percent of the increase in fuel economy relative to the baseline to be captured by sales-mix shifts in the emissions-stabilization scenario. In the 20-percent emissions-reduction case, sales-mix shifting is assigned to account for 35 percent of the reduction. While it is unclear how DRI determined that such a large component of emissions reduction would come from sales-mix shifting, the study does illustrate the radical changes in the vehicle-size mix necessary to achieve this much fuel savings. In the 20-percent reduction case, the class of Large vehicles is entirely eliminated, and Mini and Subcompact vehicles make up 50 percent of the vehicle fleet.

Charles River Associates (CRA, 1991) examines feebates briefly, in a larger analysis of whether a gas tax or an increase in CAFE standards is a more efficient means of achieving a large increase (to almost 40 mpg for new-car CAFE by 2001) in fleet average fuel economy. The CRA report estimates the magnitude of the feebate necessary (in dollars per mpg) to achieve a target level of fuel economy from two different baselines. The high (DOE) baseline is most comparable with the baseline used in this Department of Energy report. For this baseline, CRA estimates that a nominal mpg feebate rate of $20 to $50 per mpg is necessary to achieve improvements in new-car CAFE of 4 to 20 percent. The findings of this report are within the range estimated by CRA (see the section on fuel-economy feebates in Chapter 4).

The cost (in terms of lost consumer surplus) of sales-mix shifts has been estimated by Greene and others (Greene, 1989; Difiglio, Duleep, and Greene, 1990). These studies, however, do not seek to estimate the effects of different feebate schedules; rather, they analyze the compensation necessary to maintain consumer utility given the requirement of changing the structure of the vehicle fleet to improve fuel efficiency.

DeCicco, Geller, and Morrill (DeCicco, Geller, and Morrill, 1993) recently completed a survey report that describes different feebate design elements in detail. The authors advocate a size-based feebate as a means of mitigating the distributional disparities between foreign and domestic vehicles of the consumption-based feebate, and they provide extensive discussion of this type of scheme. This paper is primarily a background resource; it does not make any attempt to quantify the impacts of feebate programs.

In summary, the previous research on feebates has yet to provide a comprehensive empirical examination of the program impacts on both the supply and demand sides of the vehicle market. Several studies provide useful background, and several others provide applicable methodology. There remains, however, a need for forecasts of the effects of different types of feebate programs that successfully integrate the supply and demand sides of the private vehicle market and that provide quantitative estimates of improvements in vehicle fuel economy. This study is intended to fill that need.

2. METHODOLOGY

Feebate Scenarios

To explore the ramifications of different feebate designs, this study examines six feebate scenarios:

- GPM LOW is a consumption-based feebate. The purchase-price incentive varies in direct proportion to the vehicle's fuel consumption, which is measured in gallons per mile (gpm). This feebate applies a different zero point to cars and to trucks.
- GPM HIGH is the same as GPM LOW, except the feebate rate is set twice as high.
- ONE ZERO POINT is also a consumption-based feebate, with cars and trucks pooled together for the calculation of the feebate. It calculates the feebates around the sales-weighted average of the entire fleet. ONE ZERO POINT is designed to provide an incentive for increased fuel economy comparable to GPM LOW and is intended to isolate the effects of assigning feebates to cars and trucks separately.
- MPG LOW is an efficiency-based feebate. In this scheme feebates are proportional to fuel economy, which is measured in miles per gallon (mpg), the inverse of fuel consumption.
- NONLINEAR LOW varies the effective feebate rate over the range of possible fuel economies, increasing the rate in the range that most vehicles fall in, and decreasing it in the extremes. This approach to feebate design has the effect of encouraging more mix shifting in the range where it will affect the most vehicles. NONLINEAR LOW is designed to provide an average feebate rate that is similar to GPM HIGH, but a range of feebates that is close to GPM LOW.
- SIZE-BASED applies feebates in proportion to fuel consumption per unit of interior volume. This size-indexing has been proposed as a means of mitigating the adverse distributional impacts of consumption-based feebates on domestic manufacturers. This scenario is designed to be comparable with GPM LOW.

Together, these six scenarios provide a comprehensive examination of many possible variations of feebate programs intended to encourage vehicle fuel economy. To determine the effects of these six different feebate programs, each of these scenarios is compared to a reference forecast that assumes no policy changes. This business-as-usual scenario, called BASELINE, is described in Chapter 3, and the six feebate scenarios are described and analyzed in detail in Chapter 4.

Integrated Supply and Demand Model

To forecast the characteristics of the U.S. vehicle fleet under the different feebate scenarios, this study uses an integrated supply and demand model called the Automobile Use, Technologies, and Ownership (AUTO) model. As can be seen in Figure 2–1, AUTO combines data on individual households with data on vehicles and fuel prices to forecast vehicle characteristics,

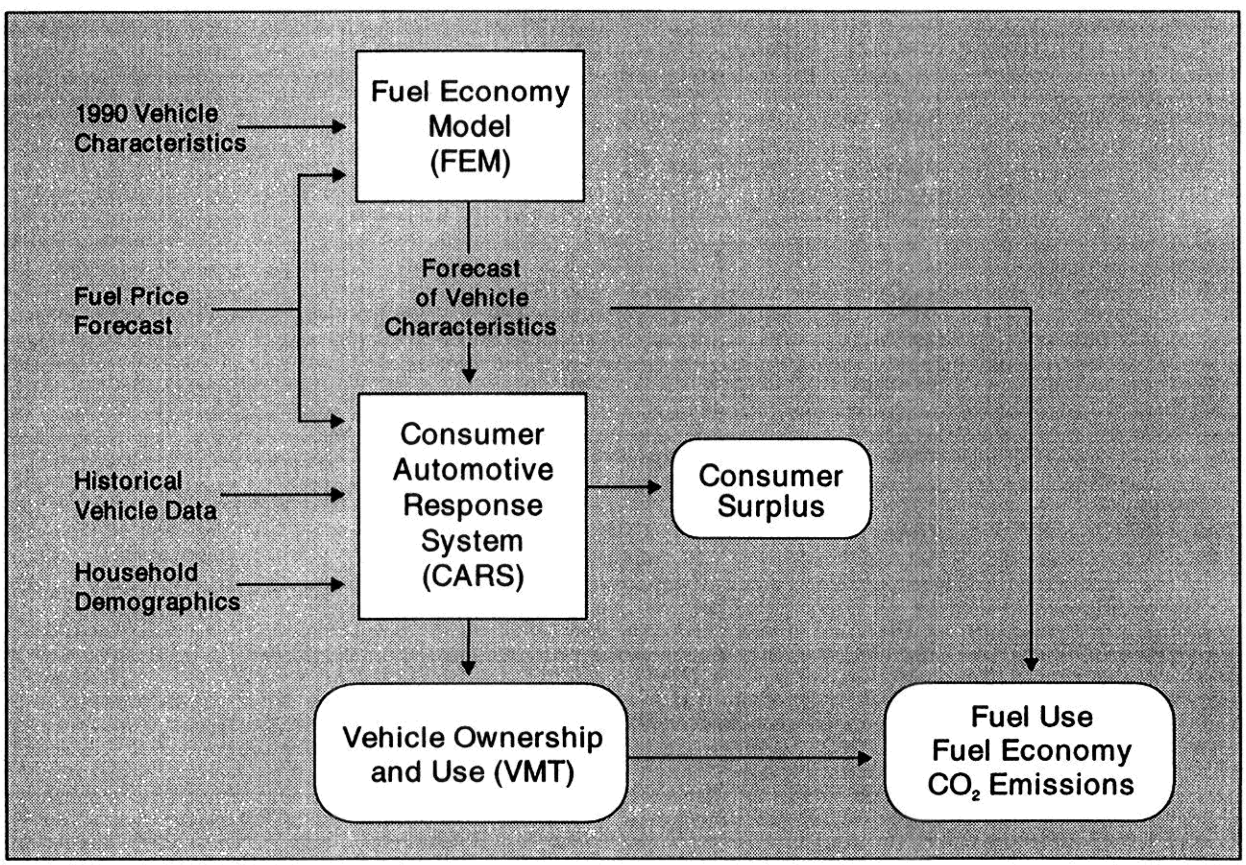

Figure 2–1. Overview of the Automobile Use, Technologies, and Ownership Model

ownership, and use—and thus fuel consumption, fuel economy, and carbon dioxide (CO_2) emissions—of the entire vehicle stock. AUTO can forecast these quantities at a very disaggregate level, by household, and by vehicle subclass and vintage.

As the figure also shows, AUTO consists of two main components: the Fuel Economy Model (FEM) and the Consumer Automotive Response System (CARS). FEM, a supply model, forecasts how manufacturers respond to changing economic conditions by changing the fuel-economy characteristics of their vehicle offerings (the product mix). CARS, a demand model, in turn forecasts how individual households choose which vehicles to own (the sales mix) and how much to drive them.

Vehicle Stock Class Structure

This analysis divides the stock of privately owned and operated vehicles into 95 vehicle subclasses (in 19 primary classes). Vehicle characteristics are input using this subclass structure, which is described in greater detail in Appendix C. Vehicle ownership and use are also forecast at this level of detail. This level of disaggregation was necessary for CARS to capture sales-mix shifting between subclasses. A more aggregated demand model would only capture sales-mix shifting between primary classes. Because vehicles of different size classes are poorer substitutes for one another, less sales-mix shifting would be captured. However, it was expected that feebates would encourage consumers to shift to more efficient vehicles *within* the classes they preferred; and failing to capture this sales-mix shifting (between subclasses within a single class) could significantly reduce the estimated demand response to feebates.

The 19 primary classes were developed by EEA for this and other analyses and are therefore referred to as EEA classes. The EEA classes are based on EPA size classes, with a few additional subdivisions. The correspondence of the EPA classes to the EEA classes used in this analysis is shown in Table 2–1.

When results are reported aggregated into small and large groupings, Small Cars includes classes 1–5; Large Cars, classes 6–10; Small Trucks, classes 11–16; and Large Trucks, classes 17–19.

Using EEA's nomenclature, minivans did not exist in 1990 and are therefore excluded from the forecast. This analysis thus uses 10 car and 9 light-duty-truck classes. The truck classes include vans and utility vehicles. Note that

Table 2–1. Relationship of Environmental Protection Agency Vehicle Classes to Energy and Environmental Analysis Vehicle Classes

EPA Class		EEA Class	
1	Minicompact	1	Minicompact
2	Subcompact	2	Subcompact
		8	Near Luxury
		11	Near Truck
3	Compact	4	Compact
		8	Near Luxury
		11	Near Truck
4	Midsize	5	Intermediate
		9	Midsize Wagon
5	Large	6	Large
		10	Large Wagon
6	Sports	3	Sports
7	Luxury	7	Luxury
8	Compact Pickup	12	Mini Pickup
		14	Compact Pickup
9	Standard Pickup	17	Standard Pickup
10	Compact Van	15	Compact Van
11	Standard Van	18	Standard Van
12	Compact Utility	16	Compact Utility
13	Standard Utility	19	Standard Utility
14	Mini Utility	13	Mini Utility

Note: The numbers are those assigned to the classes by EPA and EEA, respectively.

what are commonly referred to as minivans are called Compact Vans in the EEA nomenclature. EEA's minivans could also be called Subcompact Vans.

All EEA classes either correspond directly to or are proper subsets of the EPA classes, with the exception of the Near Luxury and Near Truck classes, which draw evenly from both the EPA Subcompact and Compact classes. The EEA Minicompact class may also contain some of the EPA Subcompact class in years 1979–1982.

The 19 EEA primary classes are further subdivided into subclasses by three criteria: performance (as measured by horsepower), technology, and import status. The performance criterion has three subclasses (high, low, and very low), the technology characteristic has two (high and low), and import status has two (domestic and foreign). Combined, these characteristics result in 12 (3 × 2 × 2) distinct subclasses per primary class (for example, high-performance, high-technology foreign sports car). Many subclasses are empty because no vehicles were produced in 1990 with the necessary characteristics; so, of a possible 228 subclasses, only 95 are used in the forecast. This subclass structure, as well as the criteria used to assign vehicles to different subclasses, is described in Appendix C.

With the exception of domestic-import distribution of impacts, reporting is not undertaken at the subclass level. AUTO output is first aggregated to the class level before it is charted.

Supply Side: The Fuel Economy Model

The Fuel Economy Model is an engineering economic model developed by EEA for a variety of Federal Government agencies to forecast the fuel economy of the U.S. vehicle stock (Duleep, 1992). FEM determines the cost-effectiveness of a variety of fuel-economy technologies by combining engineering calculations to determine the fuel consumption of these technologies with cost data and cost-effectiveness calculations. In this study, FEM provides a forecast of vehicle characteristics, including CAFE ratings, for each subclass and forecast year. FEM is described in greater technical detail in Appendix A, which also includes a description of all available fuel-economy technologies incorporated into FEM.

A FEM forecast starts with detailed data on average vehicle characteristics, including the penetration of fuel-economy technologies, for each of the 95 vehicle subclasses in the actual 1990 vehicle fleet. The technology characteristics are described in detail, with special attention paid to fuel economy and related vehicle characteristics (weight, horsepower, price, and the presence of various fuel-economy technologies). FEM then examines a menu of technology options—including their cost, fuel savings, availability, and interactive effects with other technologies—to determine their cost-effectiveness. Market penetration of these technologies is then calculated for each subclass as a function of their cost-effectiveness and subject to availability constraints. The output of the model is vehicle characteristics in every forecast year for each of these 95 platforms, again with special modeling attention paid to the characteristics that are affected by fuel-economy technologies: CAFE ratings, horsepower, weight, and price. This output, in turn, is used as input by CARS.

FEM uses a modified cost-effectiveness decision rule to determine if a manufacturer introduces a fuel-economy technology in a particular vehicle subclass. The process is applied to each of about 50 fuel-economy technologies for every year from 1990 to 2010. A technology is assumed to be cost-effective, and therefore introduced by the manufacturer, if its benefit/cost ratio is greater than one. The benefit of a technology is made up of two components:

- An estimated value of fuel savings (*FS*)—defined as the gasoline bill reductions resulting from the adoption of the fuel-economy technology, discounted at 8 percent per year and summed over the first 4 years of use. (Annual vehicle-miles traveled, or VMT, is provided by the Department of Energy's Motor Fuel Consumption Model; estimates of future fuel prices are based on the reference case in the Energy Information Administration's *Annual Energy Outlook 1992*.) The 8-percent, 4-year decision rule is based on empirical observation; it is equivalent to a 26-percent discount rate over the 12-year average lifetime of a vehicle, assuming constant fuel costs.
- An adder for the "consumer valuation of performance potential" (*P*)—which places a value on the technology's potential effect on acceleration. *P* is assigned to be $15 per percent improvement in fuel economy, $30 per percent for Sports and Luxury classes. This adder is significant and tends to dominate the fuel-savings component of the cost-effectiveness calculation.

To determine the degree to which a manufacturer will adopt a given fuel-economy technology that costs C, the cost-effectiveness (CE) is defined as:

$$CE = \frac{FS + P}{C} - 1$$

The degree of adoption (M) is in turn given by

$$M = M_{max}\left(\frac{1}{1 + e^{-2CE}}\right)$$

with M varying depending on *CE* between 0 and the "production constraint" (M_{max}), with a very cost-effective technology (*CE* >> 0) adopted almost to the maximum extent possible, and a technology that is just barely cost-effective adopted to $M_{max}/2$.

Once a technology is introduced, M_{max} increases depending on the actual degree of adoption in the previous 5-year period according to the schedule in Table 2–2, subject to the condition that M_{max} is never allowed to backslide—it is always at least equal to, if not more than, what it was in the previous period. This step is intended to model manufacturer retooling constraints. While the accelerated maximum penetration schedule for import vehicles is intended to reflect shorter product planning and retooling cycles of foreign manufacturers, it also could result in higher ultimate penetration of fuel-economy technologies in the import fleet, regardless of retooling lag. Were it not for the "consumer valuation of performance potential" adjustment, a fuel-economy technology would have to be very cost-effective (have a cost/benefit ratio greater than 2.1) to ever make it to the third tier of penetration in domestic vehicles.

To model the manufacturer response to a feebate program, the cost-effectiveness of a fuel-economy technology is adjusted according to the feebate rate. The incremental change in a feebate due to the introduction of a fuel-economy technology is included as a benefit in the numerator of the formula for CE and is a function of the fuel savings provided. This is reflected in the following modified equation for cost-effectiveness:

$$\mathrm{CE} = \frac{FS + P + \Delta F}{\mathrm{C}} - 1$$

Table 2–2. Manufacturer Retooling Constraints (percent)

Domestic		Import	
M	M_{max}	M	M_{max}
0–10	25	0–10	40
10–25	50	10–100	100
25–45	70		
45–100	100		

where ΔF is the change in the feebate that the fuel-economy technology captures.

The calculation of the feebate value of an incremental change in fuel economy is straightforward for all but the NONLINEAR LOW feebate scenario (see Nonlinear Feebates in Chapter 4). With nonlinear feebates, the rate of change of the feebate is very high near fleet average fuel economy. This can cause instability in the ranking of benefit/cost ratios. Two technologies (both must only induce small improvements in fuel economy in the range of instability) can each appear more cost-effective than the other depending on the order of introduction. In each case, the second technology is capturing a larger increase in the feebate because the rate of change of the feebate is increasing so quickly in this range. To avoid this technical difficulty, EEA adopted an alternative approximation to the nonlinear feebates that does not have this instability problem. (This problem is described in greater detail in the following paragraphs.) This approximation is described in Appendix A.

The manufacturer response in FEM is proportional to the effective feebate rate. Manufacturers install fuel-economy technologies only if the resultant fuel savings (the decrease in fuel use) is valued more than the additional cost of the technology minus the change in the feebate. As long as this change in the feebate, or the effective feebate rate, is constant over all ranges of fuel consumption, the manufacturer response will be the same regardless of the zero point. Because the response of FEM depends only on the effective feebate rate, incorrectly estimating the zero point in linear feebates has no effect on the calculated product-mix shift. The only consequence of incorrectly estimating the zero point is loss of the revenue neutrality of the feebate, but this can be adjusted after the fact. The mix shifting will be unaffected, because the incentive remains the same over all changes in fuel economy.

This is not the case with either the MPG LOW or NONLINEAR LOW scenarios. In modeling the manufacturer response to these feebates, it is necessary not only to know in advance the effective feebate rates, but also the zero point. For both these feebates, the size of the incentive at a given fuel economy also depends on the zero point, because the effective feebate rate is not constant. Therefore, the consequence of incorrectly estimating the zero point will be inaccurate modeling of the product-mix shift.

For illustration, consider Figure 2–2, which depicts the distribution of effective feebate rates in the NONLINEAR LOW scenario on the 1995 new-car fleet. An inaccurate forecast of the fleet average fuel economy would shift the feebate curve left or right. The largest mix shifting would be encouraged off the sales peak, resulting in lower estimated fuel-economy gains. Over the entire 20-year time horizon, this inaccuracy would be propagated and amplified in later time periods. For the MPG LOW feebate, this error feedback was expected to be negative: overestimates of the zero point will result in less mix shifting and a lower estimate of the zero point in the following period, and vice versa. Iteration of FEM was therefore undertaken only for the NONLINEAR LOW feebate scenario and proceeded as follows.

For the calculation of the feebate for the FEM runs in the nonlinear scenario, the baseline zero points in each forecast period were used as the starting estimates. The NONLINEAR LOW feebate was calculated using these zero points, and the manufacturer response determined using FEM. The vehicle-characteristics output was input into CARS, along with the NONLINEAR LOW feebate schedule. CARS was iterated as described in the previous subsection to determine the new zero points, which were in turn used to calculate a new NONLINEAR LOW feebate for input into FEM. This process was repeated until the zero points stabilized in all forecast years. This procedure

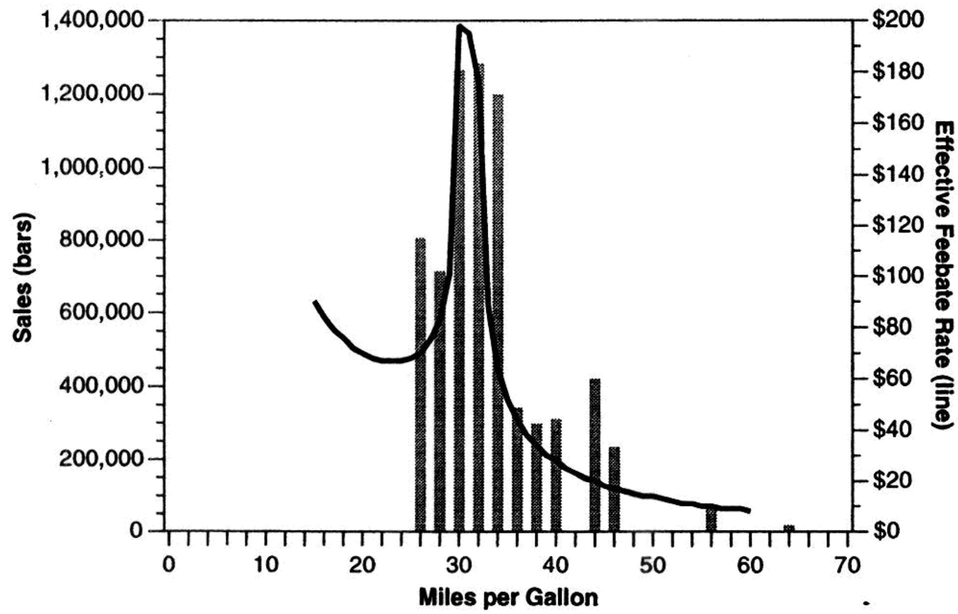

Figure 2–2. Incidence of Nonlinear Feebates, 1995

is necessary for accurate estimates of the mix-shifting response to the NONLINEAR LOW feebate.

Finally, FEM also has a subroutine to determine the extent to which manufacturers choose to increase the power of the individual vehicle platforms at the expense of fuel economy. This subroutine was used in the BASELINE scenario, but only partially in the feebates scenarios. The feebates do not introduce any additional trading of power for fuel economy—the same amount of fuel economy is traded for increased power in the feebate scenarios as in the baseline. The fuel-economy technologies added to vehicles in response to feebates are assumed to be used entirely for increased fuel economy. This is a significant shortcoming of the current implementation of this model, especially given recent trends of increasing power. It would be better to allow complete flexibility in both the decision of how much fuel-economy technology to include and the extent to which fuel economy is exchanged for additional power, or vice versa. With the introduction of feebates, for example, manufacturers might also choose to decrease the power of their vehicles so they capture a larger feebate. Such behavior is currently not captured in FEM.

Demand Side: The Consumer Automotive Response System

CARS is a nested multinomial logit or generalized extreme value model of private demand for vehicles and vehicle travel, and thus indirectly for motor fuels. CARS was developed originally by Kenneth Train (Train, 1986), later by RCG/Hagler, Bailly (RCG/Hagler, Bailly, 1991) for CO_2 emissions analysis, and finally modified at Lawrence Berkeley Laboratory (LBL) for this study's application to feebates. LBL's modifications included the disaggregation from 14 vehicle classes to 95 subclasses and recalibration to 1990 data.

CARS was originally estimated based on data from the 1978 National Personal Transportation Survey. Forecasting is based on a sample of households drawn from the Residential Transportation Energy Conservation Survey (RTECS) conducted in 1988. The model therefore applies the behavioral relations evidenced in the 1978 survey to 1988 households. Finally, the model was calibrated with 1990 data. This calibration causes CARS to exactly predict vehicle ownership and use in 1990, adjusting for constant determinants of consumer preferences not present in the 1978 data.

CARS uses behavioral equations that describe the relationships between factors that are known to influence private vehicle (cars and light trucks) ownership and use in the United States. The equations in CARS are determined from historically observed ownership and use of vehicles by U.S. households. For example, the parameters of the equation that determine how much a household is willing to pay for operating-cost reductions in the form of fuel savings have been determined through statistical techniques based upon the choices households actually made when faced with these decisions. CARS includes behavioral equations for different income groups and household sizes for the number of vehicles a household chooses to own, the subclass and vintage of these vehicles, and their usage.

CARS uses demographic variables, vehicle characteristics, and fuel prices to forecast vehicle ownership and use, disaggregated by subclass and model year of vehicle. CARS forecasts these quantities first for an actual household sample that accurately represents the demographics of U.S. households in the base year, and then for a household forecast that conforms with projected trends in income, household size, geographic distribution, and other demographic characteristics. As a demand model, CARS also calculates consumer surplus, thus providing an estimate of the welfare effects of feebates on consumers. Figure 2–3 provides an overview of the structure of the CARS model, including these inputs and outputs.

At the household level, CARS consists of a system of submodels, each of which forecasts one aspect of the household's vehicle choices. The first submodel forecasts the number (0, 1, or 2 or more) of vehicles the household chooses to own. If the household is forecast to own zero vehicles, then no further calculations are performed for this household. If the household is forecast to own at least one vehicle, then an additional pair of submodels forecasts the subclass ownership probabilities for each vehicle and vintage. The parameters that determine these choices are estimated separately for one-vehicle households and for households with two or more vehicles. The next pair of submodels then forecasts the annual VMT for each vehicle in the household.

While the expositional layout of (as well as calculation using) CARS is sequential, the characterization of actual consumer decisionmaking is not so straightforward. Not only does the decision on how much to drive depend on which vehicle or vehicles the household owns, the decision on which vehicle or vehicles to own depends on how much the household expects to drive. The

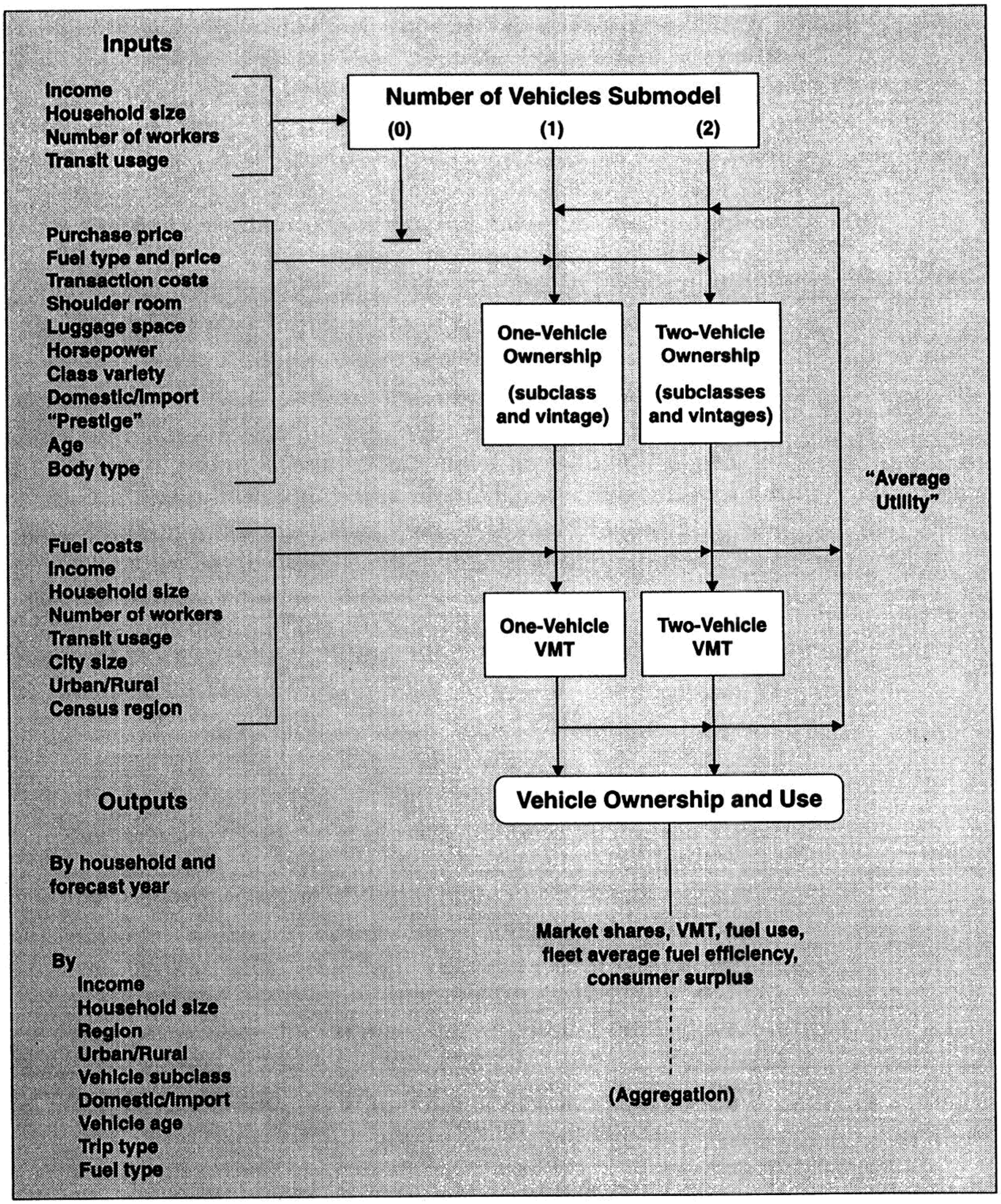

Figure 2–3. Structure of the CARS Model

estimation of the CARS coefficients recognizes this interdependency, incorporating it into the forecasting in the "average utility" term that is fed back from the VMT submodels to the subclass/vintage choice submodels, and from the four of these submodels to the number of vehicle submodels.

As shown in Figure 2–1 (and in greater detail in Figure 2–3), CARS uses three types of exogenous inputs, in addition to the forecast of vehicle characteristics provided by FEM, to determine purchase decisions:

- *Fuel Prices*. The same fuel-price forecasts used in FEM are used here—namely, the reference case in the Energy Information Administration's *Annual Energy Outlook 1992*. These are described in detail in Appendix E.
- *Historical Vehicle Data*. Historical vehicle data (aggregated into the same subclass structure as the forecast data) are needed to calculate calibration constants. The calibration constants account for independent influences (such as insurance premiums) on vehicle ownership that are not already captured in the CARS coefficients. These constants force the model to forecast ownership precisely in the base year. The vehicle characteristics required are the same for the historical and forecast data, and include purchase price, fuel type (this analysis only considers gasoline-powered vehicles), fuel efficiency, horsepower, shoulder room, luggage space, "prestige," origin (domestic or import), age, body type, and class variety. All these characteristics are included in the forecasts for this analysis, although only price, operating cost, and horsepower change in response to feebates. The compilation of the historical vehicle characteristics data, and its application to calibration, is provided in Appendix D.
- *Household Characteristics*. Household characteristics include household size, annual income, number of workers, city size, access to public transit, geographic region, and whether the household is in an urban or rural area. This household forecast is described in detail in Appendix E.

With these inputs, CARS examines the effects of changes in vehicle characteristics, fuel prices, and demographics on the characteristics and use of the vehicle stock. Because it is sensitive to price and operating-cost changes, it is useful for forecasting the response to economic policies to improve vehicle fuel economy. The disaggregate structure of the CARS model makes it especially useful for determining the distributional effects of different government actions.

To determine these effects, the model must be run at least twice: once to establish a baseline as a standard for comparison, and again to forecast a policy scenario. The differences between these forecasts are the effects attributed to the policy—the changes in fuel economy, fuel consumption, vehicle travel, fleet size and manufacturer distribution, and consumer satisfaction—relative to what was deemed likely to have occurred in the absence of government intervention.

The application of CARS to the modeling of feebates proceeds by adjusting the purchase price of the vehicle based on the feebate formula and the fuel efficiency of that vehicle. If a vehicle is more fuel efficient than the zero point, it receives a rebate and its price is adjusted downwards accordingly; vehicles that are less fuel efficient than the zero point are assessed a fee, and their price is adjusted upwards accordingly. CARS then calculates new market shares (the difference reflecting the sales mix shifts) for the vehicle market as a whole. One advantage of this type of analysis is that, unlike estimates based on elasticities, it applies well to policies that affect the entire market. The share shifts for each individual subclass take into account the changes in the vehicle characteristics of all other subclasses.

Because the response functions embodied in CARS are nonlinear, an incremental change in a feebate will evoke a different incremental demand response depending on the range in which the feebate change occurs. For example, decrease in a fee from $200 to $100 does not necessarily have the same effect as an increase in a rebate from $100 to $200. The demand response is therefore sensitive to the zero point of the feebate. The zero point, however, depends in turn on the demand response. Sales shares in part determine the fleet average fuel economy. And because of the feebates, the fuel economy of individual vehicles influences sales shares. This endogeneity necessitates iteration to determine the zero point and sales shares at which both are stable.

Revenue neutrality is achieved by adjusting the zero point. All feebates in this analysis were forecast to be revenue neutral, so iteration with the CARS model was always necessary and proceeded as follows. The zero point and the resulting feebate were first calculated using BASELINE sales shares, then the new sales shares were calculated and the zero point was adjusted to maintain revenue neutrality. CARS was then run again with feebates based on this new zero point, and new sales shares were calculated. The new sales shares again required the zero point to be adjusted. This process was repeated until the sales shares and the zero point stabilized. If iteration were not undertaken, the revenue neutrality of the forecast would be sacrificed.

Once the baseline and scenario runs are completed, the household results are aggregated. Forecasts for the United States as a whole are created by aggregating the household projections in a weighted average, using the sample proportions of each household as weights, and then multiplying the average by the number of households in the United States. This results in a forecast of the aggregate levels of ownership and use for the entire U.S. vehicle stock. The vehicle *stock* includes all vehicles on the road, new and used, which is distinct from the new vehicle *fleet* of any given year. Because CARS is a disaggregate model, with the individual household as its basic unit of analysis, aggregation can be undertaken along many lines: by subclass, for cars or trucks; by import status; by horsepower; by region; by income; or by a number of other demographic attributes. For this analysis the distribution of impacts is examined only along lines of income, to determine the equity impacts of feebates on consumers, and along lines of vehicle origin, to determine the distribution of impacts on domestic versus foreign producers.

Comparing Scenarios and Calculating Mix Shifts

The impacts of the different feebate program designs are determined by comparing the reference forecast with the six feebates scenarios, and the different feebate scenarios with each other. BASELINE represents a business as usual forecast of vehicle and household characteristics, with no policy intervention—the values that are most likely in the absence of feebate programs. In the feebate scenarios, all input variables remain unchanged except those that would be affected by a feebate: price, fuel efficiency, and power (power is initially adjusted only to account for the change in weight due to the introduction of fuel-economy technologies). The demographics and fuel prices remain the same as in the reference forecast, and the power-to-weight ratio continues to be held constant. The difference between the summary measures of interest in the reference forecast and each scenario is the effect attributed to that feebate program. Differences between different types of feebate scenarios illustrate the effects of specific feebate design elements.

Fuel-economy improvements due to different feebate scenarios are charted in terms of a percent change over the reference forecast. For new-car average fuel economy, this change is broken down into consumer and producer responses. The total effect of the feebates is the sum of these two responses. The supply, or producer, response to a feebate is calculated as the change in fleet average fuel efficiency relative to the reference forecast, had the sales weights remained unchanged, but allowing the fuel efficiency of individual subclasses to improve. The demand response is then calculated as the additional fleet fuel-efficiency improvement when the sales weights forecast by CARS are substituted for the baseline sales weights. In the long-run scenario forecasts, the consumer response depends on changes in vehicle prices as well as changes in other vehicle characteristics. The changes in the other vehicle characteristics are a supply-side effect of feebates, and the changes in the demand response are also based on these changes. In the long run, the consumer response therefore becomes a combination of both supply- and demand-side effects. The demand response for new-vehicle fuel economy in 1995 comes closest to approximating the demand-only response. In 1995, manufacturers will have not yet had much of a chance to change vehicles in response to feebates, so the demand-only response is better isolated.

3. Baseline Forecast

The baseline forecast (BASELINE) is the business-as-usual scenario, representing an estimate of future trends in the characteristics of the U.S. vehicle stock, as well as in vehicle ownership and use, given no policy intervention. It assumes that corporate average fuel economy (CAFE) standards do not increase faster than the market, and it ignores the (small) effects of the gas-guzzler tax. It is the reference forecast against which the feebate scenarios are compared.

BASELINE is generated by first running FEM with the Energy Information Administration's (EIA) 1992 fuel price projection to forecast vehicle characteristics in each year from 1990 to 2010. The vehicle characteristics and fuel price forecasts are then input into the Consumer Automotive Response System (CARS) along with projections of household demographic variables and historical vehicle data.

This chapter first provides the details of the BASELINE forecast, then the main input assumptions used to determine this forecast. The quantities forecast include fuel economy of new vehicles, fuel economy of the entire on-road stock, vehicle-miles traveled (VMT), the on-road stock's fuel consumption and carbon dioxide (CO_2) emissions, size-mix purchase and ownership shares, and consumer surplus. The input assumptions include the fuel price forecast and forecasts of a variety of household demographic characteristics. CARS can calculate all forecast quantities down to the individual household and vehicle subclass level. The results presented in this chapter are aggregated and summarized.

New-Car Fuel Economy

CARS output provides, among other things, the number of new cars purchased by subclass for each forecast year. With the subclass fuel economy ratings provided by the Fuel Economy Model (FEM), new-car and truck fuel economy can be calculated. The results of these calculations for the baseline are charted in Figure 3–1. Because of the fairly rapid introduction of vehicle fuel-economy technologies, new-car fuel economy in the baseline increases to 31.7 miles per gallon (mpg) by the year 2000 and 37.0 mpg by 2010, while the rated fleet average fuel economy for light trucks increases to 23.3 and then 25.6 mpg.

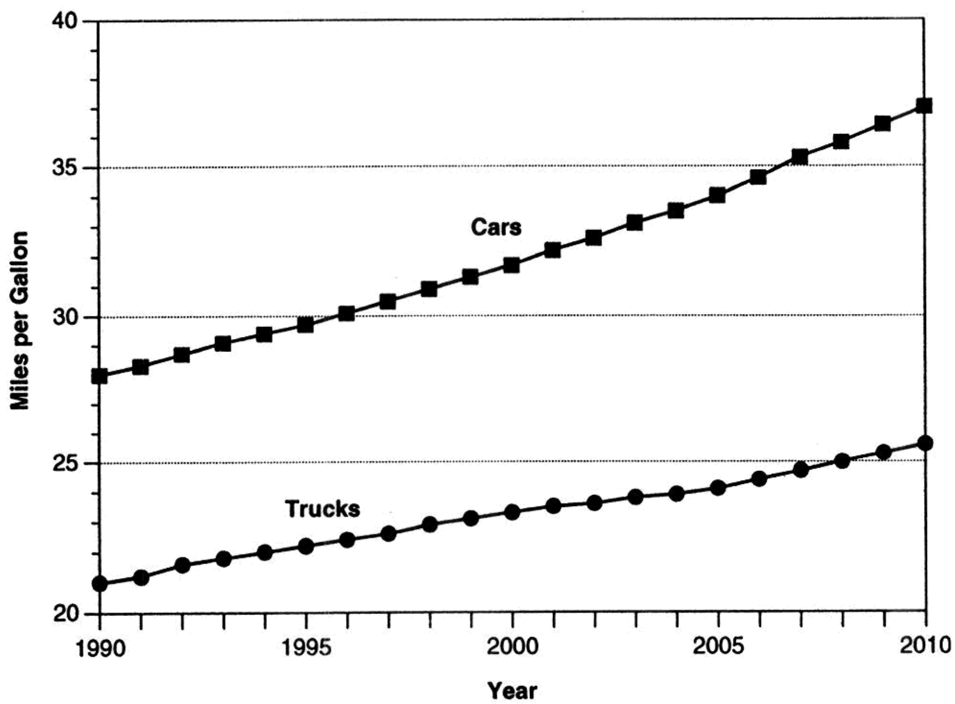

Figure 3–1. Average Fuel Economy of New Vehicles Under BASELINE Scenario

This forecast is similar to other recent forecasts, most notably that of EIA in its *Annual Energy Outlook 1992*. BASELINE shows a slightly higher fuel efficiency for new vehicles in 2010 because this scenario includes the two-stroke engine technology, which comes on line around 2005. The two-stroke technology provides large energy savings, is less expensive than competing technologies, and decreases the overall weight of the vehicle. Because this technology is so cost-effective, it quickly achieves high penetration into the new-vehicle fleet. Because it provides such high fuel savings, it has a significant immediate impact on new vehicle CAFE ratings, adding about 1 mpg by 2010, and a more moderate but still noticeable effect on on-road fuel economy.

It is important to recognize that this is a "constant power" baseline. The baseline scenario does not reflect the recent trend of increasing power in the new-vehicle fleet, which has had the effect of keeping new-vehicle fuel economy constant over the last decade. If the power of new vehicles were allowed to continue to increase, their fuel economy in the baseline would not increase as much and could even continue to remain constant. In this case, with an increasing-power baseline, the percent change in new-vehicle fuel economy due to feebates would likely be larger than with a constant-power baseline. Manufacturers, in addition to installing more fuel-economy measures, could also reduce the power of their vehicles to capture a larger feebate. In this case, feebates would cause manufacturers to increase fuel economy in two ways instead of one. Because the decision rule by which manufacturers choose to exchange fuel economy for power is not well understood, however, the constant-power assumption is retained in this analysis.

On-Road Fuel Economy

The CARS output also provides vehicle ownership by subclass and vintage in all forecast years. With fuel-economy ratings provided by FEM, the fuel economy of the entire on-road stock is calculated by adjusting the fuel-economy rating downward by 15 percent to account for the difference between the ratings and actual on-road fuel economy (Westbrook and Patterson, 1989). Although Westbrook and Patterson forecast this adjustment to increase in future years, a constant 15-percent degradation in rated fuel economy was used for this analysis.

For the years 2000 and 2010, respectively, the BASELINE on-road stock fuel economy is projected to increase to 26 and then 29.6 mpg for cars, to 19.4 and then 21.4 mpg for trucks, and to 22.6 and then 25.6 mpg for the entire stock (Figure 3–2). As will be seen later in this chapter, small trucks are forecast to play an increasing role in the fuel economy of the entire stock between 1990 and 2000. This is evident in Figure 3–2 as a more rapid increase in the fuel economy of all trucks in early years and an increasing influence of trucks in the fuel economy of all vehicles.

Size Mix of Sales and Ownership

The forecast number of new vehicles sold and owned increases as the number of households in the United States and their incomes increase (Figure 3–3). These figures are provided for the BASELINE forecast only. The effects of feebates on sales and ownership are reported for each scenario as a percent change from this baseline.

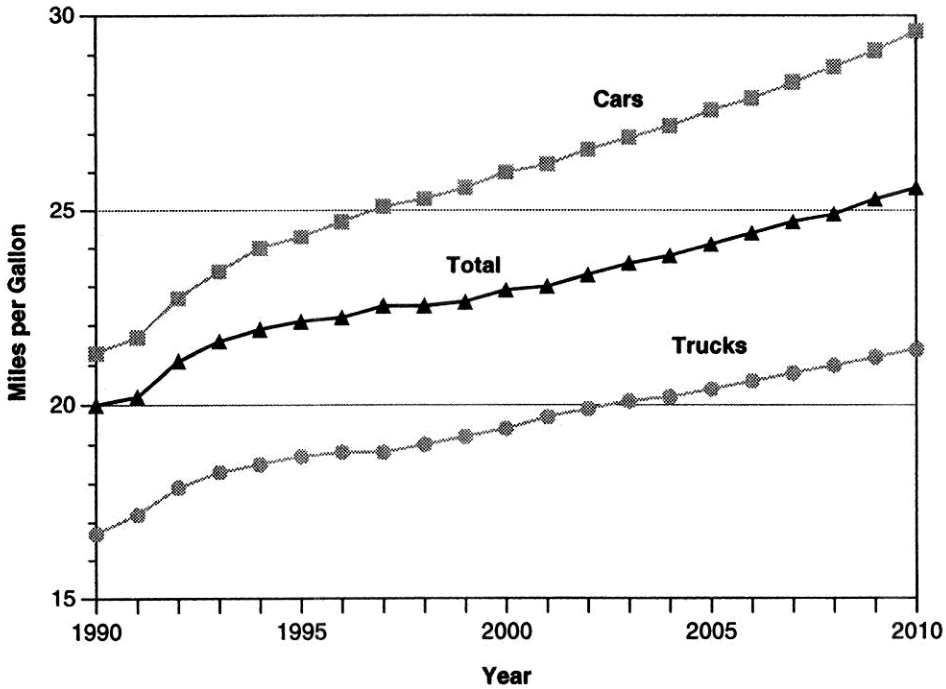

Figure 3–2. Average Fuel Economy of Entire On-Road Vehicle Stock Under BASELINE Scenario

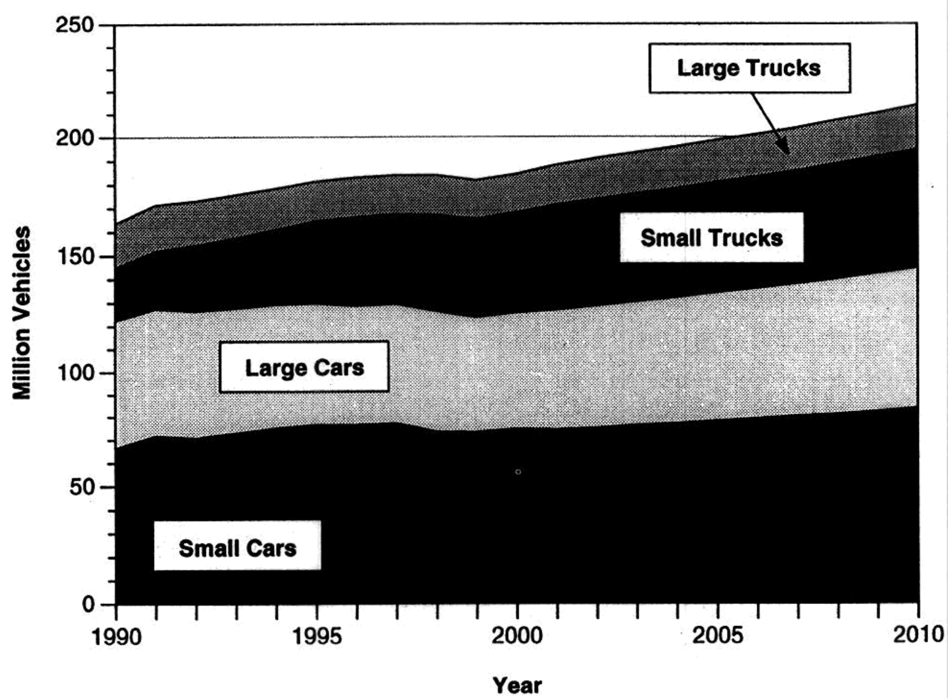

Figure 3–3. Vehicle Ownership Under BASELINE Scenario

Small Cars include the Minicompact, Subcompact, Sports, Compact, and Intermediate classes (EEA classes 1–5). Large Cars include the Large, Luxury, and Wagon classes (EEA classes 6–10). Small Trucks include the Near Pickup, Mini- and Compact Vans, Utility, and Pickup classes (EEA classes 11–16). Large Trucks include Standard Pickup, Van, and Utility classes (EEA classes 17–19). Medium-duty, heavy-duty, and commercial trucks are not considered in this analysis.

Vehicle ownership increases steadily in the BASELINE forecast over the entire forecast period, from a total of about 165 million in 1990 to 215 million in 2010. Half of this growth is due to the increase in ownership of light trucks, from 25 million to 50 million during the forecast period. Small car ownership also increases, from almost 70 million to 85 million. Large car ownership increases only slightly, and large light-duty truck ownership remains constant at about 20 million. These increases are reflected in the ownership shares charted in Figure 3–4.

Small truck holdings increase until the year 2000, after which point their ownership shares hold constant. These shares reflect the weights used in

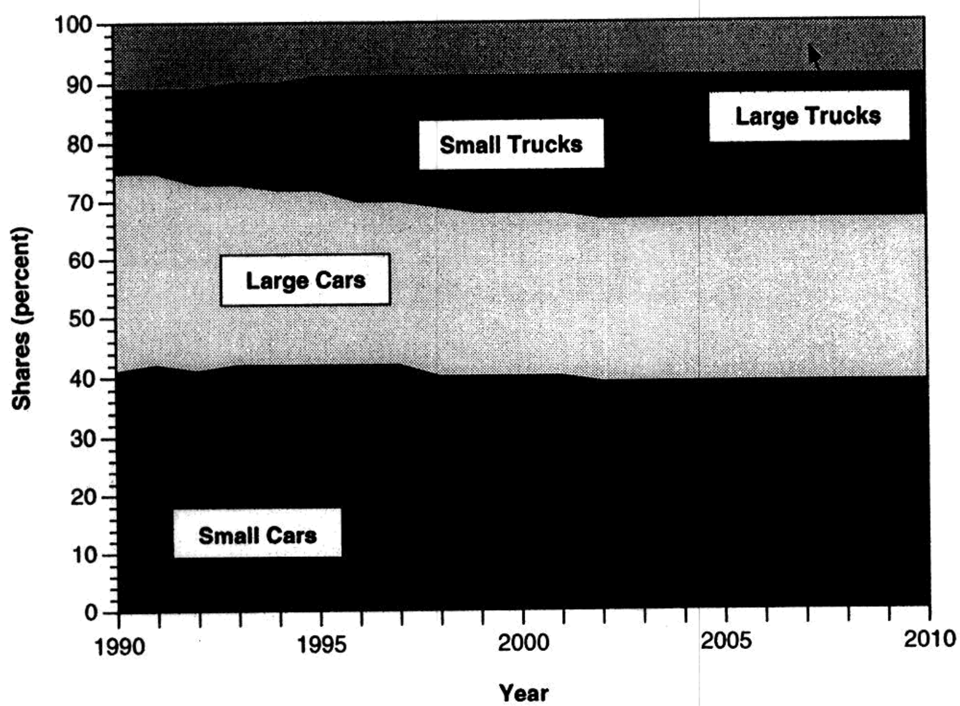

Figure 3–4. Vehicle Ownership Shares Under BASELINE Scenario

calculating average fuel economy of the vehicle stock. Truck on-road fuel economy increases slightly, increasing at a more rapid rate in the early forecast period; and the fuel economy of the entire stock is diminished as it comes to track the lower truck fuel economy more closely. Light trucks are therefore forecast to play an increasing role in determining the total fuel consumption and CO_2 emissions of the U.S. vehicle stock.

VMT, Fuel Consumption, and Carbon Dioxide Emissions

CARS also forecasts the demand for miles traveled by household, subject to the vehicle ownership decisions of the household. The forecast of household VMT is given in Figure 3–5. VMT is necessary for the calculation of fuel use by the on-road vehicle stock, as well as CO_2 emissions.

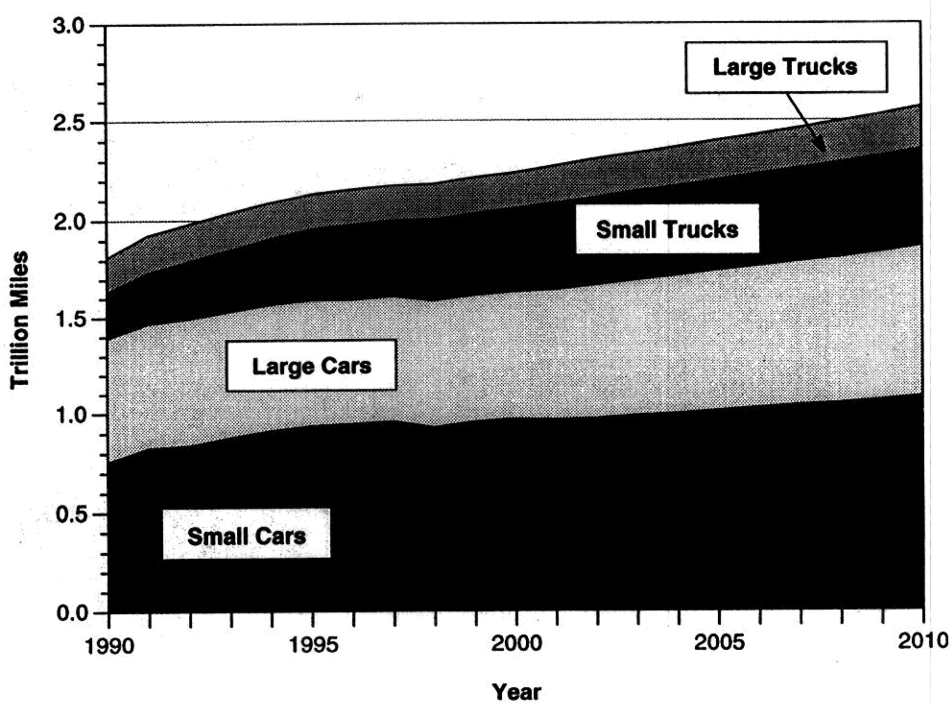

Figure 3–5. Total Vehicle-Miles Traveled Under BASELINE Scenario

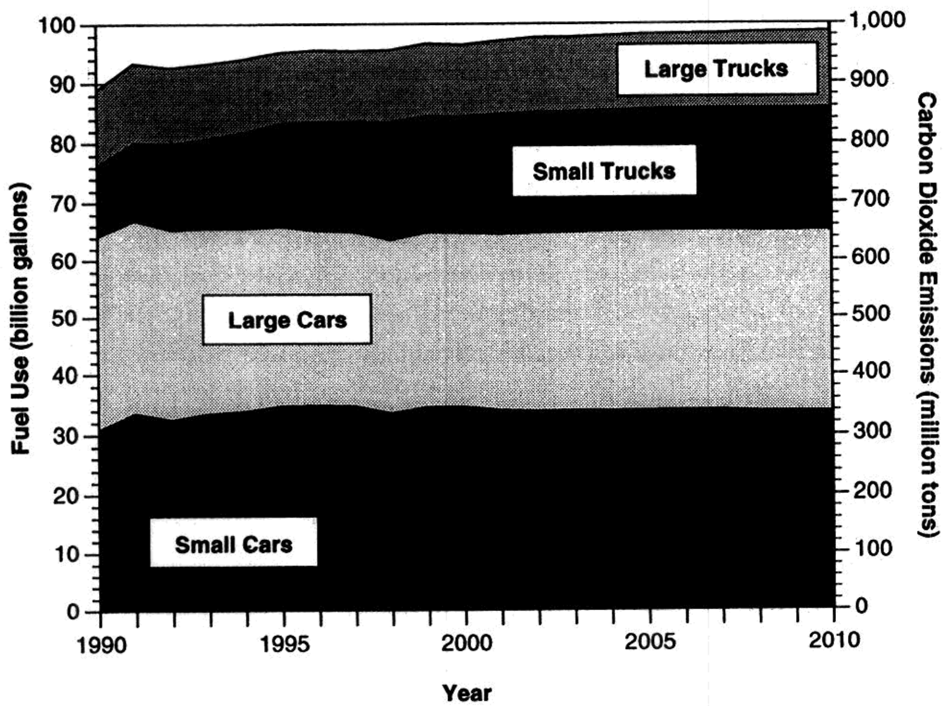

Figure 3–6. Fuel Use and Carbon Dioxide Emissions Under BASELINE Scenario

VMT is forecast to increase from 1.8 trillion miles in 1990 to 2.6 trillion miles in 2010. Again, most of the increase is due to the growth in the number of households. VMT per household increases by only 8 percent.

Despite the increase in VMT, overall fuel use and the concomitant emissions of CO_2 increase only slightly by 2010 because of the significantly improved fuel economy of the U.S. vehicle stock (Figure 3–6). The 40-percent increase in travel is for the most part compensated by an almost 30-percent increase in the fuel economy of the on-road stock.

Consumer Surplus

Consumer surplus is a measure of the satisfaction of individual households and can be expressed as a dollar amount. As calculated by CARS, consumer surplus captures the effects on consumer satisfaction of all vehicle characteristics that enter into the CARS choice and usage equations, including price, horsepower, and fuel economy. The calculation of consumer surplus therefore captures the effects on consumer satisfaction of all feebate-induced changes in vehicle characteristics. With FEM, the costs of additional fuel-economy technologies are fully incorporated into vehicle prices. Therefore, the real resource cost of these is also captured by consumer surplus. While the average cost per vehicle of additional fuel-economy technologies adopted in response to feebates is reported separately, it is also included in the calculation of consumer surplus. To add technology cost to changes in consumer surplus would be double counting. The method for calculating as well as calibrating consumer surplus is provided in Calibration of Marginal Utility in Appendix D.

Consumer surplus in the BASELINE scenario is broken down by income bracket and forecast year. Low-income households cannot afford to own as many vehicles or drive as much as middle-income households, nor can middle afford as much as high. The utility these household income groups derive from their vehicles therefore increases with income. Because richer households can afford more, they are deemed to derive more utility from their vehicles. As incomes increase and vehicles improve, consumer surplus derived from vehicle ownership and use increases slightly. Middle-income households reap the most of this increase, while the poorest third of households receive the least of this increase.

In this study, when a feebate program is compared to the baseline forecast, consumer surplus is a measure of the net benefits of the feebate program to the consumers, inclusive of all variables that enter consumer utility in the CARS model. This includes operating costs (and thus fuel bill savings) as well as increases in purchase price due to the installation of additional fuel-economy technologies. External benefits due to reductions in environmental costs, as well as decreased reliance on oil, remain unincorporated.

4. FEEBATE SCENARIOS

With the BASELINE forecast established as a reference point, the effects of introducing feebates can be examined. For the feebate scenarios, all model inputs remain the same as in the BASELINE except those that would be affected by feebates programs. As input into the Fuel Economy Model (FEM), the introduction of feebates causes the marginal benefits of installing a fuel-economy technology to increase. This results in increased fuel economy, small increases in price, and small changes in horsepower. The small horsepower adjustment depends only on the weight impacts of the fuel-economy technology—the adjustment holds the horsepower-to-weight ratio constant. These changes are input into the Consumer Automotive Response System (CARS) along with the feebate-induced price changes, and the output is compared to the BASELINE forecast.

The six feebate scenarios are examined in this manner to explore the effects of varying feebate program design. As summarized in Chapter 2, the GPM LOW and GPM HIGH scenarios are based on vehicle fuel consumption, where the feebate is applied in proportion to the relative fuel use of the vehicle, in gallons per mile (gpm). The ONE ZERO POINT scenario explores the effects of pooling cars and trucks for the determination of the fleet average, on which the feebate is based, using the GPM LOW feebate rate (all other scenarios apply separate zero points to cars and trucks). The MPG LOW scenario is based on fuel economy, where the feebate is assigned in proportion to the relative fuel economy, in miles per gallon (mpg). The NONLINEAR LOW scenario examines the impact of a feebate design that varies the effective feebate rate to achieve increased mix shifting. Finally, the SIZE-BASED feebate explores the impact of applying a feebate based on size-indexed fuel consumption.

A consumption-based (GPM) feebate is the basic feebate, the standard against which to compare all other feebates. The external costs of automotive fuel consumption provide one motivation for the imposition of feebates. A consumption-based feebate values the environmental and other nonmonetized costs of an additional unit of fuel consumption equally, regardless of the efficiency of the vehicle that consumes the fuel. The effective feebate rate is constant over all ranges of fuel economy. This constant implied valuation of the external costs of fuel consumption does not occur with any other types of feebates. With a simple units conversion (which includes a discount rate assumption), this feebate can easily be compared with a gas or carbon tax.

The efficiency-based (MPG) feebate is determined in a similar fashion, with the difference that the incentive is calculated based on fuel economy (which is the inverse of fuel consumption). This causes the effective feebate rate to increase as fuel economy increases. The nonlinear feebate increases the effective feebate rates around the fleet average, while decreasing it at the extremes. This is intended to increase the mix shifting among the majority of the vehicles on the market (half of which are within ±10 percent of fleet-average fuel economy) without increasing the range of the feebates. Finally, the size-based feebate is proportional to fuel consumption per unit of interior volume. All these other feebates, therefore, do not place a constant value on the external costs of fuel consumption.

The scenario results could be charted in a similar fashion as the reference case. However, to emphasize the comparison, the results are instead charted in relative terms, as a percent change relative to the reference case. For new-car CAFE, this change is broken down into producer and consumer responses. The total effect of the feebates is the sum of these two responses. The producer, or supply, response to a feebate is calculated as the change in fleet-average fuel economy (relative to the baseline) had the sales shares remained unchanged, but allowing the fuel economy of individual subclasses to improve. The consumer, or demand, response is then calculated as the additional fleet fuel-economy improvement when the scenario sales weights forecast by CARS are substituted for the BASELINE sales weights.

In the long-run scenario forecasts, the consumer response depends on changes in vehicle prices as well as changes in other vehicle characteristics. The changes in the other vehicle characteristics (as well as the price increases due to the introduction of additional fuel-economy technologies in vehicles) are a supply-side effect of feebates. In the long run, therefore, the consumer response becomes a combination of both supply- and demand-side effects. Although it would be possible to isolate a demand-side-only, sales-mix shift by holding the other vehicle characteristics constant and varying prices only by the amount of the feebate, this would never occur in the market and so was not modeled.

In all scenario forecasts, feebate-induced price changes begin in 1995. Manufacturers anticipate these changes in the feebate scenarios by beginning to change some of their models earlier. The consumer response in 1995 comes closest to being a pure estimate of the demand-side-only effects of a feebate. The other characteristics of vehicles have not yet had much chance to change in response to feebates, so the consumer response is due almost entirely to the change in price resulting from the imposition of the feebate. The sales-mix shifts in 1995 vary from 1 to 2 percent for the different scenarios, small compared to the product-mix shifts, which commonly exceed 10 percent in the long run.

Feebate Schedules and Rates

For each of these types of feebate programs, a nominal feebate rate must be chosen. The feebate rates used for the six feebates scenarios are as follows:

- R_l = \$50,000 per gpm for the GPM LOW and ONE ZERO POINT feebates
- R_h = \$100,000 per gpm for GPM HIGH
- R_{mpg} = \$70 per mpg for MPG LOW
- R_{nl} = \$8,000 with an exponent b = ½ for NONLINEAR LOW
- R_{sb} = about \$3,750,000 per gpm/ft^3 for SIZE-BASED

The GPM LOW feebate rates correspond to about a \$0.50-per-gallon gasoline tax, or a \$200-per-ton carbon tax. The GPM HIGH feebate is equivalent to a \$1.00-per-gallon gasoline tax, or a \$400-per-ton carbon tax, assuming a low (about 2 percent) social rate of discount and 11,500 vehicle-miles traveled (VMT) annually for 10 years. To determine R, the feebate rate equivalent of a gasoline tax, the following formula is used:

$$R[\$/\text{GPM}] = \sum_{y=1}^{10} \frac{t_{gas,y}[\$/\text{gal}] \times \text{annual } VMT_y[\text{mi/y}]}{PWF_y\left[y^{-1}\right]}$$

where $t_{gas,y}$ is the gasoline tax and PWF_y is the present worth factor. Using an 8-percent discount rate, these feebate rates correspond to a \$0.60- and \$1.20-per-gallon gas tax. Annual average VMT is based on RTECS data.

To convert a gasoline tax to a carbon tax, multiply by:

$$\frac{1 \text{ gal}}{20 \text{ lbs } CO_2} \times \frac{2{,}205 \text{ lbs}}{\text{ton}} \times \frac{11\ CO_2}{3\ C} \approx \frac{400 \text{ gal}}{\text{ton C}}$$

The MPG LOW feebate rate corresponds to a $0.50-per-gallon gasoline tax at the average mileage (between 27 and 28 mpg). The effects of MPG LOW are intended to be comparable to GPM LOW. The NONLINEAR LOW feebate also corresponds to a $0.50-per-gallon gasoline tax, if averaged over the entire range of feebates in 1990. The effects of NONLINEAR LOW should therefore also be compared to GPM LOW.

For the SIZE-BASED scenario, the Society of Automotive Engineers' standard measure of interior passenger volume was used as the fuel-consumption divisor for passenger cars. Trucks are less amenable to the application of size indexing, and many of the motivations for this feebate variant apply only to cars, so only the effects on cars were examined. The $3,750,000-per-gpm/ft^3 figure results in a corresponding average feebate rate that is about $40,000 per gpm for vehicles with the sales-weighted average interior volume of 92 cubic feet. For smaller vehicles, the feebate rate is higher; and for larger vehicles, it is lower. The effects of the SIZE-BASED scenario were therefore intended to be comparable with GPM LOW, which has a similar effective feebate rate and range of feebates. (The GPM LOW feebate rate is about 25 percent higher than SIZE-BASED, but the range is 25 percent lower for GPM LOW.)

Fuel-Consumption Feebates

The following equation describes a feebate schedule based on fuel consumption for all vehicles in the market (across all classes). The difference between the fuel consumption (in gpm) of the individual vehicle model and the entire fleet is multiplied by the feebate rate:

$$F_l = \left[FE_i^{-1} - (\overline{FE})^{-1} \right] \times R_l$$

where the variables are assigned as follows:

F = GPM feebate on an individual vehicle model,

R = GPM feebate rate, and

$\overline{FE}$ = (sales-weighted) fleet-average fuel economy, defined as

$$\overline{FE} = \left[\sum_{i}^{\text{vehicles}} \frac{Q_i / Q_T}{FE_i} \right]^{-1}$$

where:

FE_i = fuel economy of model i (in mpg),

Q_i = sales of model i, and

Q_T = total sales of all vehicles in that model year.

This formula for the sales-weighted average fuel economy is used in the following feebate formulas as well. It is a harmonic weighted average—that is, an inverse of the average of the inverses rather than an arithmetic average. It effectively averages fuel consumption rather than fuel economy, so the fleet average can be used for the calculation of fleet-average fuel consumption.

One trait of consumption-based feebates that is evident from the above formula is that, to maintain revenue neutrality, the sales weights must be estimated in advance. Inaccuracy in this estimation results in a zero point that is not necessarily revenue neutral. The incentive rate, however, is completely specified in advance by R, and so the impact of the feebate on mix shifting is unaffected by any inaccuracy in the identification of the revenue-neutral zero point.

Figure 4–1 shows the actual GPM LOW feebate schedule applied in forecasting to the 1995 U.S. vehicle fleet, the first year the feebates are introduced. The figure illustrates the use of two separate zero points for cars and trucks (the zero points for the GPM LOW feebates are the sales-weighted average fuel consumption of each of the car and truck fleets). Because of this, trucks pay a lower fee and receive higher rebates than cars of the same fuel economy. This has the potential to increase sales shares of trucks, at the expense of cars, which is contrary to the general objectives of feebates. This effect, however, turns out to be small.

The ranges as well as the leverages of the GPM LOW feebates over the entire forecast period are illustrated in Figure 4–2. The sales-weighted average absolute value, or leverage, of the GPM LOW feebate when it is introduced is about $200 for cars and $350 for trucks. This does not mean that the average rebate is higher than the average fee (they are equal in a revenue-neutral program); leverage is the average absolute value of fees and rebates both—its magnitude could just as well be reported as a negative number. Truck and car leverages both decrease slightly over time, as the ranges narrow, and the maximum truck fee decreases. On the whole, the GPM LOW feebate remains fairly stable over time.

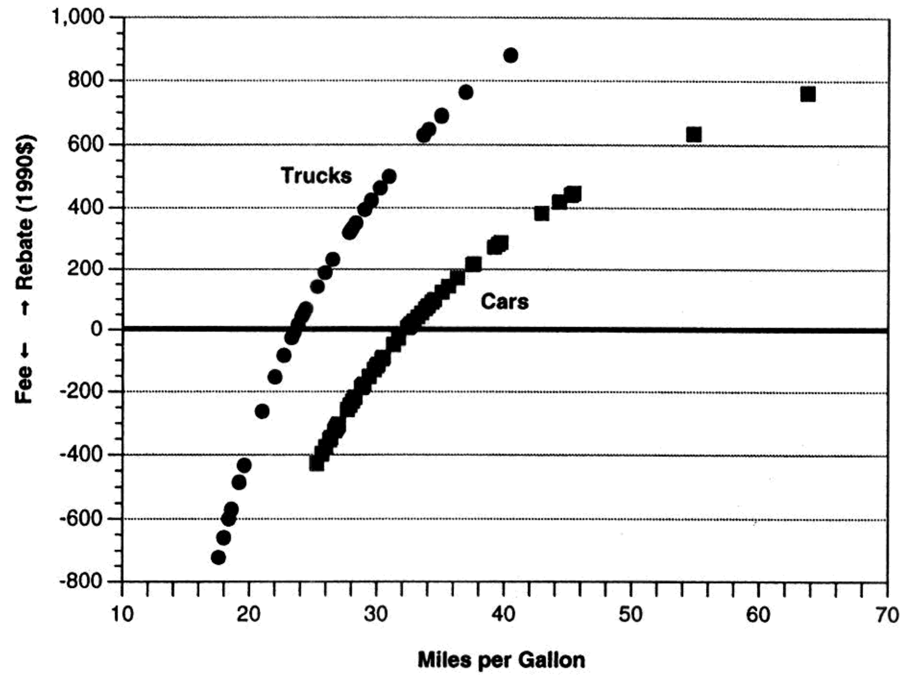

Figure 4–1. Feebate Schedule in 1995 Under GPM LOW Scenario

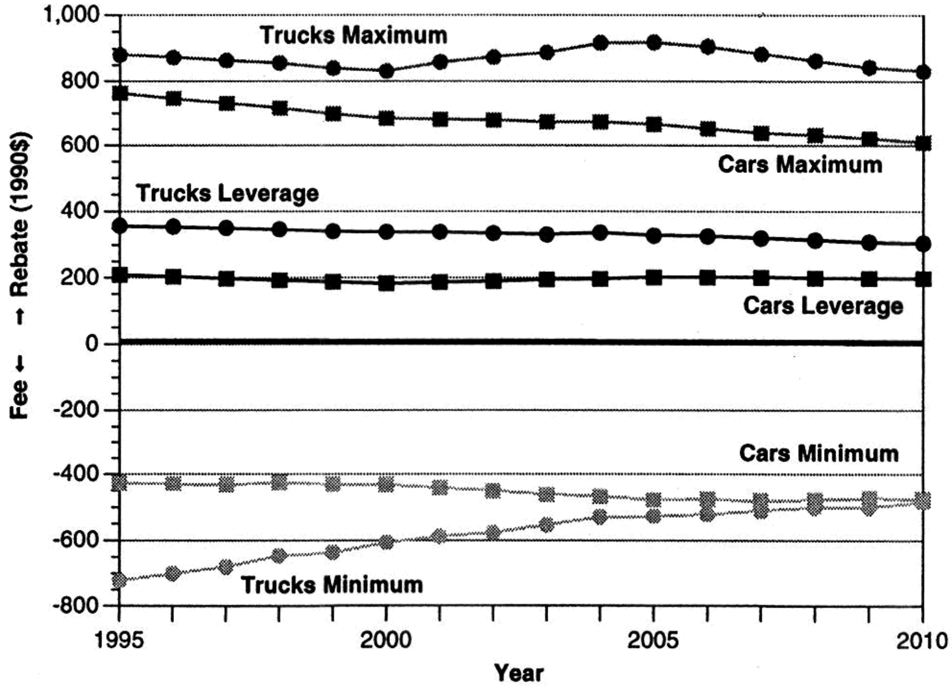

Figure 4–2. Leverages and Ranges Under GPM LOW Scenario

GPM LOW versus BASELINE

The forecasted effects of GPM LOW are wide-ranging and significant. The GPM LOW feebate has a large effect on new-vehicle fuel economy, primarily because of the response of the manufacturers to feebates. By 2010, new-car fuel economy is forecast to reach 42.1 mpg, 14 percent higher than in the baseline. In the long run, as these vehicles penetrate the entire stock, on-road stock fuel economy also shows large improvements. Stock fuel consumption and CO_2 emissions are correspondingly reduced. Because more efficient vehicles are cheaper to drive, vehicle travel increases slightly, taking back some of the gas consumption and emissions reduction savings. Finally, all of this is achieved while at the same time increasing consumers' satisfaction with their vehicle options.

The introduction of the GPM LOW feebate has a significant impact on the sales shares of new vehicles. Table 4–1 shows the percent changes in discounted cumulative sales in response to the GPM LOW feebate over the entire forecast period.

Because cars and trucks are treated separately, there is still an opportunity for trucks to gain market share. This reflects the incentive for the consumer to

Table 4–1. Change in Discounted Cumulative Sales From 1995 to 2010, GPM LOW Versus BASELINE (percent)

Cars		Trucks	
Minicompact	5.9	Near Truck	7.9
Subcompact	3.3	Minivan	9.0
Sports	−2.7	Mini Utility	9.7
Compact	1.6	Compact Pickup	4.1
Intermediate	−1.2	Compact Van	2.4
Large	−1.9	Compact Utility	0.6
Luxury	−10.3	Standard Pickup	−2.5
Near Luxury	−0.8	Standard Van	−1.7
Midsize Wagon	−1.1	Standard Utility	-4.5
Large Wagon	−2.2		
All Cars	−0.5	**All Trucks**	1.0

switch from a car that is less fuel-efficient than average to a fuel-efficient truck, even if at a slight loss in absolute fuel efficiency. This effect turns out to be relatively small. When discounted and cumulated, new-car sales decrease 0.5 percent, while new truck sales increase 1.0 percent in response to GPM LOW.

The effects on some classes are larger. A tendency to shift from the less fuel-efficient larger size classes to the more fuel-efficient smaller ones is clearly evident. Luxury cars especially show large decreases, while the smallest trucks show large gains. These sales-mix shifts, however, result in small fuel-economy gains relative to those captured by new fuel-economy technologies introduced in response to feebates.

In the long run, the average price of all new vehicles increases because the additional fuel-economy technologies make vehicles slightly more expensive. The average price increases of new vehicles due to the feebate-induced installation of additional fuel-economy technologies is charted in Figure 4–3. The penetration of additional fuel-economy technologies is accelerated during the

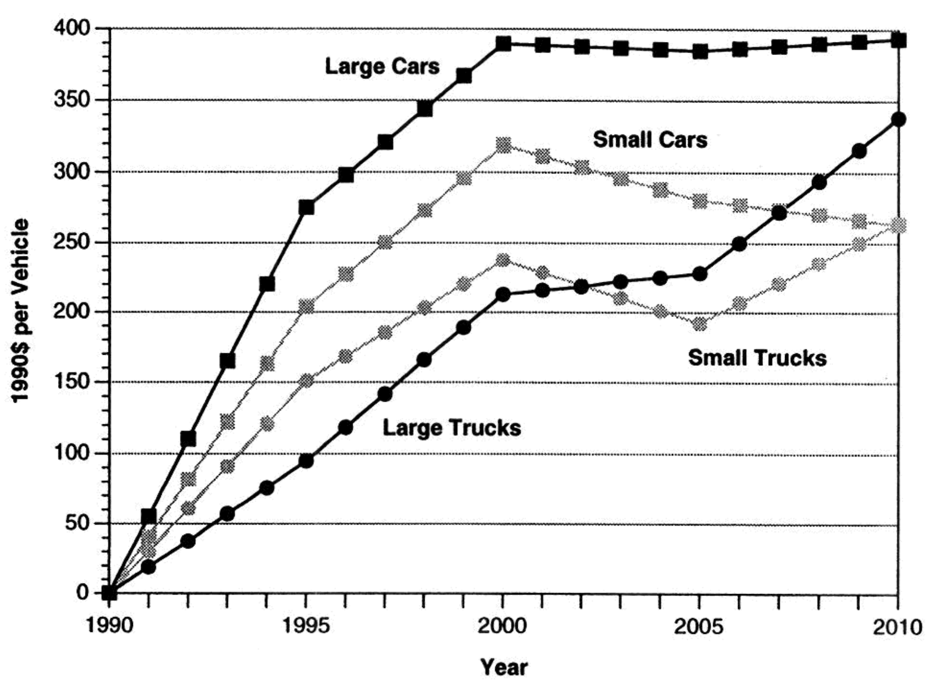

Figure 4–3. Average Price Increase of New Vehicles Under GPM LOW Scenario

first decade of the forecast, peaking in the price-increase range of $200 to $400 per vehicle.

Feebates also have an effect on total new-vehicle sales and ownership, and thus on the profits of the vehicle manufacturers. The price changes directly attributable to the feebate cause the share shifts. The estimated sales impact of feebates is to first increase, then decrease, total new-vehicle sales (Figure 4–4). During the first decade of the forecast period, sales are stimulated because consumers perceive an overall improvement in new vehicles. This indicates that consumers value the fuel-economy technologies more than they dislike the added purchase price of the vehicles. In the second decade, the used vehicles in the stock now have higher fuel economy than in the reference case. In the choice of whether to retain their used vehicles longer or purchase new ones, consumers choose the former to a greater extent than in the baseline.

The bulk of the decrease in total new-vehicle sales is accounted for by large cars. Large cars and large trucks both experience decreased sales, while the sales of small cars and small trucks increases (Figure 4–5). Smaller vehicles, being relatively more fuel efficient, are favored by the introduction of feebates. Their advantage over the baseline diminishes in the second decade of the forecast, when they are competing with a more efficient used-vehicle stock.

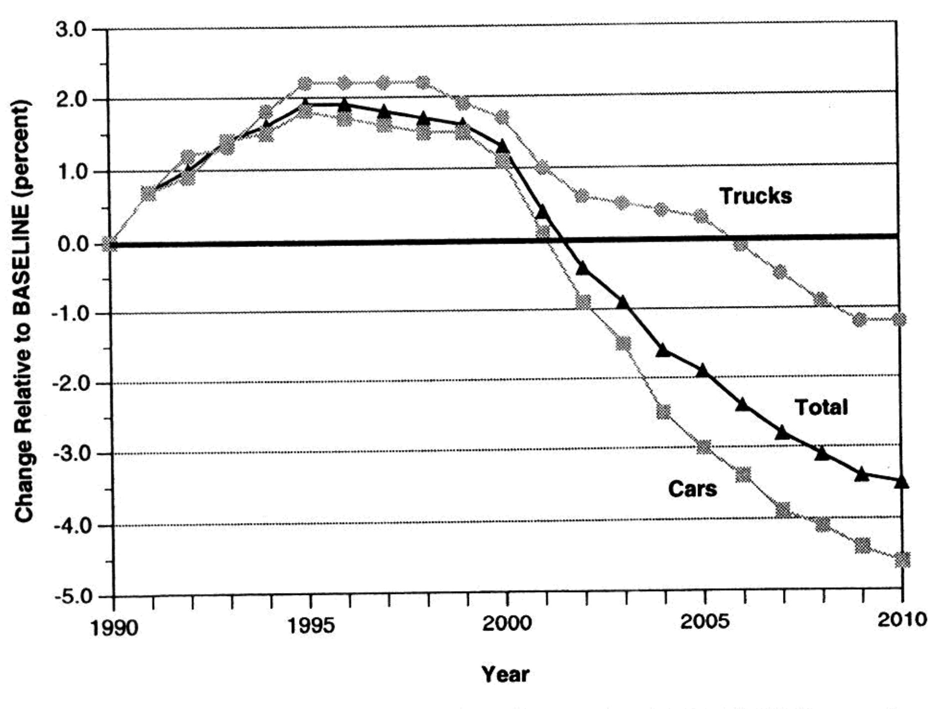

Figure 4–4. Change in New-Vehicle Sales Under GPM LOW Scenario

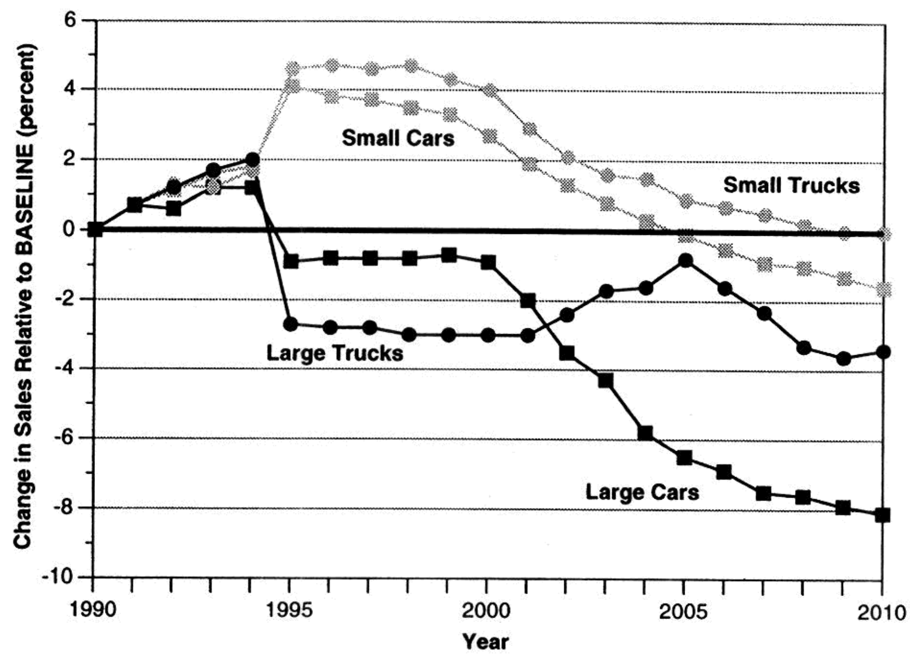

Figure 4–5. Change in New-Vehicle Sales by Size Under GPM LOW Scenario

This is also evident in the increased ownership of all vintages of small vehicles (Figure 4–6).

Because the vehicle fleets of foreign manufacturers are generally smaller and less powerful, they have greater fuel economy than domestic fleets. When feebates are introduced, the fees therefore tend to fall largely on the purchasers of domestic vehicles. The GPM LOW feebates result in an average fee in 1995 of $80 on domestic vehicles, which in effect subsidizes an average rebate of $150 on foreign vehicles. As a result of this difference, initially foreign manufacturers capture a larger share of the increase in sales. In 1995, the sales of foreign vehicles are forecast to increase by 3.5 percent as a result of the GPM LOW feebates, while the sales of domestic vehicles are expected to increase only 1.1 percent. This disparity is not forecast to continue. Over time, domestic manufacturers are forecast to make up some of this difference by capturing the larger untapped fuel-economy potential in their vehicles. By the year 2000, the impact of feebates no longer favors foreign manufacturers. Shortly thereafter, however, the impact of feebates on the sales of both domestic and foreign manufacturers becomes negative. Figure 4–7 illustrates these trends.

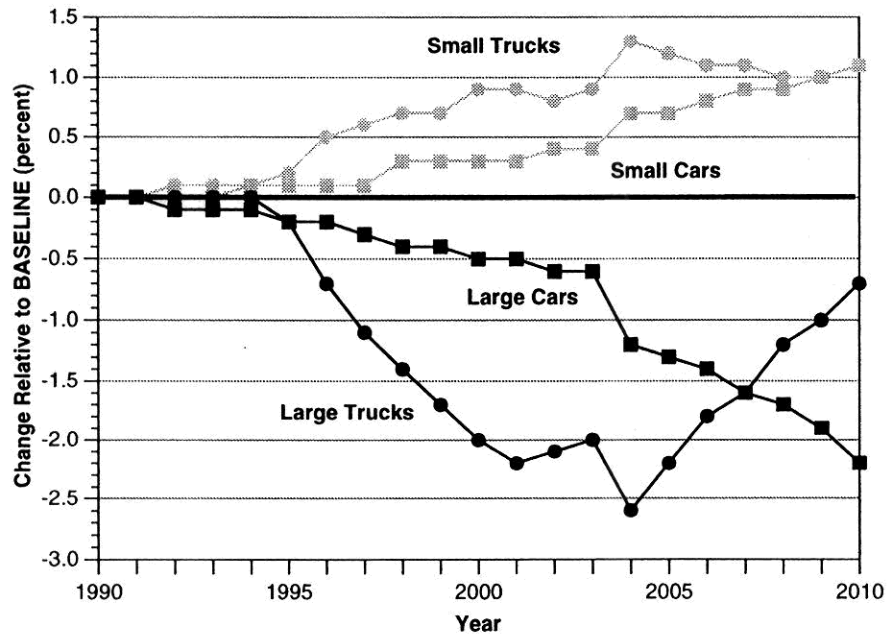

Figure 4–6. Change in Vehicle Ownership Under GPM LOW Scenario

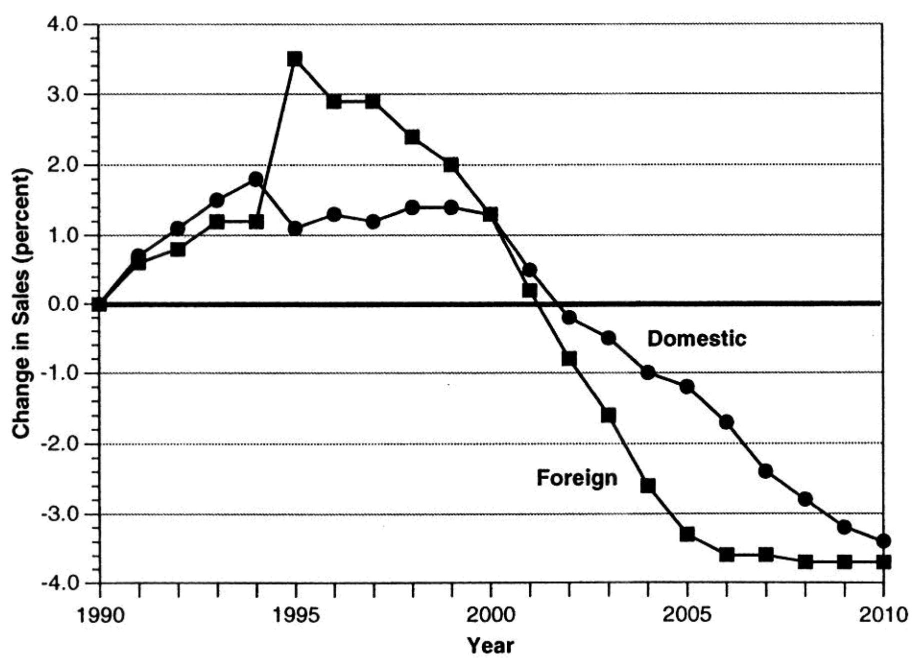

Figure 4–7. Foreign and Domestic Vehicle Sales Under GPM LOW Scenario

The other feebate scenarios (except SIZE-BASED) show a similar pattern in the sales of new domestic versus foreign vehicles, though the magnitude of the difference varies. The sales advantage that feebates provide foreign manufacturers is most pronounced when the feebates are introduced. Under the GPM LOW feebates, in 1995 the change in market share from domestic to foreign carmakers is 0.5 percent. Domestic manufacturers still experience an increase in sales, but foreign manufacturers experience a larger increase. If these changes in sales are discounted (at 8 percent real) and cumulated over years to make the entire time profile of changes in sales comparable, foreign manufacturers come out further ahead. From this perspective, the effect of the GPM LOW feebates on domestic manufacturers is negative. They experience a 1.3-percent decrease in overall discounted sales, while foreign manufacturers experience a 0.4-percent increase in sales.

Figure 4–8 provides the relative improvement of new-car fuel economy in the GPM LOW scenario relative to the BASELINE scenario. The total effect is decomposed into sales- and product-mix effects. The figure illustrates that the manufacturer response to the GPM LOW feebate is an order of magnitude more influential in determining the increase in new-car fuel economy ratings.

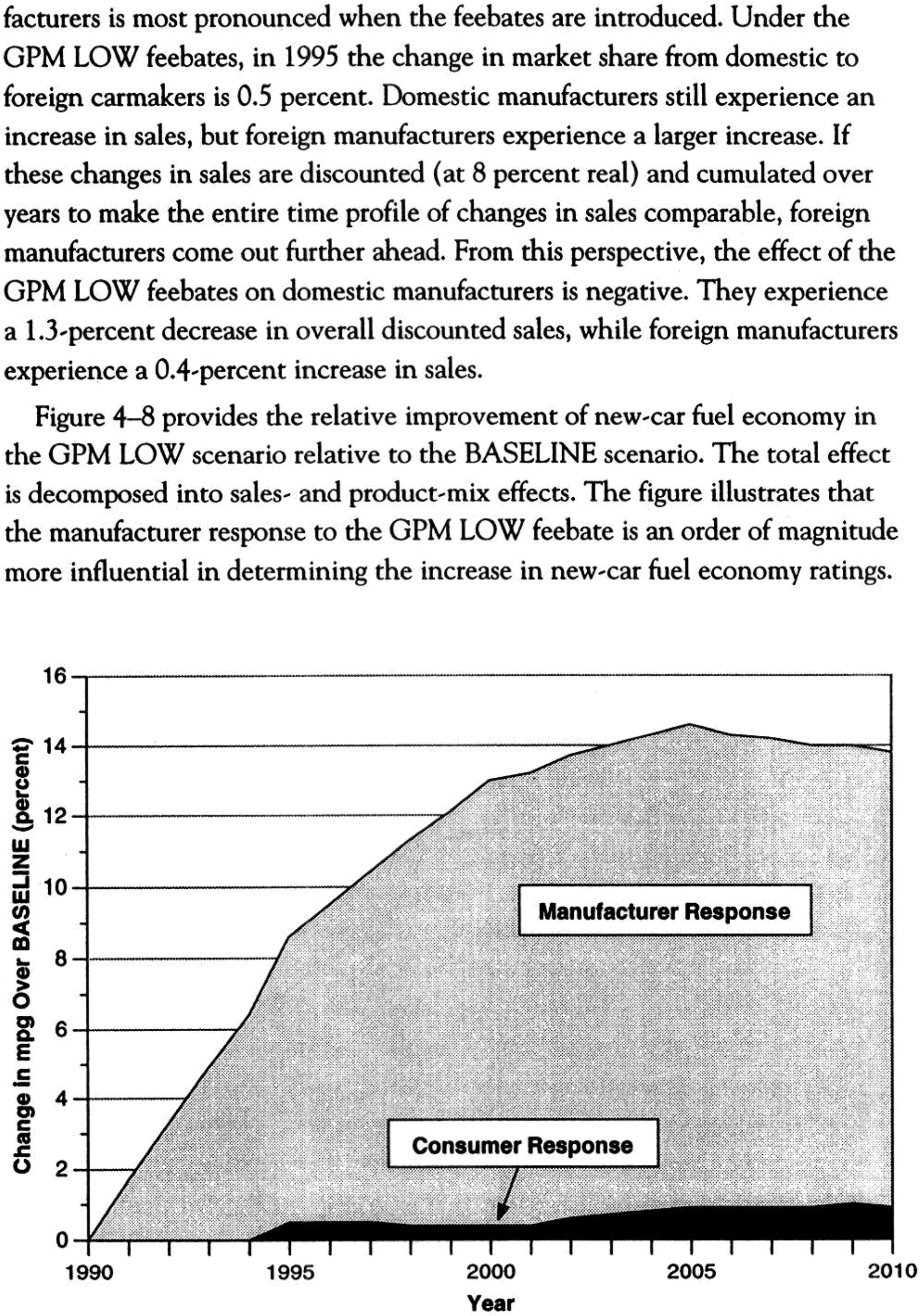

Figure 4–8. Improvements in the Average Fuel Economy of Cars Under GPM LOW Scenario

While sales-mix effects immediately reach close to their maximum and hold it throughout the forecast period, this maximum is relatively small, at about 1 percent. The product-mix effects, on the other hand, start out much higher—8 percent in 1995—because manufacturers have anticipated the introduction of the feebate—and they continue to increase as retooling constraints are eliminated and new manufacturing techniques are adopted over time. The increased vehicle efficiency resulting from the manufacturer response reaches a maximum of almost 14 percent by 2005, by which time the automakers have had time to completely turn over their initial stock of plants and equipment. The total mix-shifting effect on new-car fuel economy reaches nearly 15 percent in the GPM LOW scenario by 2005. After this date, mix shifting declines slightly as the BASELINE catches up.

New-truck fuel economy (Figure 4–9) shows similar mix-shifting trends in response to the GPM LOW feebates. Increased fuel economy due to manufacturer response is smaller for trucks than for cars, but still constitutes nearly the entire response. Sales-mix shifting starts at about 1 percent (in 1995, the year

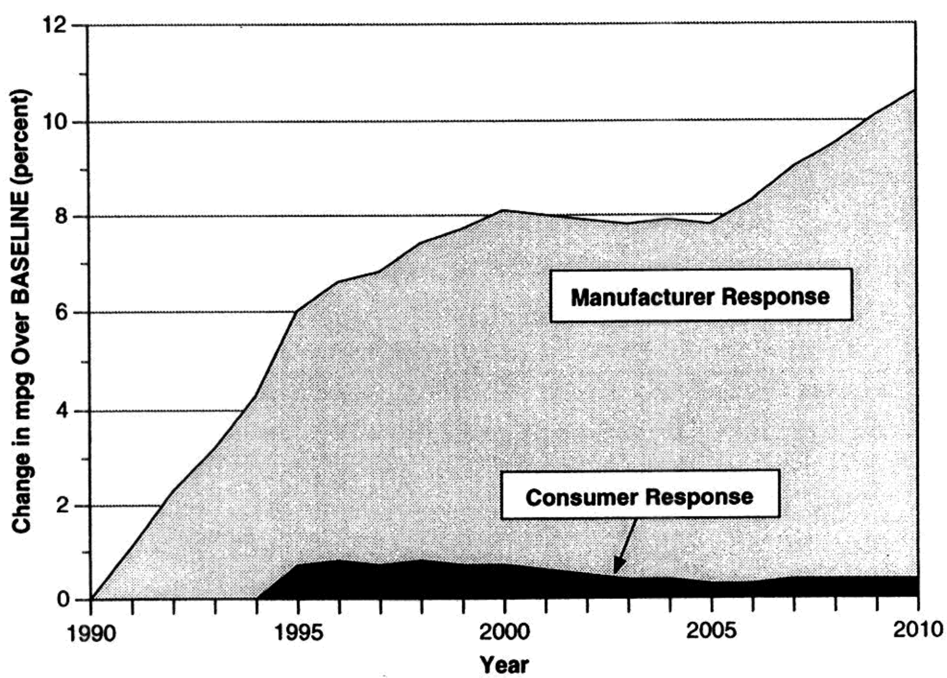

Figure 4–9. Improvements in the Average Fuel Economy of Trucks Under GPM LOW Scenario

in which these effects are best isolated). The decrease in the latter half of the forecast period in the consumer response is also due to changes in other vehicle characteristics that come bundled with fuel-economy technologies. The increase in the producer response after 2005 is due to the introduction of two-stroke engine technology. The total fuel-economy increase approaches 11 percent by 2010.

The effects of the introduction of more efficient vehicles on the fuel economy of the entire on-road stock takes place more slowly, as new and increasingly efficient vehicles enter the stock, and older, less-efficient vehicles are retired. As a result, the increases are not seen as quickly. GPM LOW is still forecast to result in large long-run gains in stock average on-road fuel economy (Figure 4–10).

These gains translate into large savings in gasoline consumption and carbon dioxide emissions, thereby reducing U.S. dependence on foreign oil and decreasing the impact of the U.S. transportation sector on global climate change, as shown in Figure 4–11. By 2010, the GPM LOW feebate is projected to save close to 7 billion gallons of gasoline per year and about 70 million tons

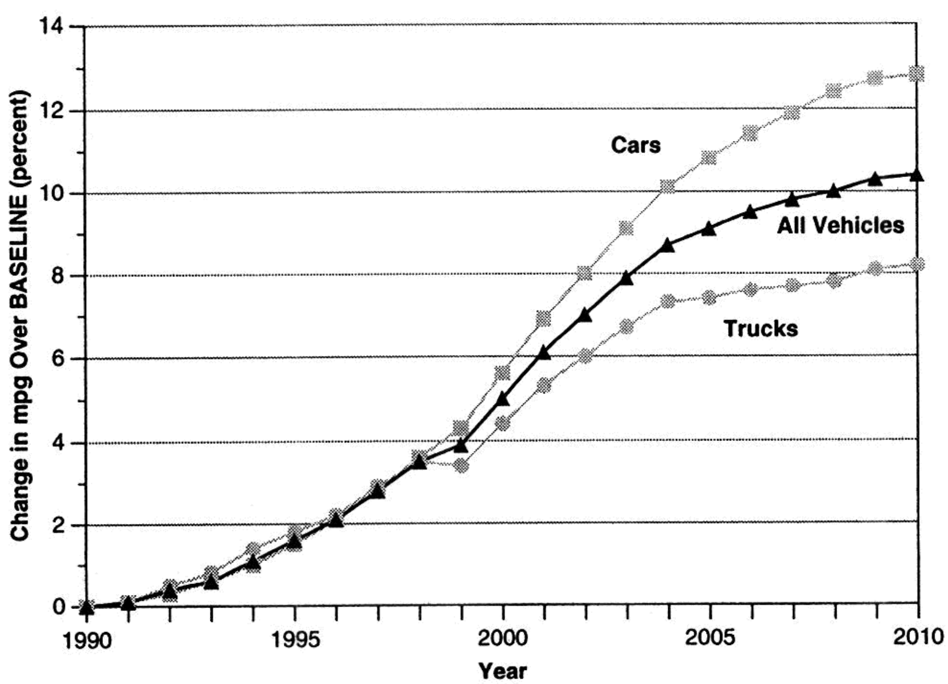

Figure 4–10. Improvement in Average Fuel Economy of On-Road Vehicle Stock Under GPM LOW Scenario

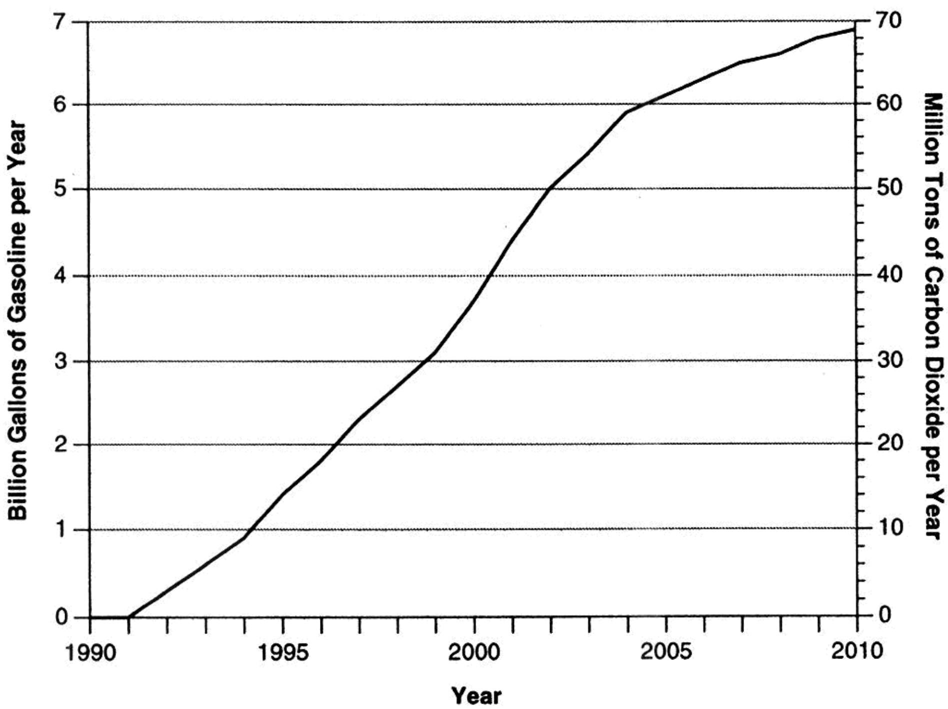

Figure 4–11. Savings in Fuel Use and Carbon Dioxide Emissions Under GPM LOW Scenario

of CO_2 emissions. The CO_2 conversion is somewhat rough to allow easy charting on the same figure. (There are 19.6 to 19.8 pounds of CO_2 emitted for every gallon of gas burned in a vehicle, and a metric ton equals 2,205 pounds.)

Consumers travel more in response to the reduction in the cost of driving. VMT is therefore expected to increase faster with the GPM LOW feebate than without, by close to 100 million miles annually by 2010. This increase in vehicle travel cancels some of the fuel consumption and CO_2 emissions reductions that would be obtained if driving patterns did not change. This "take-back effect" results in a loss of 25 percent of overall fuel savings. Annual fuel savings are reduced from almost 10 billion gallons to about 7 billion gallons in 2010. This reduction contributes to a significant net increase in consumers' satisfaction with their driving alternatives.

Consumer surplus per household is forecast to increase by more than $80 by 2005. Spread across the 121.8 million households in the United States, this yields a net benefit of more than $10 billion annually by the year 2010 (Figure 4–12). Throughout the forecast period, the GPM LOW feebate is estimated to

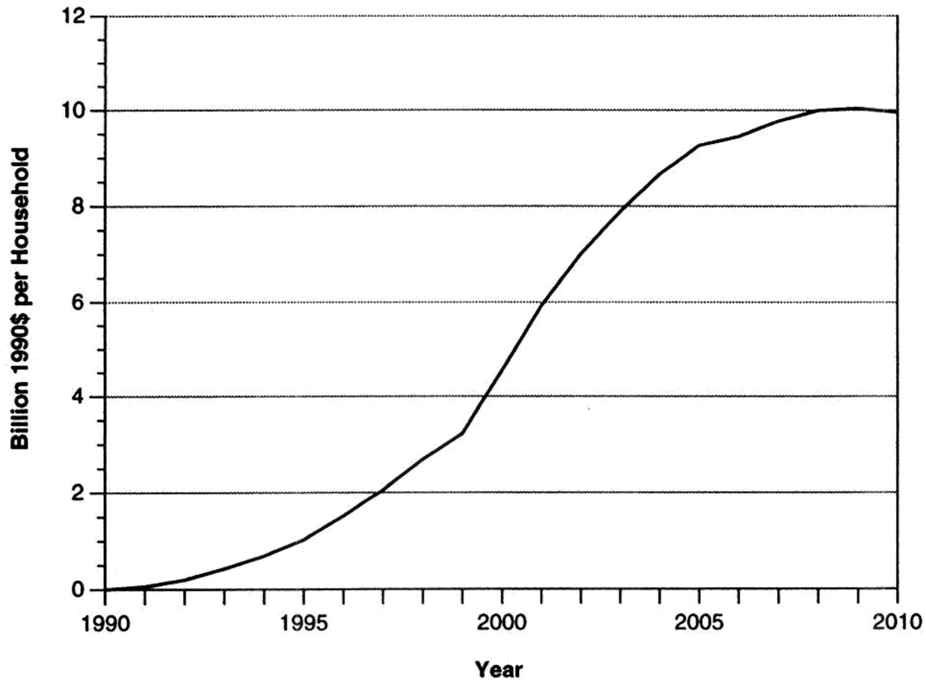

Figure 4–12. Increase in Consumer Surplus for All Households Under GPM LOW Scenario

provide about $51 billion in discounted net benefits, in addition to saving energy and reducing greenhouse-gas emissions.

The GPM LOW feebate increases consumer surplus for all income groups. In fact, low- and middle-income groups receive a larger proportional increase than high-income consumers (Figure 4–13). The distribution of the increase in consumer surplus across income brackets is similar for all other feebate scenarios. Because richer households start with more to begin with, they receive larger absolute increases. In absolute terms, feebates can be said to be regressive in income, while in proportional terms they are income-neutral or slightly progressive.

In the following sections, other feebate formulas are examined. All of these formulas increase fleet fuel economy by both shifting sales shares and advancing the pace of technology introduction, thereby reducing fuel consumption and CO_2 emissions. Because the directions of the effects are always the same, such an exhaustive comparison with the BASELINE forecast is not repeated.

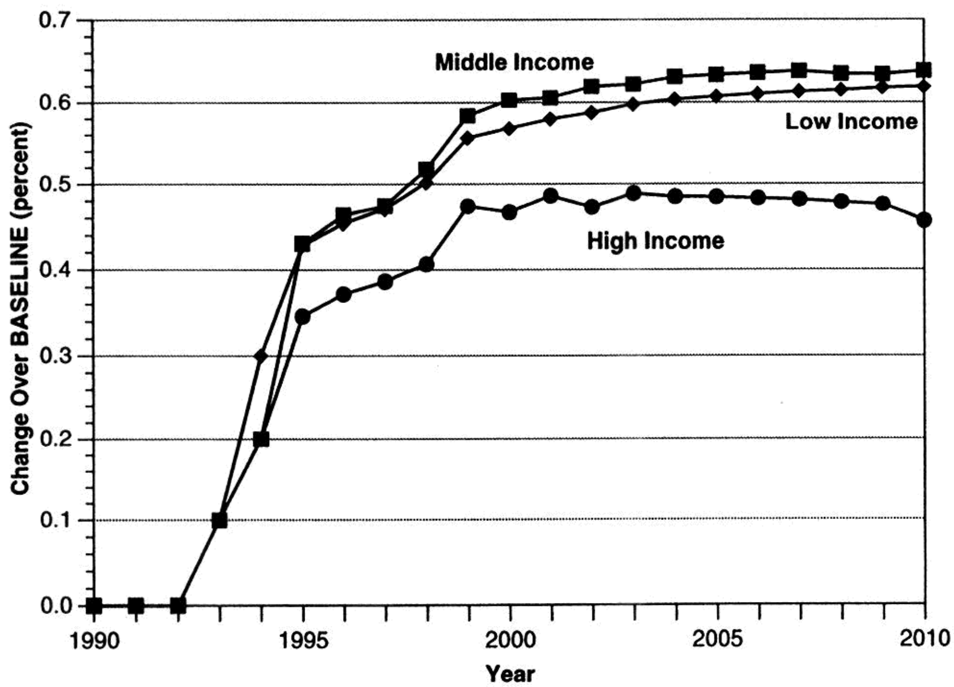

Figure 4–13. Increase in Consumer Surplus by Income Group Under GPM LOW Scenario

The mix shifting is reported, as are the gasoline and CO_2 savings and consumer-surplus benefits.

GPM HIGH Versus BASELINE

GPM HIGH is identical in every respect to GPM LOW, with the one exception that the feebate rate is twice as high, at $100,000 per gpm. The average leverages and ranges of the GPM HIGH feebates are provided in Figure 4–14.

The aggregate effect of GPM HIGH on new-vehicle sales is similar to GPM LOW. Sales of new trucks are stimulated a fraction of 1 percent more in the first decade of the forecast period, and sales of both new cars and trucks are reduced about 1 percent further by the end of the second decade. When the sales-mix effects on small versus large vehicles are examined, however, GPM HIGH has roughly double the impact of GPM LOW on the change in new-vehicle sales (Figure 4–15).

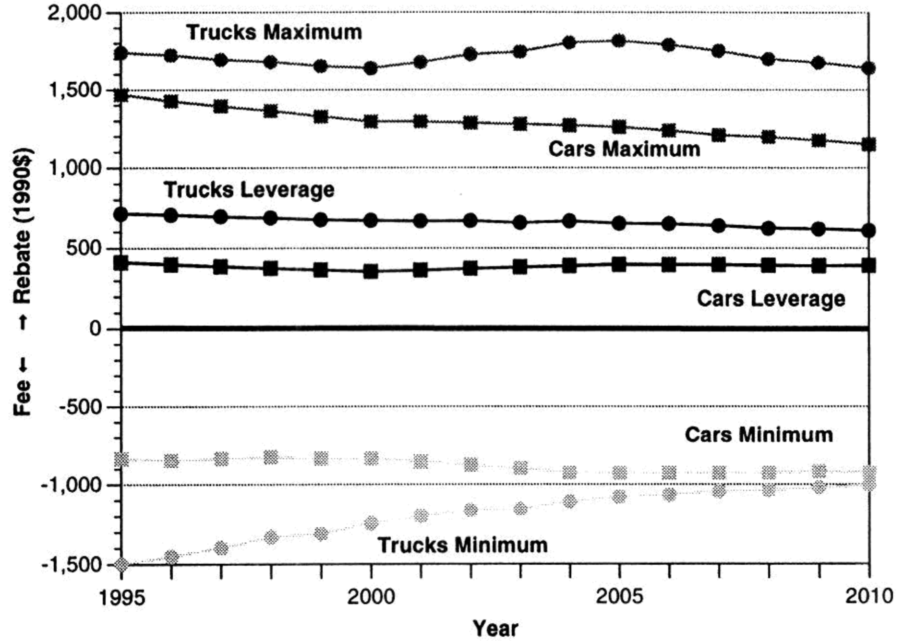

Figure 4–14. Leverages and Ranges Under GPM HIGH Scenario

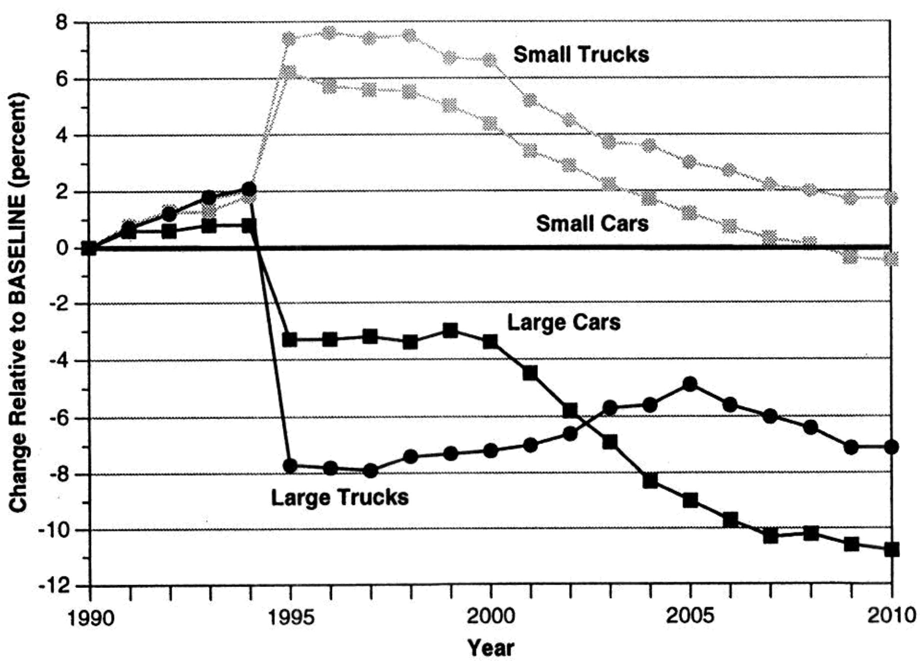

Figure 4–15. Change in New-Vehicle Sales by Size Under GPM HIGH Scenario

The increase in small-car and small-truck sales when the GPM HIGH feebate is introduced in 1995 is 6 to 7 percent. The decrease in large-car sales is about 4 percent, and the decrease in large-truck sales is about 8 percent. Sales of new small vehicles decrease and return to the baseline level by 2010. The decrease in the sales of large trucks remains fairly stable, and sales of large cars continue to decline, to a reduction of about 11 percent by 2010.

Under GPM HIGH, the sales of new foreign vehicles in 1995 are forecast to increase 5.5 percent, while the sales of domestic vehicles increase only 0.1 percent. Compared to GPM LOW, the disparity in the change in sales is increased by the higher feebate rate. The change in market shares to foreign from domestic manufacturers is 1.2 percent in 1995 (in vehicle, not dollar terms). When discounted, average annual new-vehicle sales decrease 0.4 percent for domestic vehicles and increase 1.0 percent for foreign.

Total private vehicle ownership increases slightly (by about 1.1 percent in 2010) in GPM HIGH. Small vehicles account for more than their share of this increase, as the stock ownership mix shifts to favor the smaller vehicles that receive higher feebates on the average. By the end of the forecast period, ownership of small vehicles increases about 3 percent, while the ownership of large vehicles decreases 2 percent.

While these demand-side effects are roughly twice as large in GPM HIGH, the product-mix effects are only slightly larger. The two effects combine to result in an almost 18-percent increase in new-car fuel economy, which is achieved 10 years after the introduction of the GPM HIGH feebate (Figure 4–16). Again, the total mix shifting is dominated by the manufacturer response, which accounts for a 16-percent improvement by 2005. The consumer response accounts for the remaining 2 percent of the increase in new-car fuel economy.

Similar effects are observed for trucks. Because the total effects on new-truck fuel economy are smaller, the sales-mix shifting between classes and subclasses is proportionately more important for trucks. New-truck fuel economy quickly reaches a plateau at a 10-percent improvement by the year 2000, then continues to increase again with the introduction of two-stroke engine technology (Figure 4–17).

The on-road fuel-economy improvements are again delayed as the new-vehicle improvements trickle into the entire vehicle stock. By 2010, under the GPM HIGH scenario, the fuel economy of the entire on-road stock of trucks increases more than 10 percent, and the fuel economy of the on-road stock of

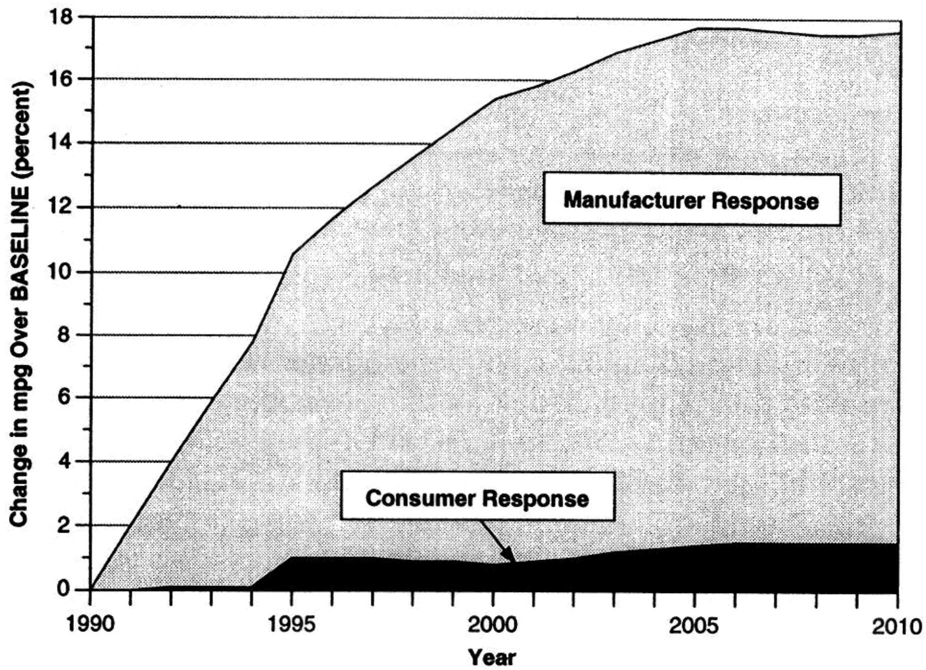

Figure 4–16. Improvements in the Average Fuel Economy of Cars Under GPM HIGH Scenario

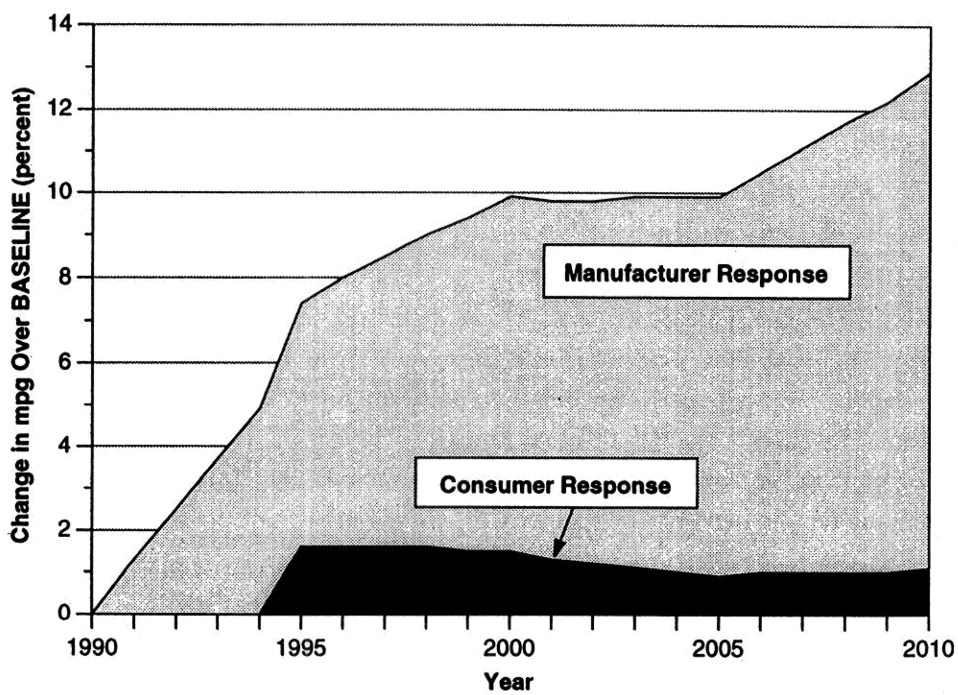

Figure 4–17. Improvements in the Average Fuel Economy of Trucks Under GPM HIGH Scenario

cars increases 15 percent. These improvements reduce fuel consumption by more than 8 billion gallons, saving $13 billion and reducing carbon dioxide emissions by more than 80 million tons annually. Again, all this is accomplished while the benefits to consumers increase by an average of about $91 per household, yielding a net present benefit of $56 billion. Feebates result in a new-vehicle mix that saves gasoline, and one that consumers prefer.

GPM LOW versus GPM HIGH

While the GPM HIGH feebate is twice as large as GPM LOW, the mix-shifting response and fuel savings are only slightly greater than under the GPM LOW feebate. Because the most cost-effective fuel-economy technologies are already captured in the BASELINE and GPM LOW scenarios, there are fewer gains left to be encouraged by the additional increase in the GPM HIGH feebate rate. The average additional technology cost is a useful proxy for the amount of fuel-economy technology installed in new vehicles under the feebate.

Figure 4–18 charts the average additional technology cost that manufacturers choose to pass on as a result of each additional $50,000-per-gpm increase in the feebate rate, from the BASELINE scenario to GPM LOW, and from GPM LOW to GPM HIGH. The chart illustrates that not many more fuel-economy technologies are introduced as a result of the GPM HIGH feebates. GPM HIGH has, on average, only about 25 percent additional impact over GPM LOW.

The effects of the decreasing rate at which fuel-economy technologies penetrate the market are also reflected in the relative new-car fuel economy mix shifting. Figure 4–19 provides the manufacturer response to the two levels of consumption-based feebates. Doubling the feebate rate only yields an additional 4-percent improvement in new-car fuel economy by 2010. The additional improvement to new-truck fuel economy due to manufacturer response is less than 2 percent.

Diminishing returns are not as evident in the consumer response. GPM HIGH yields close to twice as much sales-mix shifting as GPM LOW (Figure 4–20). However, because the sales are such a small component of total-mix shifting, on the whole, GPM HIGH still yields diminishing returns.

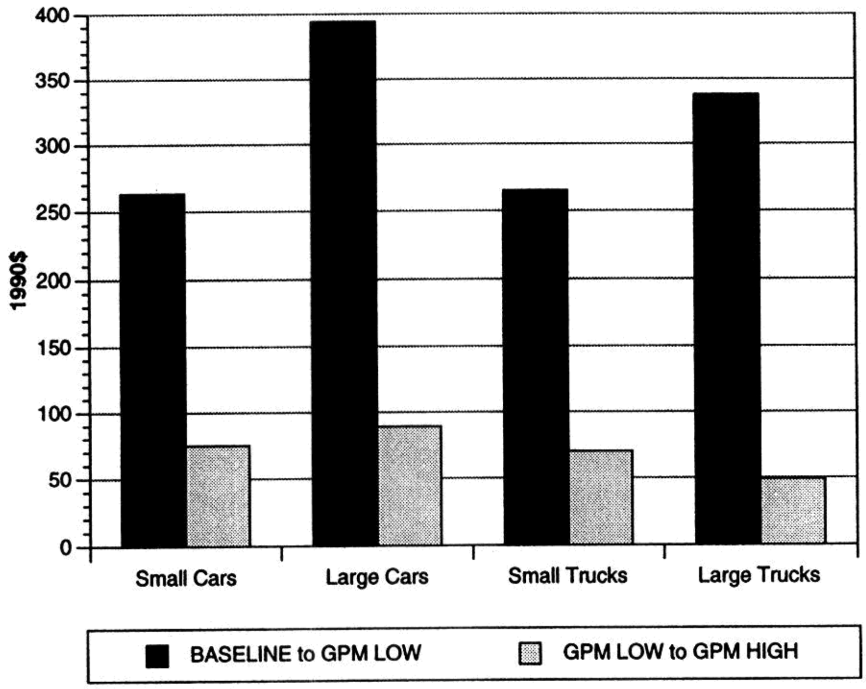

Figure 4–18. Average Increase in Price in 2010 for Each $50,000-per-gpm Increase in Feebate Rate

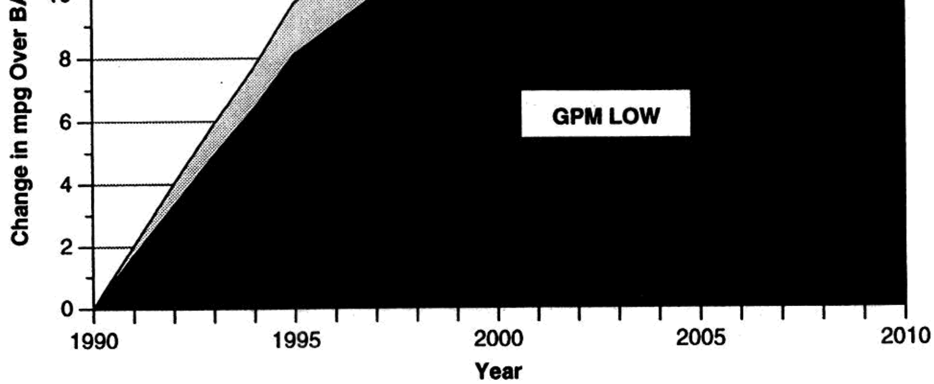

Figure 4–19. Improvements in the Average Fuel Economy of New Cars as the Manufacturer Response

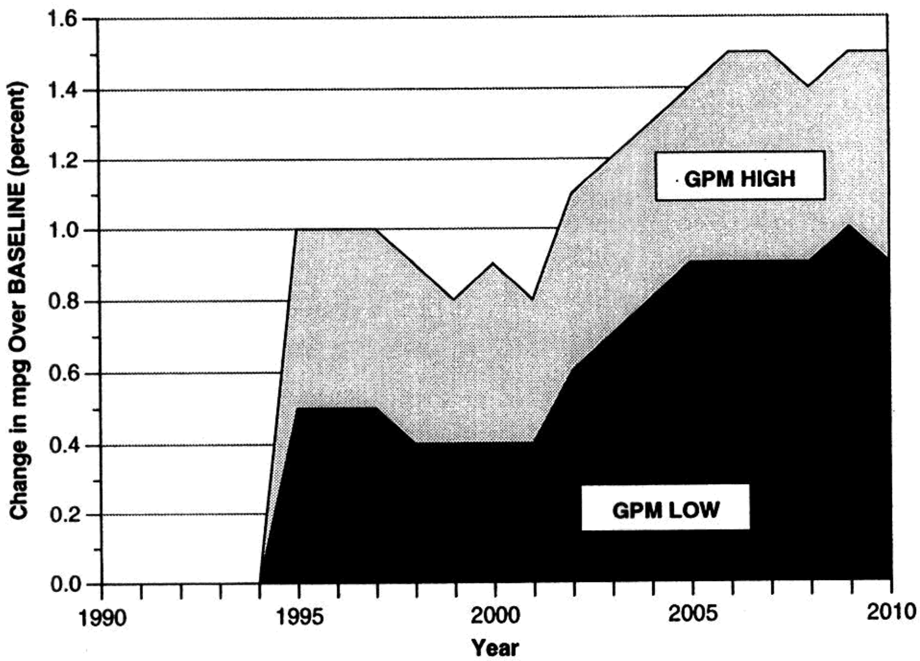

Figure 4–20. Improvements in the Average Fuel Economy of New Cars as the Consumer Response

ONE ZERO POINT

In the GPM LOW and HIGH feebates (and in all the following feebate scenarios), a separate zero point is applied to cars and to trucks. This approach is consistent with CAFE standards, which treat these vehicle types separately, allowing trucks to meet a more lenient standard. This approach, however, perpetuates the large fuel-economy gap between cars and trucks by sending the wrong price signal to consumers who are close to indifferent between cars, vans, and trucks. With two zero points, a consumer might choose a relatively fuel-efficient truck (compared with other trucks) over a relatively inefficient car (compared with other cars) even though the inefficient car gets better mileage, in absolute terms, than the efficient truck. The expected result is higher fuel consumption overall.

The ONE ZERO POINT scenario applies the GPM LOW feebate rate, but with cars and trucks pooled together for the determination of a single zero point around which all feebates are based. This scenario thus values fuel savings equally, regardless of vehicle type; but in so doing, it creates the potentially contentious situation in which trucks bear the brunt of the fees, while cars enjoy rebates. Figure 4–21 shows the ONE ZERO POINT feebates applied to the 1995 forecast vehicle fleet. The average rebate a new car receives in 1995 is about $160. This is financed by an average truck fee of $280. Car buyers never pay a fee greater than $300, as is illustrated in Figure 4–22. Car rebates are about $200 higher than in GPM LOW. Truck buyers never receive a rebate higher than $500, and they pay fees of up to $1,100. The average magnitude of truck feebates is higher than car feebates and is dominated by fees.

Because the effective feebate rate (that is, the change in the feebate for each gpm improvement) is the same for the ONE ZERO POINT scenario as for GPM LOW, the manufacturer response for both cars and trucks is identical under both scenarios. This is evident for cars in Figure 4–23.

Consumers respond differently under the ONE ZERO POINT scenario than under GPM LOW because the absolute size of the feebate is different. However, the difference in consumer response among car subclasses is small—not

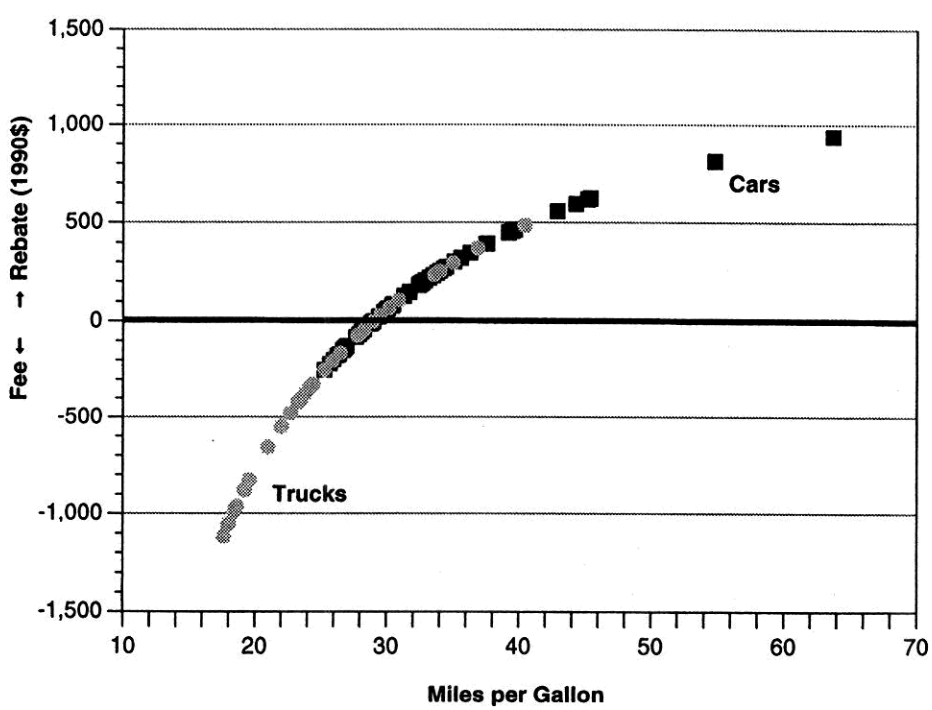

Figure 4–21. Feebate Schedule in 1995 Under ONE ZERO POINT Scenario

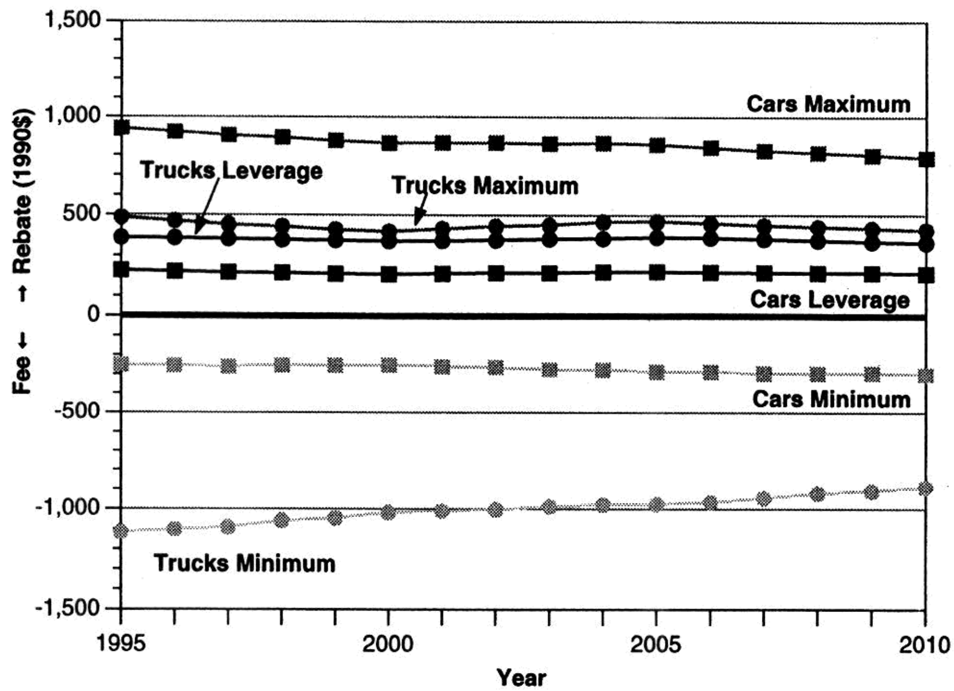

Figure 4–22. Leverages and Ranges Under ONE ZERO POINT Scenario

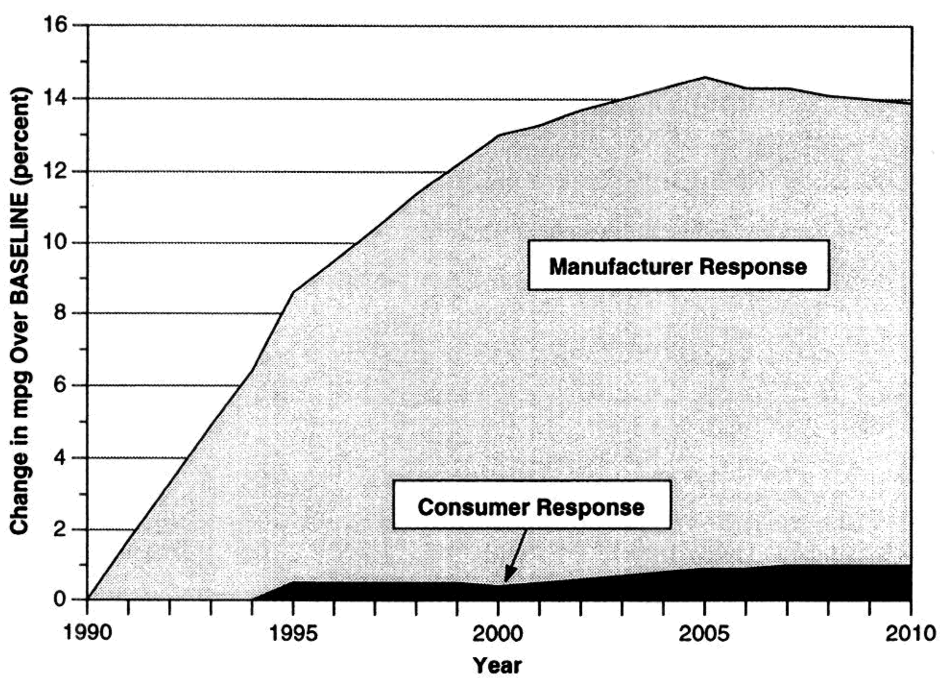

Figure 4–23. Improvements in the Average Fuel Economy of Cars Under ONE ZERO POINT Scenario

discernible on the scale of the figure. New-truck fuel economy shows similar results. The differences in on-road fuel economy for trucks are also negligible.

The only difference between ONE ZERO POINT and GPM LOW is the effects on the sales and ownership shares of cars versus trucks. With the introduction of the ONE ZERO POINT feebate, new-car sales jump several percent, while truck sales fall a similar amount (Figure 4–24). This does not occur in the BASELINE scenario. The change in new-car sales relative to the baseline scenario is initially 2 percent higher for ONE ZERO POINT than for GPM LOW, while the change for trucks is 4 to 5 percent lower. As these sales penetrate the entire vehicle stock, truck versus car ownership is also affected. Relative to the baseline, truck ownership actually drops slightly, while car ownership increases to about 2 percent above the baseline by 2005. Under the GPM LOW feebate, the ownership of both cars and trucks increases slightly.

The most important difference between the ONE ZERO POINT feebate and GPM LOW is this approximately 1-percent shift in ownership shares in favor of cars over trucks (Figure 4–25). In 2010, only about 200 million gallons of gas (and 2 million tons of carbon dioxide emissions) are saved by this slight shift from trucks to cars. Again, this is entirely due to the demand response.

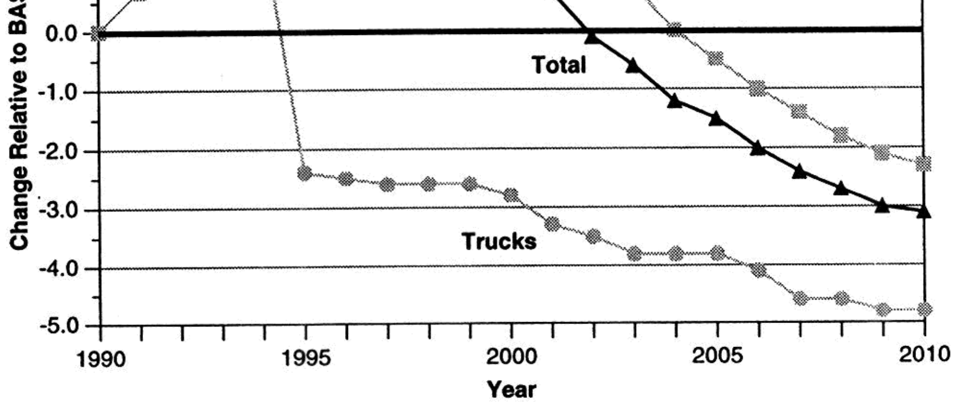

Figure 4–24. Change in New-Vehicle Sales Under ONE ZERO POINT Scenario

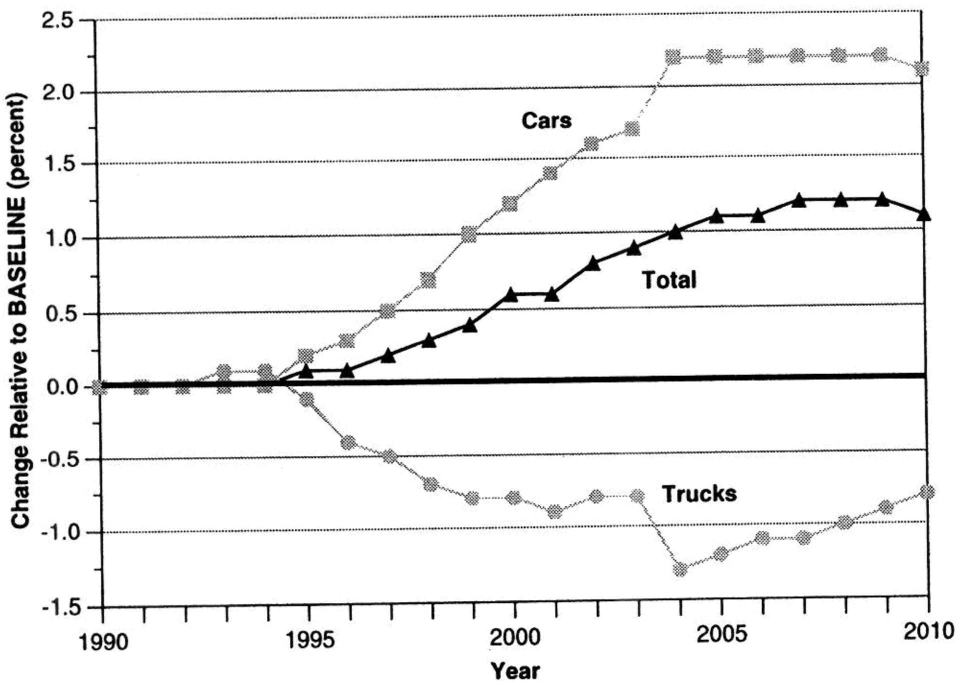

Figure 4–25. Change in Vehicle Ownership Under ONE ZERO POINT Scenario

Because the more important supply response is the same for GPM LOW as it is for ONE ZERO POINT, the effects of these two types of feebate schemes differ little. There is, therefore, a less compelling argument to counter the precedent set by CAFE standards of determining the feebates for cars and trucks separately.

In the ONE ZERO POINT scenario, fees on domestic trucks subsidize the rebates on both foreign and domestic cars to a large magnitude. It is estimated that purchasers of domestic trucks would pay a total of $1.2 billion in fees in 1995, about the same as what purchasers of *both* cars and trucks (foreign and domestic) would pay in the GPM HIGH scenario. Foreign cars capture a larger share of the rebates than domestic cars ($800 million versus $500 million in 1995). This gap (between rebates captured by foreign versus domestic cars) is forecast to close, but the total fees on domestic trucks are forecast to increase. This difference in the incidence of feebates is forecast to allow foreign manufacturers to increase their sales 4.0 percent in 1995 (relative to the baseline), while the sales of domestic manufacturers only increase 0.9 percent. Domestic manufacturers cede 0.7 percent of market share. Discounted cumulative sales over the entire forecast period are projected to drop by 0.1 percent for domestic manufacturers and rise 0.8 percent for foreign carmakers.

Fuel-Economy Feebates

Because CAFE standards are specified in terms of fuel economy, several feebate proposals have likewise been specified in terms of changes in miles per gallon. Such a feebate is not linear in fuel consumption—it values a gallon saved from an already fuel-efficient vehicle more than a gallon saved from an average vehicle; an increase from 10 to 11 mpg is valued the same as an increase from 60 to 61 mpg, despite the fact that the former increase saves 33 times as much fuel. A fuel-economy feebate therefore places a premium on increasing the fuel economy of already fuel-efficient vehicles. This could have the effect of pushing the envelope of vehicle fuel efficiency, similar to "technology forcing" standards.

The following equation describes a feebate schedule based on fuel economy. The difference between the fuel economy of the individual vehicle model and the entire fleet is multiplied by the feebate rate.

$$F_{mpg} = \left[FE_i - \overline{FE}\right] \times R_{mpg}$$

where:

F_{mpg} = mpg feebate on an individual vehicle model,

R_{mpg} = mpg feebate rate,

FE_i = fuel economy of model i (in mpg), and

$\overline{FE}$ = (sales-weighted) fleet-average fuel economy, defined as above.

Again, a negative result indicates a fee; a positive result indicates a rebate. In this case, a 2.5-mpg improvement in fuel economy earns the same change in feebate regardless of the starting point.

The feebate rate applied in this scenario is $70 per mpg. At 26.7 mpg, this rate translates into $50,000 per gpm, as in GPM LOW. At 37.8 mpg, the rate is $100,000, as in GPM HIGH.

With the MPG LOW feebate, the most efficient vehicles receive a very high rebate. Furthermore, unlike other feebates, the range of the MPG LOW feebate increases as fuel economy increases over time (Figure 4–26). For cars (which have higher fuel economy), the difference between the maximum fee and maximum rebate exceeds $4,000 by 2010.

This feebate structure has the largest impact on cars, which reach further into the high-mpg ranges and thus capture larger increases in rebates. New-car

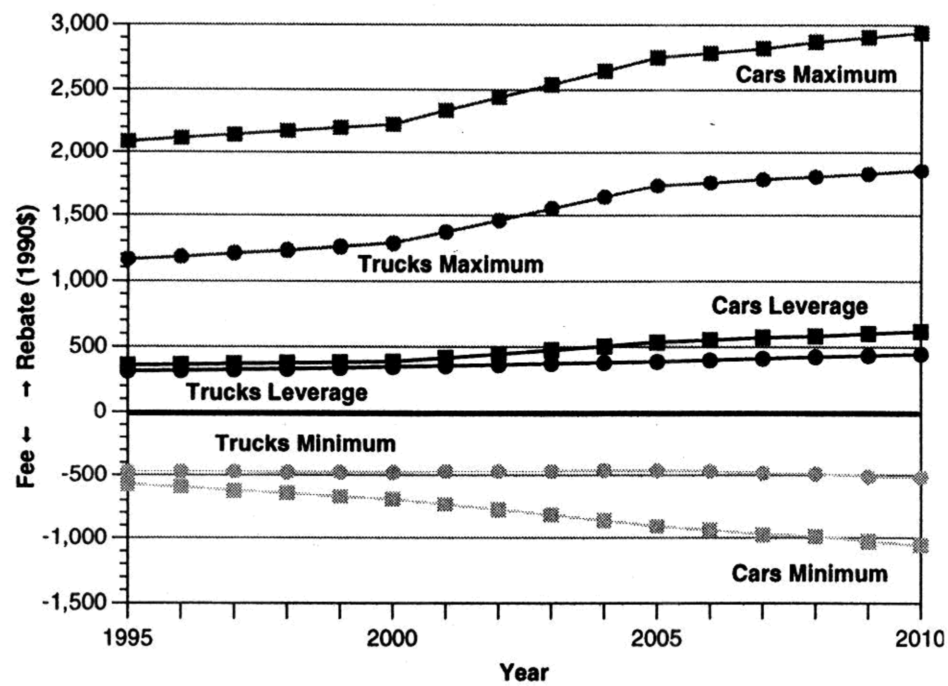

Figure 4–26. Leverages and Ranges Under MPG LOW Scenario

CAFE improvements relative to the baseline total more than 18 percent by 2010 (Figure 4–27). This improvement is about the same improvement as is obtained with GPM HIGH. This occurs because cars in the forecast period have fuel-economy levels closer to 37.8 mpg, so the feebate rates are closer to GPM HIGH.

The new-truck CAFE mix-shifting response is much closer to GPM LOW, because trucks do not reach into such high ranges of CAFE ratings. This is also evident in the large difference between car and truck on-road-stock fuel-economy improvements (Figure 4–28).

By 2010, fuel economy of the car stock exceeds the baseline by more than 15 percent and is still increasing. In fact, fuel-economy improvements in the car stock in MPG LOW mirror those in GPM HIGH, while fuel-economy increases in the truck stock are almost the same as they are in GPM LOW. This is the result of the large boost in sales and ownership that small cars receive, because they capture such a high rebate (Figure 4–29). Sales of new small cars are forecast to jump 6 percent initially. While the change in new-car sales declines after that, the difference in small-car sales versus large-car

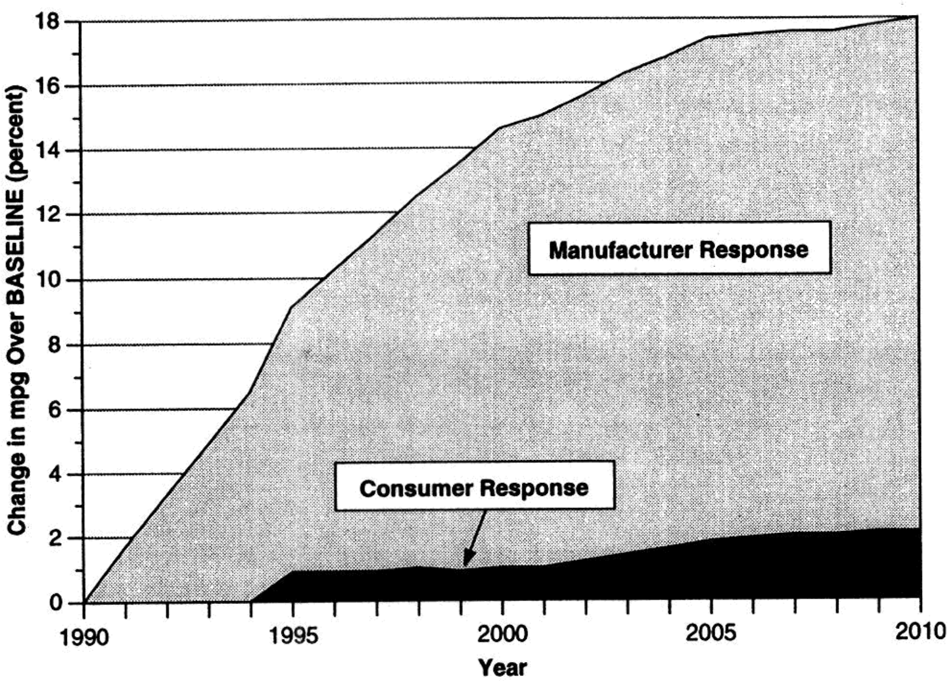

Figure 4–27. Improvements in the Average Fuel Economy of New Cars Under MPG LOW Scenario

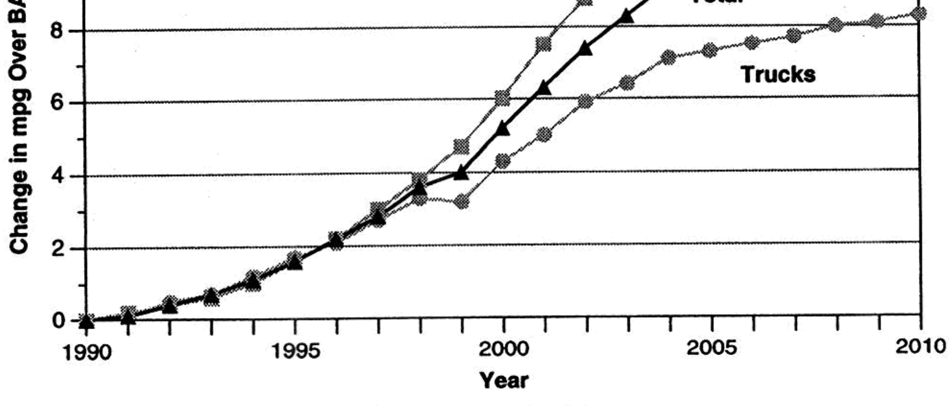

Figure 4–28. Improvement in Average Fuel Economy of On-Road Vehicle Stock Under MPG LOW Scenario

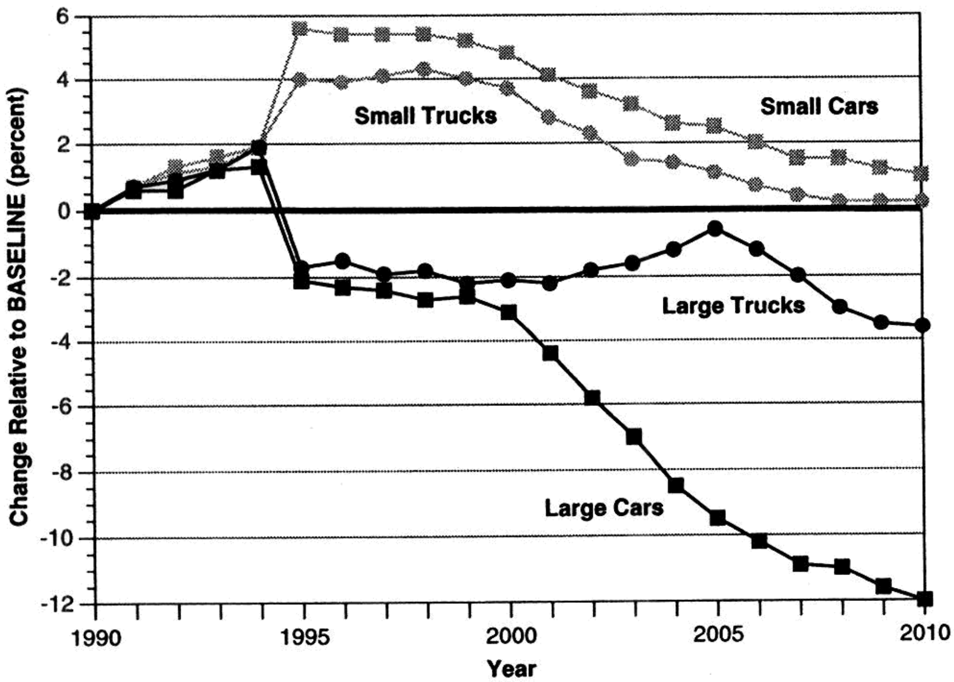

Figure 4–29. Change in New-Vehicle Sales by Size Under MPG LOW Scenario

sales continues to increase because of the sizable decrease in the sales of new large cars. This is due both to the relative increase in the desirability of new small vehicles and to the used vehicles that have further penetrated the stock by the later forecast period. Again, total new-vehicle sales are also forecast to drop, by 0.3 percent over the entire forecast period.

Figure 4–29 is similar to that for GPM LOW (Figure 4–5), with the difference that the change in the sales of small cars is higher, and in large cars lower. The sales of new trucks in MPG LOW are approximately the same as they are in GPM LOW. About 2 percent more small cars are sold, however, while the difference in the sales of large cars drops by about 4 percent by 2010.

The effects of new-vehicle sales on ownership penetrate the stock more gradually. Figure 4–30 shows that the MPG LOW scenario more strongly favors small cars.

Total ownership is again forecast to increase slightly as the increased desirability of used vehicles increases vehicle holdings. The number of two-vehicle households increases, and the vehicle scrappage rate decreases slightly. The differences in ownership between the MPG LOW and GPM LOW scenarios are similar to the difference in new-car sales. The difference in ownership of small versus large vehicles in the MPG LOW scenario is much

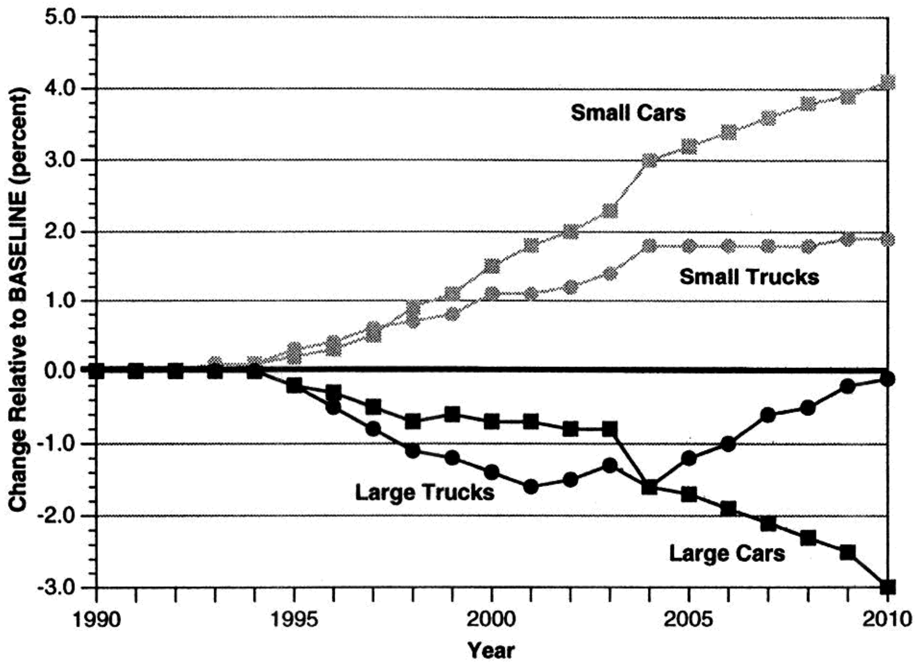

Figure 4–30. Change in Vehicle Ownership Under MPG LOW Scenario

larger than in the GPM LOW scenario. Again, this is due to the larger feebate differentials for cars in the MPG LOW scenario, because they span a larger range of fuel economies.

In the MPG LOW scenario, increases in consumer surplus, net benefit, and fuel and CO_2 emissions savings all split the difference between GPM LOW and HIGH. The increase in consumer surplus is $87 per household by 2010, total net benefits exceed $10 billion per year, fuel savings reach 7.7 billion gallons per year (saving $12 billion in annual fuel bills), and carbon dioxide emissions are reduced 77 million tons per year. Discounted total consumer benefits exceed $50 billion.

The MPG LOW scenario exaggerates the disparity between foreign and domestic cars by placing a premium on highly fuel-efficient vehicles. Purchasers of domestic vehicles pay a total of $800 million in fees in 1995, $600 million of which is paid on cars. This amount is actually forecast to increase in the MPG LOW scenario as the fuel economy of vehicles increases. Sales in 1995, relative to the baseline, increase 4.5 percent for foreign vehicles and 0.9 percent for domestic vehicles. The transfer in market share is 0.8 percent.

When discounted, the change in sales from 1995 to 2010 is +1.3 percent for foreign manufacturers and –0.7 percent for domestic manufacturers.

Nonlinear Feebates

Nonlinear feebates apply different effective feebate rates at different levels of fuel consumption. One type of nonlinear feebate—the type investigated in this report, called NONLINEAR LOW—applies a high effective feebate rate close to the zero point and a lower rate farther from the zero point. The motivation for this type of nonlinear feebate is found in the fact that the large majority of vehicles have fuel-economy ratings close to the average, and only a few vehicles have extremely high or low fuel economy. In fact, half of vehicle sales in 1990 were within 2 mpg of the fleet-average fuel economy. NONLINEAR LOW applies a high effective feebate rate among these vehicles without imposing unreasonably large feebates on vehicles with very low or high fuel efficiency, thus increasing the mix-shifting response of the majority of vehicles without increasing the range of the feebates.

Increasing the feebate differentials in the middle range of fuel economy will better distinguish vehicles that are otherwise close substitutes, making consumers more prone to switch to the more fuel-efficient vehicles. This could enhance the competition to introduce improved fuel economy in the midrange of the market, where the majority of consumers make their purchase decisions. Because these vehicles make up the bulk of the market share, increased mix shifting among them is likely to result in larger fuel savings than in the linear case with the same range of feebate values.

The following formula determines the nonlinear feebate schedule:

$$F_{nl} = a\left[\left|FE_i^{-1} - \overline{FE}^{-1}\right|^b\right] \times R_{nl}$$

where:

F_{nl} = nonlinear feebate on an individual vehicle model,

a = sign of the feebate, negative when fuel economy is less than average, and positive otherwise,

FE_i = fuel economy of model i (in mpg),

$\overline{FE}$ = fleet-average fuel economy, defined above as in the linear case,

b = exponent between 0 and 1, and

R_{nl} = nonlinear feebate rate.

As in the GPM feebates, the difference between the fuel consumption (in gpm) of an individual model and the entire fleet is determined. Before multiplying this difference by the feebate rate, however, the magnitude of the difference is raised to an exponent *b* between 0 and 1. The choice of this exponent is discretionary; it is used to determine the rate of change of the feebates around the fleet-average fuel economy—the smaller *b* is set, the greater the difference in feebates around the average. A term *a* is included to adjust the sign of the feebate—negative when fuel economy is less than average and positive otherwise. R_{nl} must be adjusted depending on the choice of *b* to result in the desired average magnitude and range of feebates. If the distribution of vehicle fuel economy is skewed, then the zero point will also have to be adjusted to maintain revenue neutrality.

For the NONLINEAR LOW scenario, $b = ½$ and R_{nl} = \$8,000, chosen so that the range of the feebates is the same as that of GPM LOW. As an alternative, R_{nl} could be chosen to result in average feebate magnitudes that are the same as in GPM LOW. In any event, it is the shape of the curve that is important to compare between these two cases (Figure 4–31).

The range and average magnitude of the NONLINEAR LOW feebates are provided in Figure 4–32. While the range of the NONLINEAR LOW feebates is closer to the GPM LOW scenario, the average magnitude of the feebates is closer to GPM HIGH. The feebate differentials are increased without increasing the range. As a result, the mix shifting is also increased. As shown in Figure 4–33, new-car fuel economy reaches almost 17 percent more than the BASELINE scenario by 2005—2 percent higher than in GPM LOW and about 1 percent lower than in GPM HIGH. New-truck fuel economy in the NONLINEAR LOW scenario also lies between GPM LOW and HIGH. Consequently, NONLINEAR LOW on-road vehicle fuel economy, fuel consumption, and CO_2 emissions also lie between the GPM LOW and HIGH results. Consumer surplus, however, is very close to that of GPM HIGH.

Size-Based Feebates

Another possible feebate approach involves indexing vehicle fuel economy by some measure of vehicle size (see DeCicco et al., 1991). One way to do this is to divide a vehicle's fuel economy by its passenger interior volume.

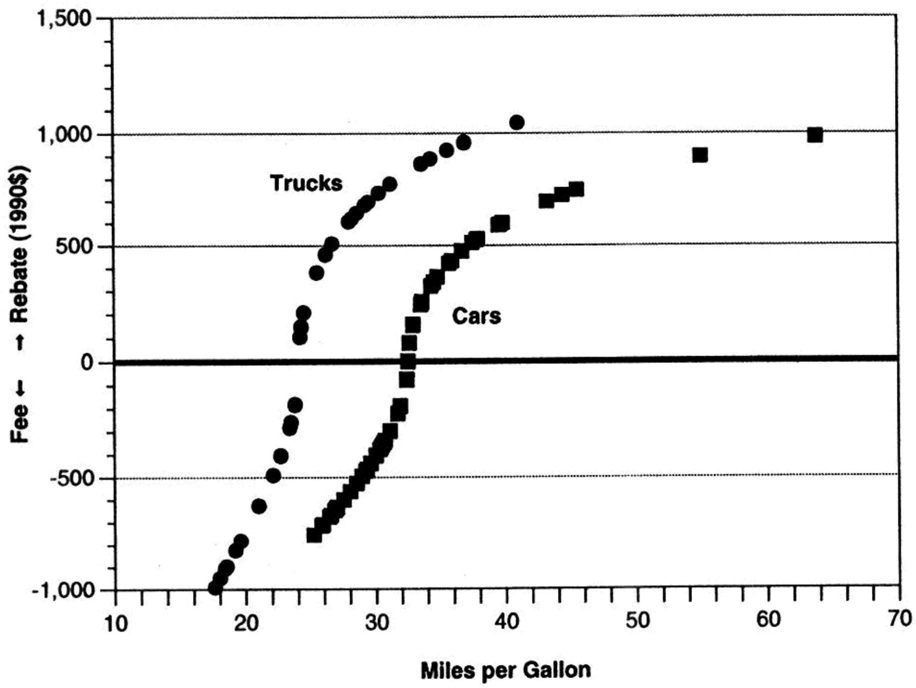

Figure 4–31. Feebate Schedule in 1995 Under NONLINEAR LOW Scenario

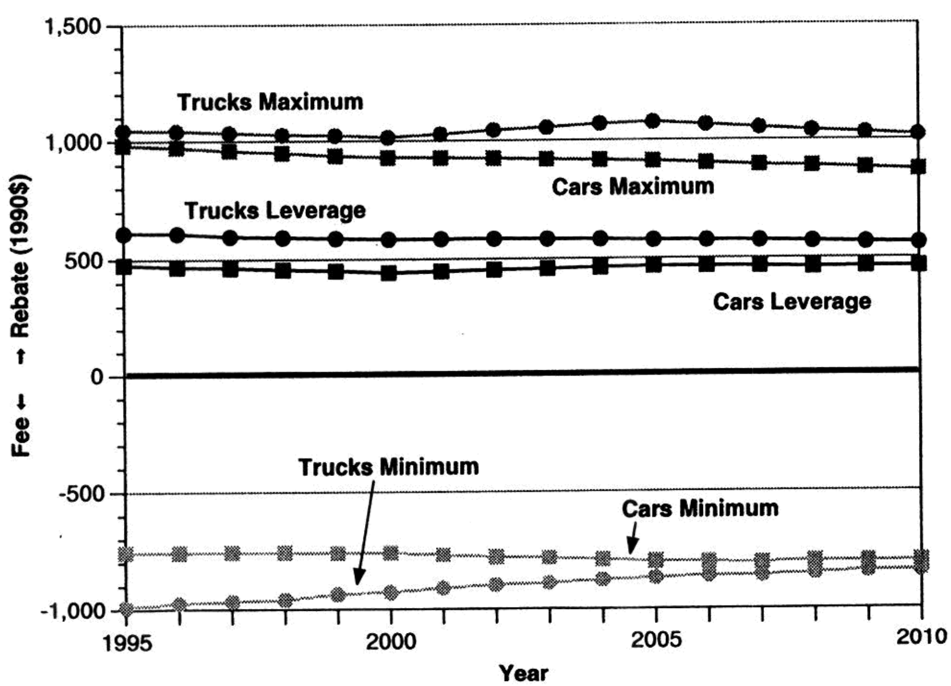

Figure 4–32. Leverages and Ranges Under NONLINEAR LOW Scenario

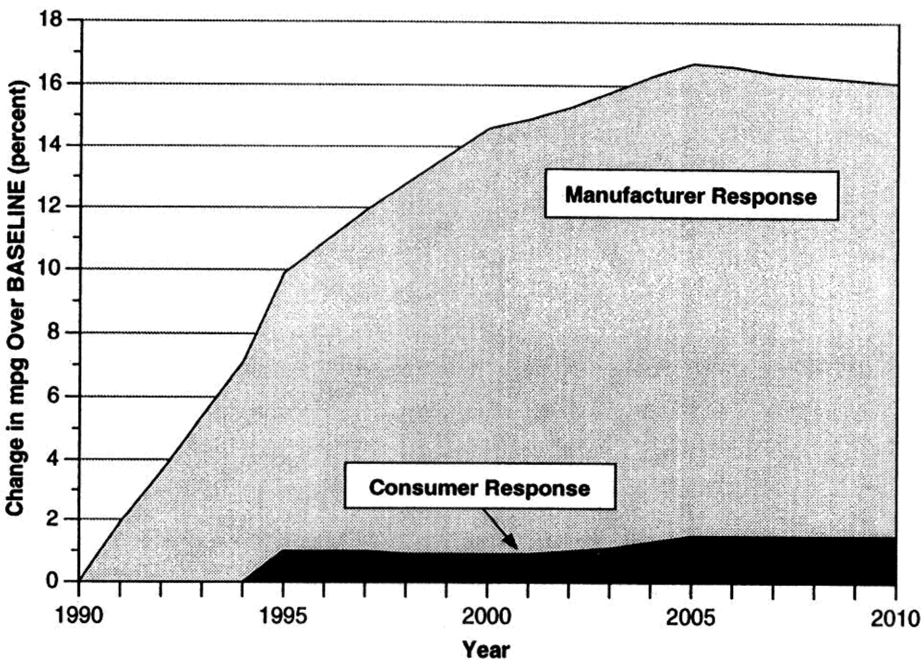

Figure 4–33. Improvements in the Average Fuel Economy of Cars Under NONLINEAR LOW Scenario

The formula for determining the size-indexed feebate for model *i* is as follows:

$$F_{sa} = \left[(S_i \times FE_i)^{-1} - \left(\sum_{i}^{\text{vehicles}} \frac{Q_i / Q_T}{S_i \times FE_i} \right) \right] \times R_{sa}$$

where:

F_{sa} = size-adjusted feebate on an individual vehicle model,

S_i = size index measure (for example, interior volume, total vehicle volume, shoulder width, payload weight, or "footprint"),

FE_i = fuel economy of model *i* (in mpg),

Q_i = sales of model *i*,

Q_T = total sales of all vehicles in year, and

R_{sa} = feebate rate for size-adjusted feebates.

A size-normalized feebate is intended to redress disparities between the incidence of consumption-based feebates on foreign versus domestic fleets. Domestic fleets cater to demand for larger vehicles, tend to consume more fuel, and therefore bear the heavier burden of fees in the other feebate programs. Because a size-based feebate is determined by fuel consumption per unit size, this disadvantage is mitigated. Domestic manufacturers perform better in terms of size-normalized fuel economy than in terms of mpg alone. Both Ford and GM had sales-weighted, size-normalized average fuel efficiencies that were higher than the industry-wide average in 1990, but their sales-weighted, average mpg ratings were below the industry-wide average (Geller and DeCicco, 1991). When size is accounted for, differences in fuel economy between U.S. and Japanese manufacturers as a whole are much less pronounced.

A disadvantage of introducing size normalization into the measure of fuel economy and basing incentives on this value is the potential for increasing vehicle size, which could erode the fuel savings produced by fuel-economy measures alone. For example, increasing the height of vehicles' roofs would increase their interior volume, and thereby allow less efficient vehicles to obtain rebates. Furthermore, size normalization will decrease the variation in feebates among vehicles. Unless the feebate rate were increased accordingly, this would narrow the range of feebates and reduce the incentive for mix-shifting. Moreover, fuel economy is a simple measure that consumers are familiar with. Factoring vehicle size into the measure of efficiency would undermine simplicity and could confuse consumers.

The alternative size measures include interior volume (possibly inclusive of some measure of luggage volume), passenger capacity, wheel base, track width, "footprint," or "shadow." Wheel base is the distance between the front and rear axles. Track width is the distance between the centers of the right and left tires, or the average when this distance differs between front and rear. The "footprint" of a vehicle is the product of the wheel base and average track width. The "shadow" of a vehicle is the product of its exterior dimensions except height, or the area under the vehicle. These size measures all have different advantages and disadvantages when applied to feebates.

Practically, data availability is the most important attribute when selecting among size measures. Interior and luggage volumes are already included in the historical and forecast data provided by EEA. The number of seats, length and width of body (the product of which is the shadow), and wheel base are also available. For trucks, only interior volume is available.

Another attribute to consider is whether the measure is universally applicable to all vehicles to which the size-based feebate will apply. Passenger capacity, wheel base, track width (and therefore footprint), and shadow are all universally applicable measures. Interior volume is not universally applicable without adjustment. It applies well enough to standard passenger vehicles, but falls short on station wagons, vans, utility vehicles, and trucks. Because none of the universally applicable size-based measures is already assembled by EEA for trucks, this criterion has little practical applicability in the case at hand. If a universally applicable size-based scheme is to be developed, additional effort must be undertaken to assemble these data.

Currently, data limitations constrain the study to a volume-based feebate for cars only. The fact that such a feebate cannot be extended to trucks is of less concern because most feebate proposals treat trucks separately. Using passenger (and not luggage) volume reduces the disparity between wagons and all other cars. The size-based feebate examined is linear in fuel consumption (not fuel economy), so the "energy rating" (which is multiplied by the feebate rate) and the resulting feebate, for cars only, will be comparable to the GPM LOW feebate. For the purposes of comparison, trucks in the SIZE-BASED scenario are assigned the GPM LOW feebates, both so the models would not exaggerate the increase in ownership of cars and so fleet totals (such as fuel consumption and on-road fuel economy) would be more comparable with other scenarios.

The chosen feebate rate of $3,750,000 per gpm per cubic foot results in a feebate range of approximately $1,500—about 25 percent higher than GPM LOW. If the feebate range is indeed the binding constraint on the magnitude of the feebate rate, then this feebate should be considered larger than GPM LOW. This feebate, however, only results in a feebate rate for average-sized vehicles (92 cubic feet in 1995) of about $41,000 per gpm, about 25 percent lower than the GPM LOW case. This feebate rate is higher for smaller vehicles and lower for larger vehicles.

The SIZE-BASED feebate schedule is provided in Figure 4–34. Note how it differs from the other feebate schedules—the fuel-economy signal is blurred somewhat by size-indexing. The range and leverage of the SIZE-BASED feebates for cars are provided in Figure 4–35.

The SIZE-BASED feebate increases new-car CAFE by 12 percent in the year 2010 relative to the baseline (Figure 4–36). Fuel savings by the year 2010 are 6.3 gallons. This improvement is lower than under GPM LOW because the

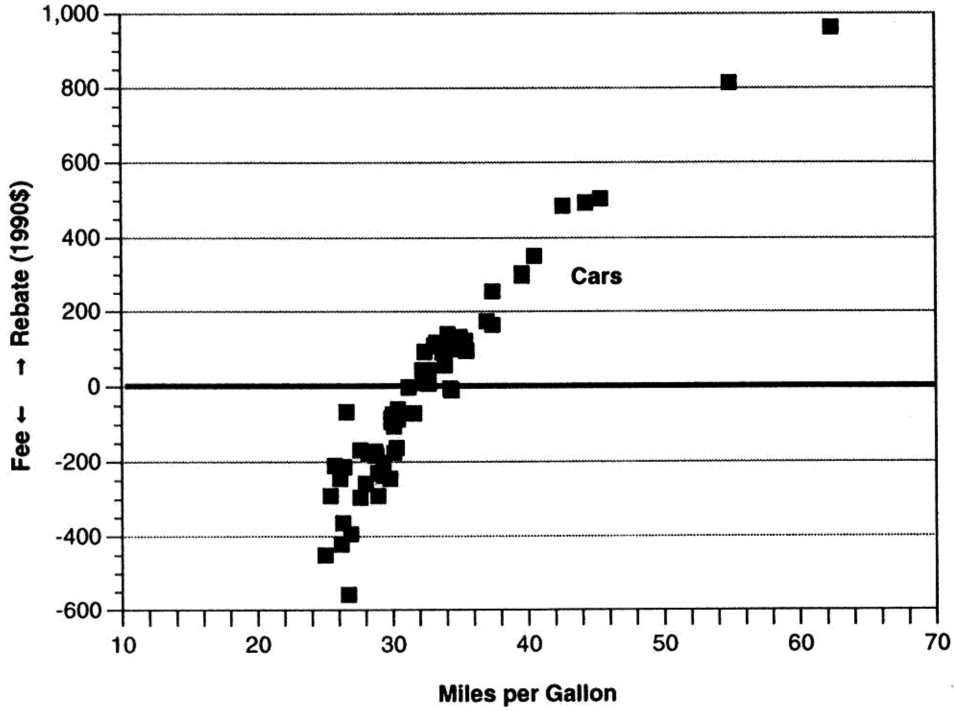

Figure 4–34. Feebate Schedule in 1995 Under SIZE-BASED Scenario

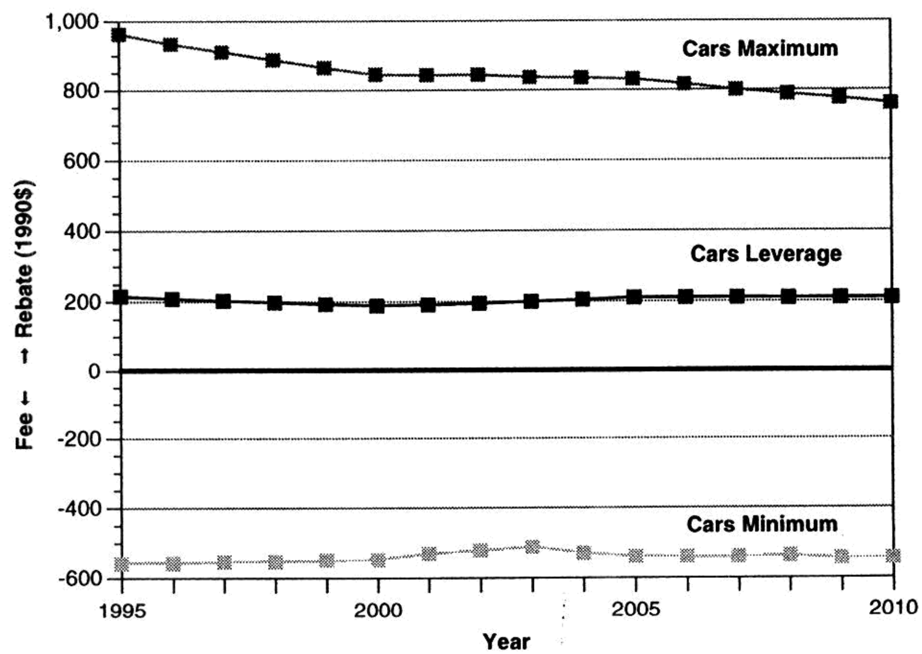

Figure 4–35. Leverages and Range Under SIZE-BASED Scenario

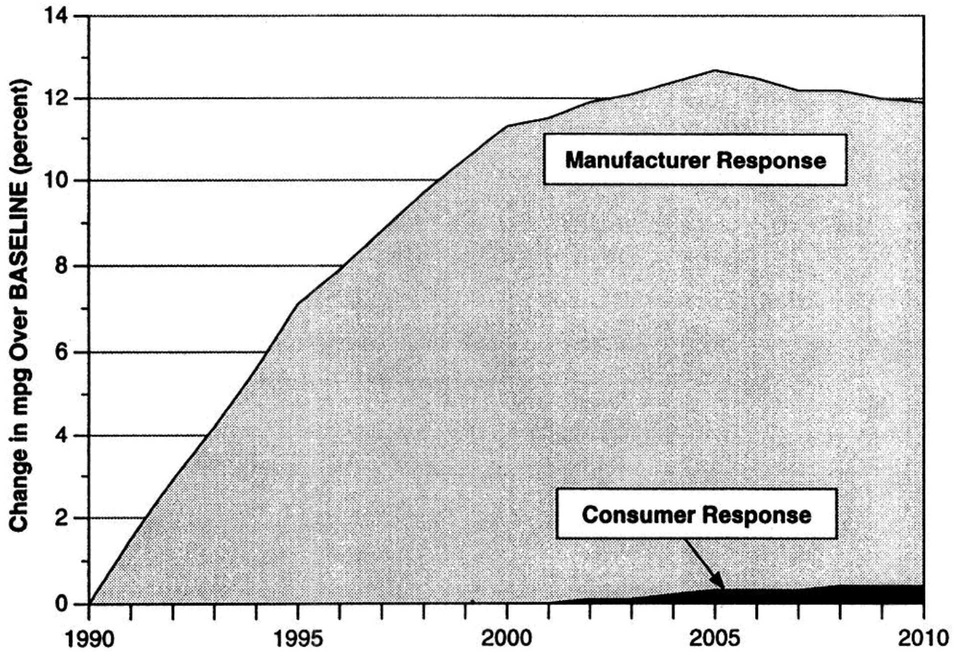

Figure 4–36. Improvements in the Average Fuel Economy of Cars Under SIZE-BASED Scenario

average feebate rate on cars is lower. The SIZE-BASED feebates were specified to have a lower average rate to avoid a large increase in the range of the feebates (the difference between the largest and smallest feebate). To achieve the same average feebate rate with a size-based feebate, the range of the feebates must be about 50 percent larger than a GPM feebate. Because the manufacturer response is closely positively correlated with the average feebate rate, and the manufacturer response is the most important determinant of fuel savings, a size-based feebate could be set to elicit the same response as a consumption-based (GPM) feebate simply by increasing the feebate rate. However, this also increases the range of the feebates. If the range of the feebates is not a binding constraint on the magnitude of the feebate rate, then the SIZE-BASED feebates could protect domestic manufacturers while still achieving the same level of fuel-economy benefits.

Under SIZE-BASED feebates, unlike any of the other scenarios, domestic sales are stimulated, while foreign sales decline. Between 1995 and 2010, discounted cumulative sales increase 0.2 percent for domestic manufacturers, and these sales decrease 3.2 percent for foreign manufacturers.

While the fuel-economy benefits can be as high, the distribution of improvements under SIZE-BASED feebates will be different from the consumption-based feebates—more fuel economy will be incorporated into smaller vehicles than larger ones. Furthermore, if manufacturers respond by increasing the size of their vehicles (which would also allow them to capture a larger feebate), some of the fuel-economy improvements will be lost.

As expected, size-indexing the feebate attenuates the sales-mix shifting compared with GPM LOW—the consumer response is almost invisible. This is a result of large and small vehicles being put on more equal footing in a size-indexed feebate. As a result, sales and ownership of small versus large vehicles track one another more closely after the introduction of the feebate (Figure 4–37). Size-basing eliminates the disparity between the vehicles.

Size-basing also eliminates the disparity between the sales impacts of feebates on foreign versus domestic manufacturers. In fact, it actually reverses this disparity. Figure 4–38 illustrates the difference.

The forecast indicates that size-basing does not materially change the effect of feebates on fuel consumption and CO_2 emissions. New-car CAFE is forecast

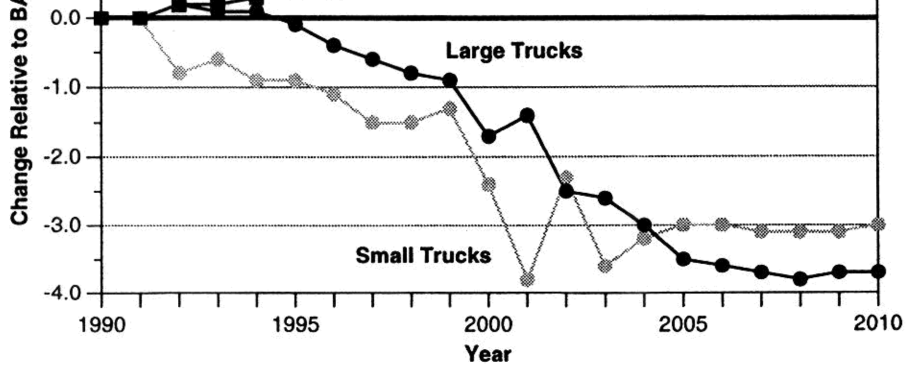

Figure 4–37. Change in Vehicle Ownership Under SIZE-BASED Scenario

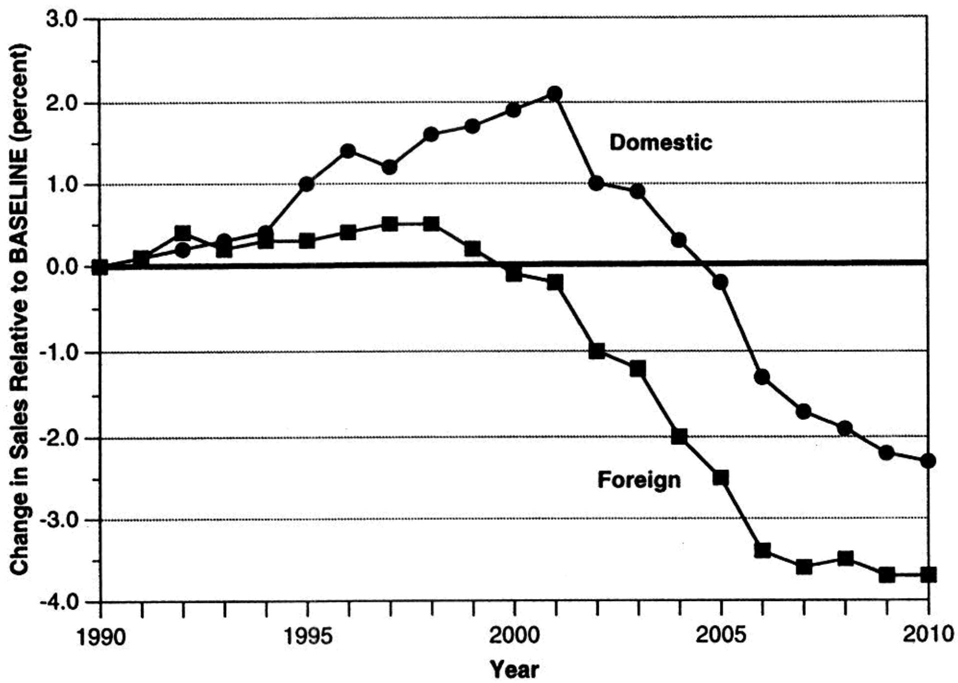

Figure 4–38. Foreign and Domestic Vehicle Sales Under SIZE-BASED Scenario

to rise by 12 percent under the SIZE-BASED scenario, compared with 14 percent under GPM LOW. Total fuel savings by 2010 are estimated to be 6.3 billion gallons per year, compared with 6.9 billion gallons under GPM LOW. It is important to note, however, that this reduction in benefits is due not only to size-basing per se, but rather to the fact that the feebate rate per gpm is somewhat lower under the SIZE-BASED scenario than under GPM LOW (the rate for an average-sized car is $41,000 per gpm under SIZE-BASED, compared with $50,000 per gpm under GPM LOW).

It is also important to note that this analysis does not incorporate the possibility that manufacturers might increase the size of their cars in response to SIZE-BASED feebates rather than (or in addition to) improving their cars' fuel economy. Under SIZE-BASED feebates, manufacturers can obtain higher rebates or lower fees by increasing the interior volume of their vehicles, holding fuel economy constant. To the extent to which manufacturers actually do this, SIZE-BASED feebates will obtain less benefits than comparable consumption-based feebates.

5. Conclusions

All six feebate programs examined in this study provide substantial fuel-economy benefits in the U.S. private vehicle stock. Figure 5–1 compares the effects of these feebate programs on the fuel economy of the entire on-road stock of vehicles relative to the reference forecast.

Feebates (introduced in 1995) result in a 9- to 12-percent improvement in stock fuel economy within 10 years. In all scenarios, about one-fourth of the fuel savings due to increased efficiency is taken back by increased driving. Still, all scenarios result in 6 billion to 8 billion gallons of fuel savings annually by 2010, or 60 million to 80 million tons of annual avoided carbon dioxide emissions (Table 5–1).

New vehicle fuel economy increases more quickly after the introduction of feebates, with total on-road fuel-economy increases following behind as these new, more fuel-efficient vehicles are added to the vehicle stock. By the end of the forecast period (2010), the average fuel economy of new cars improves by

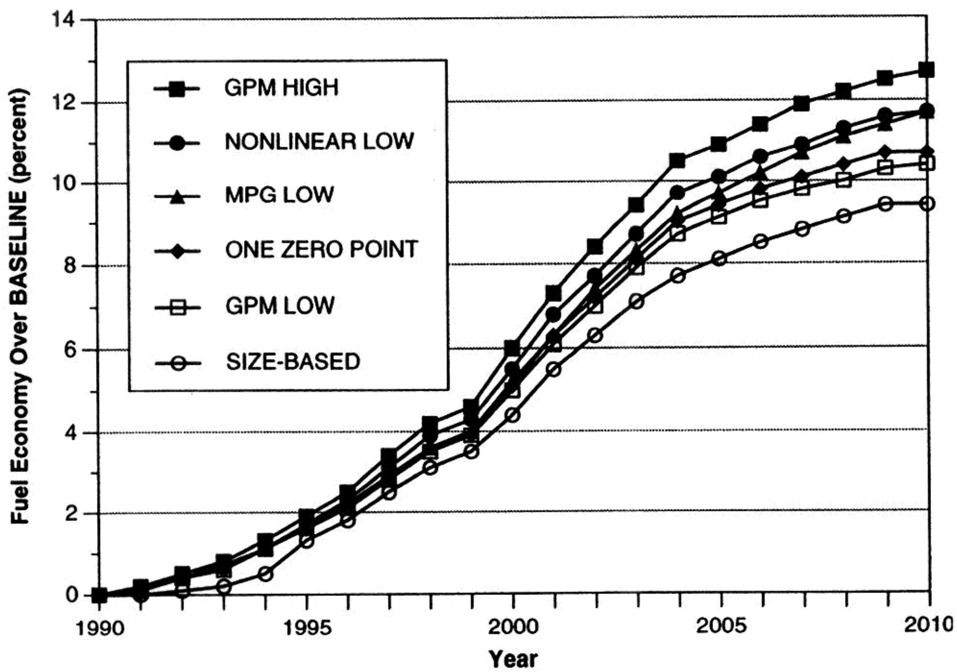

Figure 5–1. Feebate-Induced Improvements in Fuel Economy Under All Scenarios

13 to 18 percent, and the fuel economy of new trucks improves by 10 to 13 percent.

The majority of fuel-economy improvements result from the response of manufacturers to feebates. Manufacturers are projected to install more fuel-economy technologies in their vehicles, because feebates make them more cost effective. The consumer response is estimated to be much less important, accounting for only a 1- to 2-percent improvement in fleet-average fuel economy of new vehicles. There is much less latitude for improvements in fleet fuel economy due to changes in the class mix of vehicle ownership. This finding underscores the importance of understanding the manufacturer response and of designing a feebate to guarantee its capture.

The fuel-economy improvements that result in these savings bring with them reductions in operating costs that provide net benefits to consumers. These operating cost reductions are deemed by consumers to be worth the increase in vehicle price—consumers are willing to pay for the additional fuel economy technologies. It is estimated that the peak benefits to U.S. households reach $70 to $91 per year per household in the various scenarios and, in several scenarios, total more than $10 billion annually when summed over all households. These benefits take into account the additional cost of the fuel-economy technologies, but they do not include external (for example, environmental) benefits or macroeconomic effects. The administrative cost of the program is also not included, but would be much smaller. These consumer

Table 5–1. Reductions in Carbon Dioxide Emissions Under the Six Feebate Scenarios

	2010		Cumulative Total, 1995–2010
	million tons	% savings	million tons
GPM LOW	69	7.0	750
GPM HIGH	83	8.4	890
ONE ZERO POINT	71	7.2	770
MPG LOW	77	7.8	800
NONLINEAR LOW	77	7.8	830
SIZE-BASED	63	6.4	660

Table 5–2. Effects of Feebates on Consumer Surplus

	Maximum Annual Increase in Consumer Surplus per Household, 2010 (1990$)	Discounted Total Benefits, 1995–2010 (billion 1990$[a] in 1995)
GPM LOW	82	51
GPM HIGH	91	56
ONE ZERO POINT	75	47
MPG LOW	87	52
NONLINEAR LOW	90	55
SIZE-BASED	70	43

[a]Discounted at 8 percent per year, from the point of the introduction of feebates (1995).

surplus impacts are summarized in Table 5–2. The second column is the present value of total benefits between 1995 and 2010 (discounted at 8 percent).

The consumer surplus benefits accrue more to higher income households, because such households purchase more vehicles and travel more. Poor households, however, receive a larger proportional increase—the benefit they receive is a larger *share* of their incomes.

The effects of feebates are negative, but small, for domestic manufacturers, except for the SIZE-BASED scenario. Because foreign manufacturers have more fuel-efficient fleets, they initially capture higher feebates. In 1995, purchasers of domestic vehicles pay an average fee of $70 to $91 in five of the six scenarios, while purchasers of foreign vehicles received an average rebate of almost twice that magnitude, $150 to $300. It is important to recognize that this causes a transfer between U.S. consumers, and not a transfer from domestic to foreign manufacturers. Changes in sales are a better indicator of manufacturer impacts. Table 5–3 summarizes the sales impacts.

Feebates in all but the SIZE-BASED scenario cause domestic manufacturers to lose a small amount of market share, at least initially. This share shift is in the neighborhood of 1 percent and decreases later in the forecast period. Because feebates are forecast to stimulate sales initially, the increase in sales makes up for most of these losses in market share, and the discounted percent change in average annual sales of domestic manufacturers decreases only slightly. Total sales increase, and foreign manufacturers capture a larger share

Table 5–3. Impacts of Feebates on Auto Industry (percent)

	Change in Market Share, 1995	Change in Discounted Cumulative Sales, 1995–2010	
	Domestic	Domestic	Foreign
GPM LOW	-0.5	-1.3	0.4
GPM HIGH	-1.2	-1.0	1.4
ONE ZERO POINT	–0.7	–0.1	0.8
MPG LOW	–0.8	–0.7	1.3
NONLINEAR LOW	–1.0	–0.5	1.2
SIZE-BASED	0.0	0.2	–3.2

of this increase. Still, the sales increases largely ameliorate the negative effect of feebates on the profits of domestic manufacturers. The SIZE-BASED scenario, in which the sales impacts are reversed, actually favoring domestic car makers.

Implications

The analysis finds that low feebates (on the order of 1 to 2 percent of vehicle price) will induce a significant reduction in fuel consumption and carbon dioxide emissions. Consumers benefit from the feebates, because they prefer the more efficient vehicles that manufacturers offer in response to the feebates. Consumers benefit even though they bear, through higher vehicle prices, the cost of fuel-economy technologies that are implemented in vehicles—the model finds that they are willing to pay for these technologies. In all but one of the six cases, domestic manufacturers may cede market share in small measure, but the short-run stimulation of total sales is expected to compensate for most of this loss, mitigating the impact on total profits. Since the cost of fuel-economy technologies is incorporated into the price of the vehicles, manufacturers are expected to entirely recoup these costs.

Another key finding is that nearly all of the impact of feebates stems from the response of the manufacturers to feebates. Manufacturers are assumed to implement fuel-economy technologies in their vehicles if the value of the fuel savings exceeds the cost of the technology. Manufacturers incorporate more fuel economy because, with the feebate considered, the technology becomes effectively less expensive.

An implication of this finding is that the effect of State-level feebates will likely be small, because they will be largely unsuccessful in eliciting a manufacturer response. Vehicle sales in a single State make up only a fraction of the total sales of any given manufacturer. It would be more costly and impractical for the manufacturer to modify only a small portion of its product line in response to feebates in a single State. A Federal feebate is required to ensure the benefits of a manufacturer response.

The most important finding of this study is that feebates result in large benefits to the hundred million U.S. households that own and use vehicles. These benefits are achieved at little (or, in the case of the SIZE-BASED scenario, no) expense to U.S. automakers. This result is dependent on the empirical observation that consumers are willing to pay for increased fuel economy. The magnitude of the estimated consumer surplus benefits suggests that the benefits easily outweigh the costs of feebates. Using the market rather than government regulation, feebates are likely to be effective in achieving energy, environmental, and economic goals simultaneously.

APPENDIX A. FUEL ECONOMY MODEL

This appendix provides a detailed technical description of the supply-side model used in this analysis. This model is known as the Fuel Economy Model (FEM) and was developed by K.G. Duleep at Energy and Environmental Analysis, Incorporated (EEA). Additional documentation is available in Duleep (1992).

FEM starts with the fuel-economy characteristics of actual 1990 vehicles. For each of the 95 subclasses (see Appendix C for a detailed description of this subclass structure), FEM forecasts how these characteristics will change, given different fuel prices and policy scenarios. In addition to fuel economy, these characteristics include weight, horsepower, and price. The central calculation in FEM determines cost-effectiveness of each individual fuel-economy technology for every vehicle subclass. This cost-effectiveness in turn determines the market penetration of the fuel-economy technologies, subject to retooling and regulatory constraints, as well as technology interactions. The effect of the introduction of additional fuel-economy technologies on the vehicle characteristics is calculated for every subclass. Finally, these characteristics are adjusted slightly, to account for small increases in horsepower. In the following sections, these calculations are specified precisely, example calculations are given, and as much input data is described as practical. Technology cost and savings data are provided. The modification to the FEM algorithm necessary for the NONLINEAR feebate scenario is also discussed.

1990 Vehicle Characteristics

Table A–1 summarizes the characteristics of the 1990 vehicles that serve as the starting point for all FEM forecasts. The characteristics as reported at the class level are sales-weighted averages of the subclass characteristics, and as such are not used directly in the FEM forecasts. They do, however, summarize the magnitudes of the actual subclass input. Similarly, the subclass data are in turn weighted averages of model characteristics. Ideally, modeling could be undertaken at the configuration level, but because there are more than 1,000 configurations available in each model year, cost and computing constraints require some degree of aggregation. The 95 subclasses used in this analysis represent a feasible compromise.

Table A–1. Base-Year (1990) Vehicle Characteristics

	Class	No. of Sub-classes	No. of. Makes (Imp.)	No. of. Makes (Dom.)	Sales (1,000s)	Price (1990$)	CAFE (mpg)	Horse-power
Minicompact	1	5	26	0	259	$11,236	37.2	97
Subcompact	2	9	28	6	1,547	$10,618	34.0	94
Sports	3	8	24	6	663	$15,439	26.9	142
Compact	4	7	13	28	2,095	$13,433	29.4	115
Midsize	5	8	5	39	1,934	$15,738	26.6	137
Large	6	2	0	9	599	$18,331	24.5	162
Luxury	7	6	57	12	941	$32,904	22.7	180
Near Luxury	8	7	19	8	477	$18,851	25.8	144
Midsize Wagon	9	5	2	10	149	$16,469	26.0	141
Large Wagon	10	2	0	5	31	$18,746	22.7	143
Near Truck	11	4	10	3	77	$15,101	26.5	121
Minivan	12	2	3	0	20	$13,569	33.8	95
Mini Utility	13	2	4	0	55	$12,625	30.8	79
Compact Pickup	14	6	16	11	890	$11,799	24.7	122
Compact Van	15	9	8	17	968	$17,579	22.8	140
Compact Utility	16	5	7	8	478	$19,209	20.6	150
Standard Pickup	17	3	0	27	945	$15,339	18.0	177
Standard Van	18	3	0	22	292	$15,770	17.4	175
Standard Utility	19	2	0	14	175	$20,860	16.4	200
Domestic Cars	1–10 D	30	117	—	4,983	$16,570	26.5	137
Import Cars	1–10 D	29	—	174	3,714	$16,043	29.8	121
Domestic Trucks	11–19 I	22	102	—	3,070	$16,305	20.1	157
Import Trucks	11–19 I	14	—	48	829	$13,882	24.0	122
All	**1–19**	**95**	**219**	**222**	**12,596**	**$16,173**	**25.2**	**136**

The most interesting thing to observe from Table A–1 is the size composition (and thus power and fuel economy) of the domestic versus foreign vehicle fleets. Foreign models comprise the bulk of the available makes of small cars, while domestic manufacturers provide the majority of the available medium to large car makes. In the truck market, the minis are all imports, while large trucks are all domestic. The predominance of domestic manufacturers in the truck market is also evident. The result of this difference in the size composition of the foreign and domestic vehicle fleets is that power is lower and fuel economy higher in the foreign fleets. This is the source of the differential impacts of feebates discussed in the body of this report.

In addition to these characteristics, the percent penetration of every fuel economy technology must be known for each subclass. This determines the potential for the technology to further change the fuel economy of that subclass, and also influences the cost and savings of fuel economy technologies.

Cost-Effectiveness of Fuel-Economy Technologies

For each of these 95 subclasses, FEM calculates the cost-effectiveness of each of 55 vehicle fuel-economy technologies. This cost-effectiveness depends on expected fuel price, technology cost, fuel savings (which is in turn a function of both the technology and the distance driven), discount rate, and payback period.

There is also a term for the "value of performance" folded in to the cost-effectiveness calculation. Fuel-economy technologies affect acceleration, which is also an attribute desired by consumers. The decision of whether to incorporate a fuel-economy technology therefore depends on its effects on both acceleration (represented by the horsepower-to-weight ratio) and operating cost. Because the calculation of market penetration is based only on cost-effectiveness, the acceleration effects must be converted to dollar terms and counted as a benefit for performance effects to have any impact on the penetration of a fuel-economy technology.

The benefit/cost ratio, incorporating this valuation of performance potential as well as the impact of feebates, is therefore calculated as follows:

$$\frac{B}{C} = \frac{PVFUELSAVE + VAL\$PERF + \Delta FEEBATE}{TECHCOST} \qquad \text{(A–1)}$$

where *PVFUELSAVE* is the present value of fuel savings, *VAL$PERF* is the consumer valuation of performance potential, *ΔFEEBATE* is the change in the feebate that the fuel-economy technology allows, and *TECHCOST* is the cost to the manufacturers (before markup) of the fuel-economy technology. *ΔFEEBATE* depends on the type of feebate that is applied (see the formulas in the body of the report), and is simply the difference in the feebate before and after the fuel-economy technology is introduced. A feebate makes fuel-economy technologies more cost-effective.

The 55 fuel-economy technologies, their costs, and fuel-economy savings, as well as their weight and horsepower impacts and earliest dates of introduction, are all provided in Table A–2.

Descriptions of these technologies can be found in Duleep (1993). A description of the engineering model used to calculate the fuel-economy improvements of individual technologies is available in Duleep (1993) and OTA (1991).

With these data the cost-effectiveness calculations can be undertaken. *TECHCOST* in equation A–1 is simply *Cost* in Table A–2. *PVFUELSAVE* (for year *y*, technology *t*, and subclass *sc*) is the present value of expected fuel savings, over the first 4 years and at an 8-percent discount rate for this analysis, calculated as follows:

$$PVFUELSAVE_{y,t,sc} = \sum_{i=1}^{4} \frac{VMT_{y+i} \times EXFP_{y+i}}{\Delta\%FE_t \times FE_{sc,y}(1.08)^i} \qquad \text{(A–2)}$$

where *VMT* is the miles traveled by subclass *sc* *i* years after the base year *y*, *Δ%FE* is the percent change in fuel economy for technology *t*, given in the above table, and *FE* is the fuel economy in the base year *y* for subclass *sc*. *EXFP* is the expected fuel price in year *y* + *i*, and is given by projecting the

Table A–2. Vehicle Fuel-Economy Technologies

	Technology	Change in Fuel Economy (percent)	Cost	Change in Weight	Change in Horsepower (percent)	Year Available
1	Front Wheel Drive	6.0	$160	–8%	0	80 (85)
2	Unit Body	4.0 (6.0)	$80	–5%	0	80 (95)
3	Material Substitution II	3.3	$0.6/lb	–5%	0	87 (96)
4	Material Substitution III	6.6	$0.8/lb	–10%	0	97 (06)
5	Material Substitution IV	9.9	$1/lb	–15%	0	07 (16*)
6	Material Substitution V	13.2	$1.5/lb	–20%	0	17* (26*)
7	Drag Reduction II	2.3	$32	0	0	85 (90)
8	Drag Reduction III	2.3	$32	5%	0	91 (97)
9	Drag Reduction IV	2.3	$48	1%	0	04 (07)
10	Drag Reduction V	2.3	$64	2%	0	14* (17*)
11	Torque Converter Lockup	3.0	$40	0	0	80
12	4-Speed Automatic	4.5	$225	30	5	80
13	5-Speed Automatic	6.5	$325	40	7	95 (97)
14	Continuously Variable Transmission	7.0	$250	20	7	95 (05)
15	6-Speed Manual	2.0	$100	30	5	91 (97)
16	Electronic Transmission I	0.5	$20	5	0	88 (91)
17	Electronic Transmission II	1.0	$20	5	0	98 (06)
18	Roller Cam	2.0	$16	0	0	87 (86)
19	Overhead Cam 4	3.0	$100	0	20 (15)	80
20	Overhead Cam 6	3.0	$140	0	20 (15)	80 (85)
21	Overhead Cam 8	3.0	$170	0	20 (15)	80 (95)
22	4 (3) Valves per Cylinder 4	8.0 (6.0)	$240	30	45 (30)	88 (90)
23	4 (3) Valves per Cylinder 6	8.0 (6.0)	$320	45	45 (30)	91 (90)
24	4 (3) Valves per Cylinder 8	8.0 (6.0)	$400	60	45 (30)	91 (02)
25	Cylinder Reduction	3.0	($100)	–150	–10	88 (90)
26	5 (4) Valves per Cylinder 4	10.0 (8.0)	$300	45	55	98 (97)
27	Turbocharger	5.0	$500	80	45	80
28	Friction Reduction I	2.0	$20	0	0	87 (91)
29	Friction Reduction II	2.0	$30	0	0	96 (02)
30	Friction Reduction III	2.0	$40	0	0	06 (12*)
31	Friction Reduction IV	2.0	$50	0	0	16* (22*)

Table A–2. Vehicle Fuel-Economy Technologies (continued)

	Technology	Change in Fuel Economy (percent)	Cost	Change in Weight	Change in Horsepower (percent)	Year Available
32	Variable Valve Timing I	5.0	$140	40	10	98 (06)
33	Variable Valve Timing II	3.0	$40	40	15	08 (16*)
34	Lean Burn	10.0	$150	0	0	12* (18*)
35	Two Stroke	15.0	$150	−150	0	04 (08)
36	Throttle-Body Injection	2.0	$40	0	5	82 (85)
37	Multi-Point Injection	3.5	$80	0	10	87 (85)
38	Air Pump	1.0	$0	−10	0	82 (85)
39	Idle Off	1.5	$15	0	10	87 (85)
40	Oil SW-30	0.5	$2	0	0	87
41	Oil Synthetic	1.5	$5	0	0	97
42	Tires I	1.0	$16	0	0	92
43	Tires II	1.0	$16	0	0	02
44	Tires III	1.0	$16	0	0	12*
45	Tires IV	1.0	$16	0	0	18*
46	Accessory Improvements I	0.5	$15	0	0	92 (97)
47	Accessory Improvements II	0.5	$15	0	0	97 (07)
48	Electric Power Steering	1.5	$40	0	0	02
49	4WD Improvements	3.0	$100	−5%	0	02
50	Air Bags	−1.0	$300	30	0	87 (92)
51	Emissions Tier I	−1.0	$150	20	0	94 (96)
52	Emissions Tier II	0.0	$150	30	0	03 (04)
53	Anti-Lock Brakes	−1.0	$300	20	0	87 (90)
54	Side Impact	−1.0	$100	40	0	96
55	Roof Crush	−1.0	$100	40	0	01

Notes: When data differ for trucks and cars, the truck data are given in parentheses. Costs are given in 1990 dollars or 1990 dollars per pound (for Material Substitution II–V). Weight changes are given in pounds unless a percent sign is shown. An asterisk indicates that the fuel-economy technology was not available in the time horizon of the feebates forecast, and thus not included in this analysis. When a fuel-economy technology has more than one stage (for example, Drag Reduction II–V) then the latter stages are marginal, in addition to the earlier stages, and thus do not supersede the previous stages, but do require them. For example, Variable Valve Timing II will save a total of 8 percent on fuel economy over the baseline, and cost $180. It cannot, however, be evaluated for cost-effectiveness independent of Variable Valve Timing I). The last 6 options are not fuel economy technologies *per se,* but are regulatory requirements on vehicle technology that affect fuel economy.

average nonnegative increase in fuel price from those between 3 and 5 years before the base year:

$$EXFP_{y+i} = FC_{y-3} + \tfrac{1}{2}\max(0, FC_{y-3} - FC_{y-5}) \times (i+2) \qquad \text{(A–3)}$$

where *FC* is the fuel cost in year *y*, in 1990 dollars per gallon.

Finally, the valuation of performance, *VAL\$PERF*, is dependent on changes in income versus expected operating cost:

$$VAL\$PERF = \$PER\%HP \times \Delta\%HP \times \left(\frac{\Delta\%I}{\Delta\%EXOC}\right) \qquad \text{(A–4)}$$

where Δ%*HP* is the percent increase in horsepower due to the fuel-economy technology (displacement held constant), Δ%*I* is the percent increase in household income over the base year, and Δ%*EXOC* is the percent increase in expected operating cost (calculated based on the expected fuel price in equation A–3, over the actual fuel price 5 years earlier). *\$PER%HP* is \$15 per percent increase in horsepower for all but Sport and Luxury cars, where it is \$30 per percent. This reflects the fact that performance enhancing technologies are more desired in these subclasses. For the technologies that increase performance, the *VAL\$PERF* term commonly dominates in the determination of cost-effectiveness.

Market Penetration

With these three terms, the calculation of the benefit/cost ratio is fully specified. The degree of market penetration of each individual fuel-economy technology (M) is a logistic function of this ratio:

$$M = M_{max} \times P_{max} \times \left(\frac{1}{1+e^{-2\left(\frac{B}{C}-1\right)}}\right) \qquad \text{(A–5)}$$

This logistic curve effectively allows a spread around the central estimate of the cost-effectiveness decision rule by which manufacturers choose to incorporate fuel-economy technologies. One is subtracted from the ratio to set a technology that is just barely cost-effective to a penetration of $M_{max} \times P_{max} / 2$.

M therefore varies depending on the benefit/cost ratio between 0 and the "production constraint" ($M_{max} \times P_{max}$), with a very cost-effective technology (B/C >> 1) adopted almost to the maximum extent possible. Note that all available technologies are adopted to some extent, but very cost-ineffective technologies approach zero penetration. The coefficient on this adjusted benefit/cost ratio (–2) determines the rate at which penetration changes with changes in cost-effectiveness. M_{max} is the maximum market share for the technology (input exogenously, and determined largely by technical constraints). P_{max} is the retooling percentage, included to model the gradual introduction of technologies, to reflect retooling constraints. P_{max} is a function of the logistic adjusted P_{max} 5 years earlier, as indicated in Table A–3.

Note that this functional form for P_{max} reflects the observation that foreign manufacturers can retool their production facilities more quickly than can domestic manufacturers. Also note that any declines in actual market share over time are overridden, with penetration held constant instead.

The final step in determining penetration is to apply the engineering notes. These notes quantify the interactions between fuel-economy technologies, and consist of overrides to the penetration calculations described previously. Engineering notes are of four types: mandatory, supersedes, requires, and synergistic. The "mandatory" note simply makes certain that market penetration is no less than some legislated minimum, usually associated with a safety or emissions technology. The "supersedes" notes are associated with new technologies that replace older ones, and guarantee that the sum of the penetrations of the newer technology and the technology that it supersedes does not exceed 100 percent. The "requires" note controls the adoption of technologies that require another technology to be present in the vehicle,

Table A–3. Retooling Penetration Lag (percent)

Vehicle Group	$M/M_{max}(y-5)$	$P_{max}(y)$
Domestic	0–10	25
	10–25	50
	25–45	70
	>45	100
Import	0–10	40
	>10	100

making sure that the penetration of the former technology does not exceed the penetration of the technology that it requires. Finally, the "synergistic" notes quantify technologies that, when installed simultaneously, interact to result in fuel savings different from those projected by multiplying the effects of the individual technologies.

With this step completed, the final market shares are determined for every fuel-economy technology. The total impacts on the fuel economy, weight, and price of each subclass is then calculated based on the penetration-weighted characteristics of the cumulation of each individual fuel-economy technology. Details regarding the implementation of these final steps are available in Duleep (1992). Finally, the effects on horsepower are calculated, and horsepower is adjusted to account for increasing demand for performance.

Horsepower Adjustment

FEM adjusts horsepower, fuel economy, and price in response to forecast increases in demand for performance in four steps, two for the horsepower adjustment and one each for fuel economy and price.

The horsepower adjustment starts with a simple step to keep the horsepower/weight ratio constant with the base year (1990):

$$HP_y = HP_{1990} \times \frac{WT_y}{WT_{1990}} \qquad \text{(A-6)}$$

Horsepower is then adjusted for forecast changes in demand for performance as follows. An annual adjustment is calculated:

$$ADJHP_y = PERFACT \times \left[\left(\frac{I_y}{I_{y-5}}\right)^{0.9} \left(\frac{P_{y-5}}{P_y}\right)^{0.9} \left(\frac{FE_y}{FE_{y-5}}\right)^{0.2} \left(\frac{FC_{y-5}}{FC_y}\right)^{0.2} - 1 \right] \qquad \text{(A-7)}$$

where variables are defined as previously, with the addition that *PERFACT*, the performance factor, is 1 for all classes except Luxury and Sport, where it is 1.2, and P is the average sales price of the vehicle subclass in year y. This equation is based on a log-linear regression on the demand for performance, where the coefficients are the parameter estimates on the $\Delta\%$ variables. Once the annual horsepower adjustment is calculated it is applied cumulatively over time to determine final horsepower, *FHP*:

$$FHP_y = HP_{1990} \times \left(1 + \sum_{y=1995}^{2010} ADJHP_y\right) \qquad \text{(A-8)}$$

Final horsepower is subject to a driveability constraint that $WT / HP \geq 25$ for Sport and Luxury classes, and $WT / HP \geq 30$ for all other classes.

Once the horsepower adjustment is determined, the final fuel economy must be calculated to reflect this change:

$$FFE_y = FE_y \times \left(1 - 0.22 \times ADJHP_y \pm 0.56 \times ADJHP_y^2\right) \qquad \text{(A-9)}$$

This equation represents the technical relationship between fuel economy and horsepower, how one attribute can be traded off for the other. At last, final price is calculated:

$$FP_y = P_y + ADJHP_y \times VALUEPERF \qquad \text{(A-10)}$$

where *VALUEPERF* is \$30 per HP for Sports and Luxury classes, and \$15 per HP for all other classes.

Nonlinear Scenarios

The incremental change in a feebate due to the introduction of a fuel-economy technology is included as a benefit in the numerator of the formula for cost-effectiveness, and is a function of the fuel savings provided. The calculation of the feebate value of an incremental change in fuel efficiency is straightforward for all but the nonlinear feebate scenarios. For NONLINEAR LOW the instantaneous rate of change of the feebate value is very high near fleet average fuel efficiency. Indeed, it approaches infinity in the neighborhood of the fleet average:

$$\frac{dF_{nl}}{dGPM} = \begin{cases} b\,R_{nl}\left(GPM - \overline{GPM}\right)^{b-1} & \text{for } GPM < \overline{GPM} \\ -b\,R_{nl}\left(GPM - \overline{GPM}\right)^{b-1} & \text{for } GPM > \overline{GPM} \end{cases} \qquad \text{(A-11)}$$

This can cause an instability in the ranking of benefit/cost ratios. Two technologies (both must only induce small improvements in fuel economy in that range of instability) can each appear more cost-effective than the other depending on the order of introduction. In each case the second technology is capturing a larger increase in the feebate because the rate of change of the feebate is increasing so quickly in this range.

Figure A–1 illustrates the feebate rates for the NONLINEAR HIGH and LOW feebates (calculated for Δmpg = 0.1). The instability at fleet-average fuel efficiency begins to show for NONLINEAR HIGH at this small a step size.

Energy and Environmental Analysis developed an alternative approach that avoids the instability around fleet average (Figure A–2). Instead of using a variable feebate rate, a constant feebate is assigned to each mpg starting value. This feebate rate is calculated as the average feebate rate that would be applied under the nonlinear scheme given a 10-percent improvement in fuel economy. This average and constant feebate rate is applied to each subclass according to its initial fuel economy, regardless of how much that fuel economy improves—the baseline for calculating the feebate rate does not advance as FETs are installed. This has the effects of flattening and widening the peak, and shifting it down slightly, as shown in Figure A–2. Note that this figure is slightly different from Figure A–1 in that it indicates the (constant) feebate rate that is

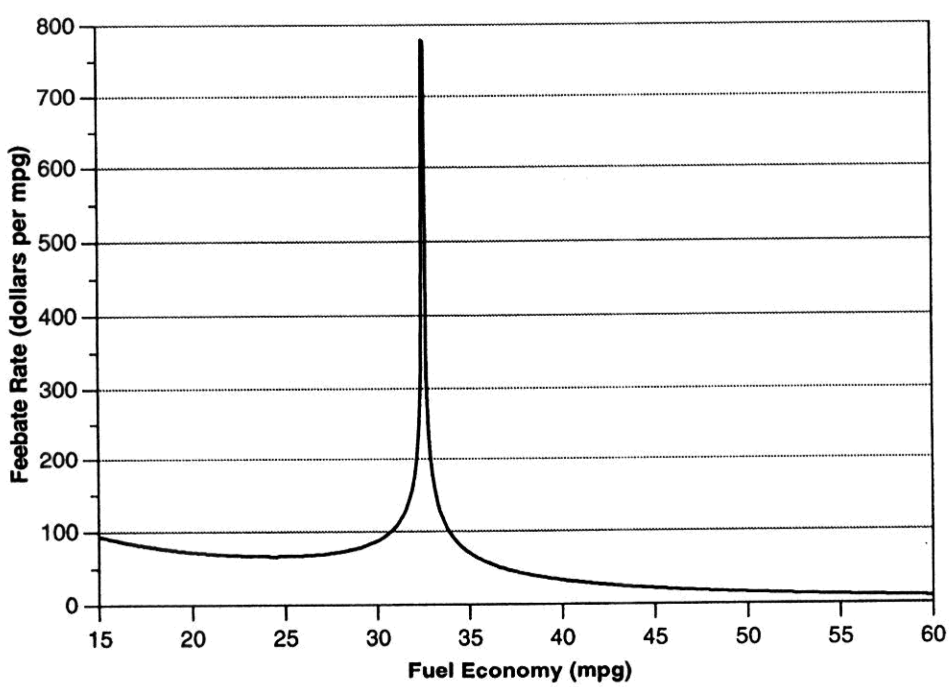

Figure A–1. NONLINEAR LOW Feebate Rate, 1995

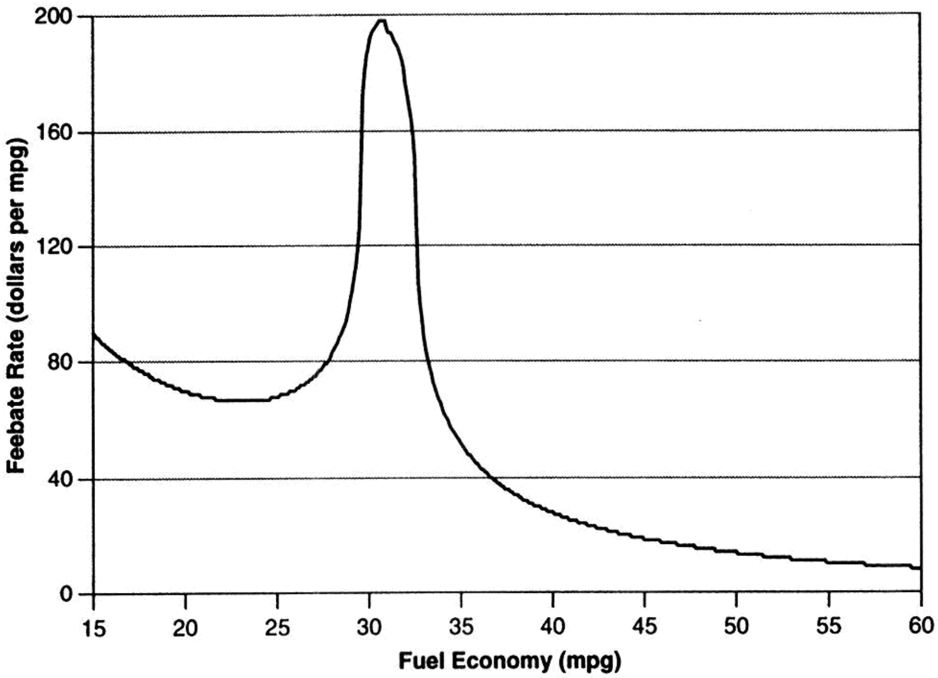

Figure A–2. Energy and Environmental Analysis' Approximation of NONLINEAR LOW Feebate Rate

applied to a subclass given its starting mpg. This approach, in addition to resolving the instability problem, also spreads the incidence of the high feebate rates over the majority of the vehicles in the fleet.

Appendix B. Consumer Automotive Response System

This appendix provides the mathematical structure of each of the five Consumer Automotive Response System (CARS) submodels: Number of Vehicles, the two Subclass and Vintage submodels, and the two Vehicle-Miles Traveled submodels. It does not reiterate the conceptual overview of the CARS model provided in Chapter 2 of this report.

Number of Vehicles Submodel

Three alternatives are considered available to a household in the Number of Vehicles submodel: owning zero, one, or two vehicles. This submodel does not explicitly incorporate the possibility of owning three or more vehicles. When forecasting, the total number of vehicles owned by two-vehicle households is scaled up to account for households with three or more vehicles. This submodel does not simply choose the most likely number of vehicles for a household with the given characteristics, but rather reports the probabilities for each alternative. When forecasting, these probabilities are used as proportions for the number of like households owning zero, one, or two vehicles.

These probabilities are estimated by specifying the sampling process as logit, using the following functional form:

$$P(N) = \frac{e^{\vec{\beta}_N \vec{\chi}_N}}{\sum_i^{1,2} e^{\vec{\beta}_i \vec{\chi}_i}}$$

where:

$P(N)$ = the probability of a household owning N vehicles,

$\vec{\chi}_N$ = a vector of household characteristics that relate to owning N vehicles, and

$\vec{\beta}_N$ = a vector of coefficients on $\vec{\chi}_N$, which is estimated.

The probability of the last alternative (chosen to be zero vehicles) is completely determined by the probabilities of the other alternatives (one and two vehicles), so only two sets of parameters need be estimated. The coefficient

Table B–1. Coefficient Estimates for Number of Vehicles Submodel

	One Vehicle		Two Vehicles	
Variable	Coefficient	T-statistic	Coefficient	T-statistic
Log Income	1.05	(3.69)	1.57	(3.52)
Number of Workers	1.08	(3.78)	1.5	(4.78)
Log Number of Members	0.181	(0.43)	0.197	(0.39)
Transit Usage	–0.0009	(1.82)	–0.0021	(3.42)
Utility	6.35	(7.14)	6.35	(7.14)
(Constant)	–1.79	(2.97)	–4.95	(5.19)

Notes: 634 observations. Log-likelihood at convergence is –475.03.

estimates are shown in Table B–1, and the interpretation of the coefficients on each variable is discussed below.

The number of vehicles a household owns depends on its income. Because both coefficients are positive, the probability of owning vehicles increases as income increases. Because the two-vehicle coefficient is larger than the one-vehicle coefficient, the model forecasts that, as income increases, the probability of owning two vehicles increases relative to one or no vehicles. The variables are specified in terms of logs to reflect the fact that the *effect* of additional income decreases as income itself increases.

The coefficients on the number-of-workers variable imply that, as the number of workers in the household rises, the probability of vehicle ownership rises and the probability of owning more than one vehicle increases faster than the probability of owning a single vehicle.

The effects of the number of members in the household is small, and the range of uncertainty in the estimation does not convincingly preclude the possibility that there is no effect. However, the point estimates are positive as expected.

Households with better access to public transportation have less need for personal vehicles. The number of public transit trips per capita in an area is used as a proxy for the quality and accessibility of public transportation. The estimated coefficients, though small, are negative as expected. Increased trips on public transportation are associated with a reduction in the probabilities of vehicle ownership.

The utility (the term is used in the economist's sense where consumers are utility maximizers) variable is in turn a function of the characteristics of the households and the vehicles. Its exact specification is given in the description of the Subclass/Vintage submodel. Unsurprisingly, the variable enters with a positive coefficient. Any change in the characteristics of a vehicle that increases the utility of the households (such as an increase in fuel efficiency or a decrease in price) will increase the probability of vehicle ownership.

Finally, constants are included in the model, and adjusted in the calibration process.

Subclass and Vintage Submodels

Once it is determined how many vehicles the household owns, one of the two Subclass and Vintage submodels determines what types of vehicles are owned. This choice is dependent on whether the household owns a single vehicle or a pair of vehicles. The ownership choice is modeled separately based on this initial choice. This pair of submodels gives the probability of ownership for each subclass and vintage of vehicles or pair of vehicles. The probabilities are again specified as logit.

Before proceeding to a discussion of the variables and coefficient estimates of these submodels, the utility variable that entered the submodel of number of vehicles owned will be specified. $\vec{\beta_i}\vec{\chi_i}$ can be interpreted as the utility that the household obtains from its choice of a particular class and vintage of vehicle (or pair of vehicles). The average utility, $\overline{U}$, over all classes and vintages of vehicle (or pair of vehicles) i can then be given by

$$\overline{U}(i) = ln\sum_i e^{\vec{\beta_i}\vec{\chi_i}}$$

or the log-sum of the individual utilities. This type of averaging is indicated by the GEV specification of the overall model, and inclusion of this variable is necessary for the calculation of unbiased estimates. It is this variable that is entered into the number of vehicles submodel.

The variables that enter the Subclass and Vintage submodels and their estimated coefficients are presented in Table B–2.

Table B–2. Coefficient Estimates for Vehicle Subclass and Vintage Submodels

	One Vehicle		Two Vehicles	
Variable	**Coefficient**	**T-statistic**	**Coefficient**	**T-statistic**
Purchase Price (I ≤ $12k)	–0.00038	(2.50)	–0.000531	(2.09)
Purchase Price ($12k < I ≤ $20k)	–0.000283	(2.06)	–0.000383	(2.28)
Purchase Price (I > $20k)			–0.0001713	(1.29)
Fuel Costs (I ≤ $20k)	–0.3209	(1.55)	–0.441	(1.96)
Fuel Costs (I > $20k)			–0.33	(1.35)
Number of Transactions	–3.63	(19.3)	–4.48	(13.5)
Front and Rear Shoulder Room (H ≤ 3)	–0.0228	(0.704)	0.037	(1.47)
Front and Rear Shoulder Room (H > 3)	0.0359	(1.05)	0.0533	(2.09)
Variance in Shoulder Room	0.00186	(1.95)		
Difference in Shoulder Room			0.024	(2.01)
Luggage Space (H ≤ 3)	0.0447	(1.28)		
Luggage Space (H > 3)	0.1033	(1.93)		
Horsepower (I > $25k)	0.0149	(1.78)	0.00954	(1.43)
Log of Vehicles in Class	0.544	(3.4)	0.307	(1.7)
Number of Foreign Cars	–0.472	(1.41)	–0.662	(1.64)
Prestige Dummy			1.2	(2.5)
Number of 0–2-Year-Old Vehicles	1.24	(2.12)	0.155	(1.67)
Number of 3–6-Year-Old Vehicles	0.6	(2.09)	0.931	(2.84)
Number of 0–2-Year-Old Vehicles (I > $12k)	0.916	(1.5)	1.35	(1.49)
Number of Pickup Trucks	0.639	(3.95)	2.05	(1.7)
Number of Vans	0.38	(0.234)	0.679	(0.56)
Number of Utility Vehicles			–2.89	(3.26)

Notes: 274 and 241 observations for one- and two-vehicle models, respectively. Log-likelihood at convergence is –371.67 and –130.55 for one- and two-vehicle models, respectively. For two-vehicle pairs, the observation is the sum of the characteristics of both vehicles. Any variable whose name begins with "Number of" is a dummy variable for the one-vehicle model. For the one-vehicle model, the purchase-price variable is partitioned into two ranges only, incomes (I) greater or less than $12,000, and the operating costs variable is not partitioned by income.
H = number of members in household.

Most of the variables that enter the two-vehicle submodel are defined as the sum of the average characteristics of the two subclass/vintages in the vehicle pair. This specification (which is required by data limitations) embodies the following model of purchase behavior: When households are considering a pair of vehicles to own, they consider the aggregate characteristics of that pair. For example, when the price of either vehicle in a pair increases, the probability of owning that pair decreases.

The coefficients on average price are all negative, as expected (as the average price of a vehicle or vehicle pair increases, the probability of owning it decreases). Average price enters separately for households of below and above average income ($12,000 per year in 1978, in then-current dollars), and also for above $20,000 per year for two-vehicle households. The coefficients are increasing with income. This indicates that, as expected, lower income households place greater emphasis on the price of a vehicle—an increase in price causes a greater decrease in the probability of ownership for low-income households.

The fuel-cost variable was calculated by dividing the price of gasoline by the fuel efficiency of the vehicle (pair). It therefore excludes depreciation, maintenance, and other costs that might be incurred at least in part on a per-mile basis. This variable also enters with a negative coefficient, as expected, indicating that as the fuel cost of a vehicle (pair) increases, then the probability of owning that vehicle (pair) decreases. In addition, if the price of fuel increases, then it becomes more likely that households will choose to own more fuel-efficient vehicles in this model. This is because an increase in the price of gasoline translates into a larger increase in fuel costs for a vehicle that is less fuel efficient.

Purchase price and fuel cost are the two most important parameters for modeling the demand response to feebates. The interval estimates for operating cost are less precise than is commonly accepted. At worst, however, the estimate for operating cost is statistically discernible from zero at the 91-percent error level (that is, it is "significant" with 91 percent confidence).

The transactions variable identifies whether one (or two) transactions are required for the household to own the vehicle (pair). This variable is zero for the subclass/vintage that the household owned in the previous year (because no transaction is required), and is one (or two) for all other vehicles (pairs). The coefficient of this variable captures the variety of transactions costs involved in parting with a currently owned vehicle and purchasing another.

Unfortunately, because the sample on which the forecast is based does not include information about the previous year's vehicle ownership, this variable must be excluded from this modeling.

The shoulder-room variable is one indicator of passenger space. As expected, as shoulder-room increases, all else held equal, the probability of purchasing the vehicle (pair) increases. Furthermore, the relative magnitudes of the coefficients for small (three or less) versus large (more than three) households imply that larger households are more concerned about shoulder room than smaller households.

The same relationships are evident for the luggage-space variable. An increase in luggage-space increases the probability of ownership of the vehicle (pair), and for larger households an increase in luggage space weighs heavier in the vehicle ownership decision.

Horsepower enters with a positive coefficient, but only for high-income households. Preliminary estimation indicated that horsepower did not affect the ownership choice of lower income households.

The variance in shoulder room and the number-of-vehicles-in-class variables both indicate that a household is more likely to purchase from a class of vehicles with a larger variety of individual models. These variables have a positive coefficient, as expected.

The remaining variables are dummies (for the one-vehicle households, or discrete 0,1,2 for the two-vehicle households). Their inclusion accounts for the preferences of households with regard to age, manufacturer, and body type, independent of price, fuel costs, and the other variables.

Vehicle-Miles Traveled Submodels

Given the household and vehicle choices provided by the previous submodels, the Vehicle-Miles Traveled submodels forecast the amount that a household will drive its vehicle or vehicles annually. Again, the coefficients in this model are estimated separately for one- and two-vehicle households. The model is specified as a log-linear regression of the form

$$ln(VMT) = \alpha + \vec{\beta}\vec{\chi}$$

where:

VMT	=	the annual vehicle-miles traveled,
$\vec{\chi}$	=	a vector of explanatory variables,
$\vec{\beta}$	=	a vector of coefficients, and
α	=	a constant.

The explanatory variables and their estimated coefficients are reported in Table B–3.

Fuel costs of the subclass/vintage of vehicle owned by the household enters with a negative coefficient, as expected, indicating that households drive more when fuel costs decrease (either through a decrease in the price of gas or an increase in fuel efficiency).

The positive coefficient on income indicates that households with greater income drive more. The other coefficients are similarly self-explanatory. They imply larger households drive more; a household with more workers drives more; households that use public transit more drive less; urban households drive more; and households drive more the farther west they live. Also, in two-vehicle households, the newer car is driven more.

Aggregation Procedure

To apply the model results to the entire United States, it is necessary to aggregate the model's household-level forecasts over a sample of households. Consider a stratified sample of households taken to be representative of all important household type distinctions in the United States. Each household is also assigned a weight, W_n, representing the number of households in the United States that have the same characteristics as the sample household. The model is used to forecast the automotive choices for each of the households in the sample. The aggregate forecasts for the entire United States are then calculated as follows.

Table B–3. Coefficient Estimates for Vehicle-Miles Traveled Submodels

Variable	One Vehicle Coefficient	One Vehicle T-statistic	Two Vehicles Coefficient	Two Vehicles T-statistic
Fuel Costs	–0.2795	(2.63)	–0.0351	(0.472)
Log Income	0.1406	(1.49)	0.276	(3.7)
Log Household Size	0.2131	(1.71)	0.0833	(0.721)
Number of Workers	0.17777	(1.61)	0.0284	(0.456)
Transit Usage	–0.000258	(0.78)	–0.000421	(2.2)
Newer Vehicle Dummy			0.432	(5.16)
City Size Dummy	0.0477	(.0283)	–0.092	(0.876)
Rural Dummy	0.1163	(0.377)	0.2	(1.06)
Northeast Dummy	–0.179	(0.93)	–0.174	(1.18)
Midwest Dummy	–0.074	(0.4)	–0.107	(0.93)
South Dummy	–0.167	(0.89)	–0.648	(0.541)
(Constant)	8.709	(15.4)	6.27	(15.8)

Notes: 226 and 419 observations for one- and two-vehicle models, respectively. R-squared is 0.114 and 0.117 for one- and two-vehicle models, respectively.

The total number of vehicles, N, is the sample-weighted sum of the sample households' projected number of vehicles owned:

$$N = \sum_n W_n[P_n(1) + F \times P_n(2)]$$

where:

- W_n = the weight assigned to each sample household, the inverse of the sample proportion,
- $P_n(1)$ = the probability of household n owning one vehicle,
- F = the average number of vehicles owned by households that own two or more vehicles, and
- $P_n(2)$ = the probability of household n owning two vehicles.

The $P_n(1)$ and $P_n(2)$ terms are provided by the number of vehicles submodel. For 1990, F was calculated to be 2.62. This adjustment corrects for the fact that the model does not explicitly account for ownership of three or more vehicles.

The aggregate number of vehicles of subclass/vintage i is calculated as

$$N(i) = \sum_{n} W_n \left\{ P_n(1)P_n(i) + F \times P_n(2)\left[2P_n(ii) + \sum_{j \neq i} P_n(ij) \right] \right\}$$

with variable assignments as above, and with the following additions:

$P_n(i)$ = the probability of a one-vehicle household n owning subclass/vintage i, and

$P_n(ij)$ = the probability of a two-vehicle household n owning the subclass/vintage pair $i;j$.

These two new terms are provided by the subclass/vintage submodels. The term $P_n(ii)$ is included to account for the possibility that a household owns a pair of vehicles of the same subclass/vintage.

The total number of miles driven on vehicles of subclass/vintage i is determined as follows:

$$VMT(i) = \sum_{n} W_n \Big\{ P_n(1)P_n(i)\,VMT_n(i) + F \times P_n(2)\Big[2P_n(ii)\,VMT_n(i \backslash ii)$$
$$+ \sum_{j \neq i} P_n(ij) VMT_n(i \backslash ij) \Big] \Big\}$$

where again the variables are defined as above, with the addition of

$VMT_n(i)$ = the forecasted VMT for household n, given that it owns one vehicle of subclass/vintage i, and

$VMT_n(i \backslash ij)$ = the forecasted VMT for household n, given that it owns subclass/vintage pair ij.

Finally, fuel consumption and the on-road stock average fuel economy are given.

The fuel consumption, FC, of subclass/vintage i is:

$$FC(i) = \frac{VMT(i)}{mpg(i)}$$

where:

$mpg(i)$ = the average fuel efficiency of vehicles in subclass/vintage i.

Finally, stock average fuel efficiency, *SMPG*, is:

$$\mathrm{SMPG} = \frac{\sum_i VMT(i)}{\sum_i FC(i)}$$

Appendix C. Vehicle Classes and Subclasses

For this analysis, the vehicle stock was broken into 19 primary classes developed by Energy and Environmental Analysis (EEA)—10 car classes and 9 truck classes. These classes are similar to the 14 Environmental Protection Agency (EPA) size classes, except that Midsize and Large Wagons are distinguished from the Midsize and Large classes, Near Truck and Near Luxury classes are drawn from the Subcompact and Compact classes, and a Minivan class is added. In addition, the vehicle classes used in this analysis are based only on passenger volume (except for Sports and Luxury vehicles), while EPA's classification scheme includes passenger and trunk space (which does not handle hatchbacks and wagons well). The names of these primary classes and their relation to the EPA size classes are provided in Table C–1.

This table also indicates how data assembled for the calibration of the earlier EPA 14-class model by Hagler/Bailly were extrapolated to apply to the current class structure. For example, data such as depreciation rates and prestige ratings for the EPA Midsize class were applied to both the Intermediate and Midsize Wagon classes for this analysis. The Near Luxury and Near Truck classes were determined to be an average of the characteristics that apply to the Compact and Subcompact EPA classes. This is the class reconciliation referred to in Appendix D.

For cars, the size ranges are as follows:

- **Minicompact**—less than 79 cubic feet
- **Subcompact**—79 to 88.5 cubic feet
- **Compact**—89 to 94.5 cubic feet
- **Intermediate**—95 to 104.5 cubic feet
- **Large**—more than 105 cubic feet
- **Sports**—less than 89 cubic feet, 2-door only
- **Luxury**—defined by price only, more than $25,000

Two wagon classes are also included, as well as a Near Luxury class for Subcompact and Compact vehicles that cost between $16,000 and $25,000.

Truck primary classes are determined by inertial weight, as follows:

- **Mini**—3,000 pounds and less (3,250 pounds for 4 × 4)

Table C–1. Comparison of EEA Primary Classes with EPA Size Classes

EEA Primary Class		EPA Size Class	
1	Minicompact	1	Minicompact
2	Subcompact	2	Subcompact
3	Sports	6	Sports
4	Compact	3	Compact
5	Intermediate	4	Midsize
6	Large	5	Large
7	Luxury	7	Luxury
8	Near Luxury	2	½ Compact, ½ Subcompact
9	Midsize Wagon	4	Midsize
10	Large Wagon	5	Large
11	Near Truck	2	½ Compact, ½ Subcompact
12	Minivan	10	Compact Van
13	Mini Utility	14	Mini Utility
14	Compact Pickup	8	Compact Pickup
15	Compact Van	10	Compact Van
16	Compact Utility	12	Compact Utility
17	Standard Pickup	9	Standard Pickup
18	Standard Van	11	Standard Van
19	Standard Utility	13	Standard Utility

- **Compact**—3,000 to 4,000 pounds (3,250 to 4,250 pounds for 4 × 4)
- **Standard**—more than 4,000 pounds (more than 4,250 pounds for 4 × 4)

A Near Truck class was added for four-wheel drive (nonluxury) cars.

When results are presented by small and large car and truck groupings, aggregation is as follows: Small cars are classes 1–5, large cars are 6–10. Small trucks are classes 11–16, and large trucks are 17–19. For modeling, these primary classes are broken down further into subclasses, by three criteria: performance (high, low, or very low), technology (high or low), and import status (foreign or domestic).

Table C–2 lists the 95 vehicle subclasses used in forecasting. These are the subclasses that were not empty, that is, there was at least one model on the market that met the criteria, at the start of the forecast period in 1990.

Table C–2. Vehicle Subclasses Used in Forecasts

Car Class	Domestic Perf.	Domestic Tech.	Import Perf.	Import Tech.
1			HiPerf	HiTech
			LoPerf	HiTech
			VLPerf	HiTech
			HiPerf	LoTech
			LoPerf	LoTech
			VLPerf	LoTech
2	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech	LoPerf	HiTech
	LoPerf	LoTech	VLPerf	HiTech
	VLPerf	LoTech	HiPerf	LoTech
			LoPerf	LoTech
			VLPerf	LoTech
3	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech	LoPerf	HiTech
	HiPerf	LoTech	HiPerf	LoTech
	LoPerf	LoTech	LoPerf	LoTech
4	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech	LoPerf	HiTech
	HiPerf	LoTech		
	LoPerf	LoTech	LoPerf	LoTech
5	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech		
	HiPerf	LoTech	HiPerf	LoTech
	LoPerf	LoTech	LoPerf	LoTech
6	HiPerf	LoTech		
	LoPerf	LoTech		
7	HiPerf	LoTech	HiPerf	HiTech
	LoPerf	LoTech	LoPerf	HiTech
			HiPerf	LoTech
			LoPerf	LoTech
8	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech	LoPerf	HiTech
	HiPerf	LoTech	HiPerf	LoTech
	LoPerf	LoTech	LoPerf	LoTech
9	HiPerf	HiTech		
	LoPerf	HiTech		
	HiPerf	LoTech	HiPerf	HiTech
	LoPerf	LoTech	LoPerf	HiTech
10	HiPerf	LoTech		
	LoPerf	LoTech		

Truck Class	Domestic Perf.	Domestic Tech.	Import Perf.	Import Tech.
11	LoPerf	HiTech	HiPerf	HiTech
			LoPerf	HiTech
12			HiPerf	HiTech
			LoPerf	HiTech
13			LoPerf	LoTech
			VLPerf	LoTech
14	HiPerf	LoTech	HiPerf	LoTech
	LoPerf	LoTech	LoPerf	LoTech
	VLPerf	LoTech	VLPerf	LoTech
15	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech	LoPerf	HiTech
	VLPerf	HiTech	VLPerf	HiTech
	HiPerf	LoTech		
	LoPerf	LoTech		
	VLPerf	LoTech		
16	HiPerf	HiTech	HiPerf	HiTech
	LoPerf	HiTech	LoPerf	HiTech
17	HiPerf	LoTech		
	LoPerf	LoTech		
	VLPerf	LoTech		
18	HiPerf	LoTech		
	LoPerf	LoTech		
	VLPerf	LoTech		
19	HiPerf	LoTech		
	LoPerf	LoTech		

Perf = Performance
Tech = Technology

APPENDIX D. CALIBRATION OF THE CARS MODEL

The calibration of the Consumer Automotive Response System (CARS) model entails the iterative adjustment of subclass-specific constants. These constants adjust the utility to the consumer of owning the particular vehicle subclass so that the ownership output of the model concurs with historical observation in the base year (1990). The number of vehicles per household is also calibrated in a similar fashion. Intuitively, these constants account for all variables that affect the utility of owning a particular vehicle that are not included in the model, either directly or as correlates of variables that are included. Train (1986) provides the theoretical justification for and description of this procedure.

For the calibration of CARS for this analysis, constants were calculated for each subclass and for four vintage groups of vehicles. Separate constants were also calculated for new vehicles by primary class. These groupings can be depicted as follows in Figure D–1.

The vintage groupings are 0–2, 3–5, 6–8 and 9+ years old in the base year. Using this method 95 subclass-specific and 3 vintage group constants are calibrated (the 6–8 year vintage group is used as the reference level). Nineteen primary class constants were also calculated for new vehicles. These constants cause the forecasted ownership to equal the actual observed ownership for the group they represent. Therefore this model forecasts total subclass as well as vintage group ownership precisely. It also forecasts class level new car ownership totals correctly in the base year. It does not, however, forecast subclass-vintage-specific ownership, nor even vintage totals exactly (except for the new vintage).

Furthermore, although aggregation over vintages does eliminate most zero ownership groups (for which constants cannot be calculated), there still remain four for which calibration constants must be estimated by other means. The method which has been used in the past is to copy a constant from a similar subclass. However, this throws all ownership totals off slightly. An adjustment to this simple method preserves the accuracy of the other subclass projections. Each zero ownership subclass is assigned the calibration constant of the most similar subclass that had nonzero ownership in the calibration period, then a log-share adjustment factor (usually $ln(½)$) was added to both, which effectively splits the observed ownership of the nonzero subclass equally between the (usually two) subclasses. The correction factor prevents inaccuracy in the projection of ownership for any of the other subclasses in the base year, and

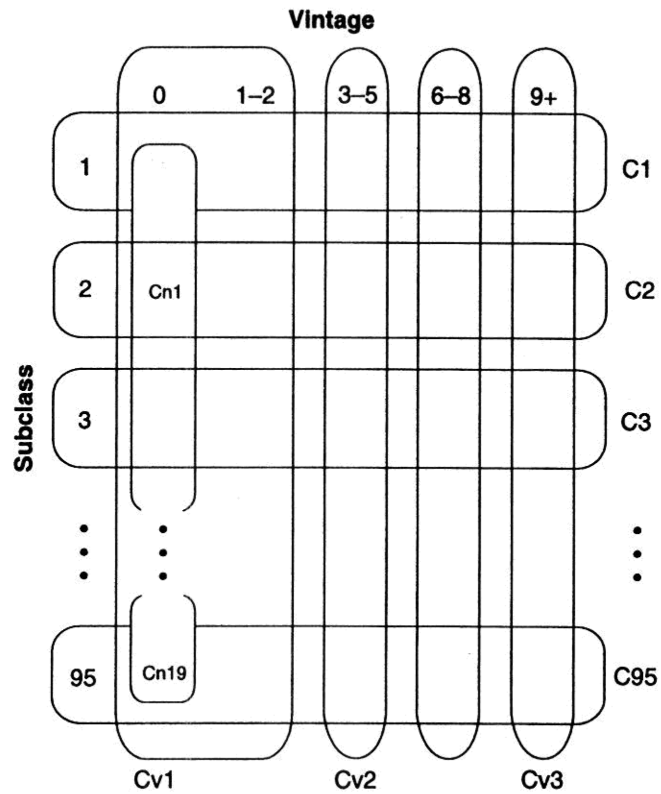

Figure D–1. Constant Groupings for Calibration of Consumer Automotive Response System

forces the total ownership of the combined classes to continue to be correctly forecasted.

Combine zero and nonzero ownership subclasses into a single subclass, and call this alternative k. k is partitioned into m subclasses, with sales s_m, s.t.

$$\sum_m s_m = s_k \qquad \text{(D–1)}$$

Applying the same calibration constant to both subclasses forces forecasted ownership to be equal between the subclasses, assuming the representative utilities of the subclasses are equal. Assuming utilities are equal (this assumption is relaxed below), applying the correction factor of

$$ln\left(\frac{s_m}{s_k}\right)$$

to each subclass results in both:

(a) no effect on choice probabilities (or subclass shares) in other subclasses:

$$P_{in} = \frac{e^{W_{in}}}{\sum_m e^{W_{mn} + ln\left(\frac{s_m}{s_k}\right)} + \sum_{j \in J_n \neq m} e^{W_{jn}}} \qquad \text{(D–2)}$$

$$= \frac{e^{W_{in}}}{\sum_m \frac{s_m}{s_k} e^{W_{mn}} + \sum_{j \in J_n \neq m} e^{W_{jn}}} \qquad \text{(D–3)}$$

$$= \frac{e^{W_{in}}}{\frac{\sum_m s_m}{s_k} e^{W_{mn}} + \sum_{j \in J_n \neq m} e^{W_{jn}}} \qquad \text{(D–4)}$$

$$= \frac{e^{W_{in}}}{e^{W_{mn}} + \sum_{j \in J_n \neq m} e^{W_{jn}}} \qquad \text{(D–5)}$$

$$\stackrel{\checkmark}{=} \frac{e^{W_{in}}}{\sum_{j \in J_n} e^{W_{jn}}} \qquad \text{(D–6)}$$

and (b) the total nonzero ownership being forecasted properly when summed across the *m* subclasses:

$$P_{mn} = \frac{e^{W_{mn}} + \ln\left(\frac{s_m}{s_k}\right)}{\sum_{j \in J_n \neq m} e^{W_{jn}}} \quad \text{(D-7)}$$

$$= \frac{s_m}{s_k} \frac{e^{W_{mn}}}{\sum_{j \in J_n \neq m} e^{W_{jn}}} \quad \text{(D-8)}$$

$$= \frac{s_m}{s_k} \frac{s_k}{S} \quad \text{(D-9)}$$

$$\stackrel{\checkmark}{=} \frac{s_m}{S} \quad \text{(D-10)}$$

where S is total sales.

If sales of the zero ownership vehicles were first apportioned within alternative *k* using these shares, then the calibration process would result in constants adjusted by this log-share factor. The ownership can therefore first be apportioned, then the calibration undertaken. Because this allows the equal utility assumption to be relaxed, this was the method that was finally undertaken.

The vehicle data required for calibration include subclass definitions; ownership by subclass and vintage; the total number of households owning 0, 1, or 2+ vehicles, total vehicle-miles traveled (VMT), and total fuel use by type in the base year; how many years each subclass remains "prestigious;" the import status of each subclass; fuel prices by region in the base year; and vehicle characteristics (price, fuel efficiency, horsepower, luggage space, shoulder room, variance in shoulder room, and number of makes and models in the class) by subclass and vintage. When data is input by vintage, it is for the base year (in this case 1990), each of the 8 previous years individually (1982–1989), and all older vehicles (1981 and earlier) together. The body type of each subclass is also necessary as calibration input, but this information is commonly contained in the classification scheme. Finally, the following information is required of a sample of representative households: annual income, number of members, number of workers, geographical location, and quality and availability of public transport.

The calibration of CARS requires ownership data by subclass and vintage in a base year. Because the effort that would have been required to assemble such data from scratch was prohibitive, these data were estimated as follows. RCG/ Hagler Bailly, Inc., assembled similar data for its calibration of an earlier CARS model, for analysis for the Environmental Protection Agency (RCG/ Hagler Bailly, 1991). These data, however, were aggregated at the primary class level, and the primary classes were slightly different than those used in this analysis. To use the Hagler Bailly data, class reconciliation was necessary. This reconciliation is described in Appendix C.

Eight input files are required for calibration: CLASSES.IN, CONTROL.IN, DEPREC.IN, FUELPR.IN, HHBASE.IN, NVEH0.IN, TOTALS0.IN, and VEHDAT.IN. The process of calibration results in an intermediate file of subclass and vintage specific calibration constants, CONSTNTS.IN.

CONTROL.IN contains only control parameters used to run the model, not data. The household sample (now called HHBASE.IN) utilized by Hagler Bailly was also utilized for this analysis, but forecast to 1990 (the Hagler Bailly base year was 1988). The 1990 ownership and VMT totals (TOTALS0.IN) were provided in the Oak Ridge National Laboratory (ORNL) *Transportation Energy Databook*, edition 13. The gasoline price forecast (FUELPR.IN) used was the 1992 Energy Information Administration forecast, which is described in Appendix E.

The remaining input files are dependent on the subclass structure of the model to be calibrated. The CLASSES.IN file specifies this subclass structure, which was described in the previous appendix. Prestige ratings are included in this file and are estimated for the current calibration by assuming that the previous class ratings apply to all subclasses within that class (this requires the class reconciliation described above). The DEPREC.IN files are constructed in the same manner. Therefore a single depreciation schedule or prestige rating is applied to all vehicles in each primary class. The CLASSES.IN file also reflects the fact that the Near Truck class is not treated as a pickup with respect to the choice model (the pickup body type dummy is not triggered).

Energy and Environmental Analysis (EEA) provided the historical vehicle characteristics, including sales, by subclass and vintage. This information provided the basis for both the NVEH0.IN and VEHDAT.IN files. For VEHDAT.IN, prices in the base year were estimated by applying the depreciation rates to the new prices provided by EEA. Conversion to 1978$ (the currency units used in CARS input) using the national consumer price index was also necessary. VEHDAT.IN is discussed further in the section on aggregation.

NVEH0.IN contains the number of personal vehicles owned by subclass and vintage in the calibration period. To estimate subclass ownership, subclass sales in each year of the calibration period (provided by EEA) were multiplied by ORNL survival rates. ORNL has published two survival rate series, for automobiles and light trucks for 1978–89 and 1978–1988, respectively. ORNL's survival rates are shown in Table D–1.

An approximation was necessary for ownership for the 1981 and earlier vintage. Sales data were provided back to 1979, while the last vintage in both CARS models includes both 1981 and all earlier vehicles. In order to estimate subclass ownership figures for the last vintage group, which includes model years earlier than 1979, it was assumed that the subclass ownership shares for

Table D–1. Vehicle Survival Rates

Vehicle Age (years)	Automobiles	Light Trucks
0	1.00000	1.00000
1	0.99559	0.99751
2	0.98888	0.99369
3	0.97874	0.98790
4	0.96361	0.97923
5	0.94142	0.96654
6	0.90971	0.94848
7	0.86602	0.92376
8	0.80861	0.89154
9	0.73753	0.85182
10	0.65539	0.80569

Source: Transportation Energy Data Book, 13th Ed., ORNL 6649, 1993.

1979 and earlier vehicles are the same as the subclass sales shares in 1979. These shares were multiplied by the Hagler Bailly 1979 and earlier vintage group ownership totals, resulting in estimates of the desired ownership figures. This estimation method is subject to error insofar as subclass sales shares differ from ownership shares and ownership shares differ between 1979 and earlier. Such errors will introduce inaccuracy only in this vintage group. The second fuel price shock occurred in 1979 and may have encouraged the purchase of more fuel-efficient subclasses than previously, but trends in ownership shares were not examined.

The actual subclass sales figures for 1990 were used directly as ownership figures. This method fails to account for scrappage of 1990 vehicles in 1990 (an error of about 0.5 percent). It is, however, much more accurate than the Hagler Bailly method, which relies on R.L. Polk figures that are assembled July 1, which fails to count perhaps one-third of that year's ownership.

Other Inputs

CARS shows consumers responsive to the relative "prestige" of owning a particular vehicle. These prestige ratings are necessary as CARS input. They were determined in the original estimation of the CARS model, and were modified for the new subclass structure using the same class reconciliation applied in the estimation of the subclass ownership data. These prestige ratings are provided in Table D–2.

If a vehicle is determined to be prestigious (for example if it is a Luxury vehicle 5 or less years old) then it receives the adder for the prestige dummy in the calculation of utility. These prestige ratings are also reflected in the CLASSES.IN file provided in the appendix.

To estimate used vehicle prices, Hagler Bailly class level depreciation rates were applied to our subclasses. The same class reconciliation procedure was again applied in this case.

Finally, it was necessary to aggregate the historical vehicle characteristics data into the forecast subclasses for calibration. The historical data provided by EEA included data for at least one vintage in 158 subclasses, while the forecast data included only 83 of these classes, as well as 12 new ones (the zero ownership in the base-year subclasses). The historic vehicle characteristics for VEHDAT.IN were combined into the forecast subclasses as follows. The sales

Table D–2. Years Vehicles Remain "Prestigious"

Primary Class	Class Name	Years Remaining Prestigious
1	Minicompact	1
2	Subcompact	1
3	Compact	2
4	Intermediate	3
5	Large	4
6	Sports	3
7	Near Luxury	4
8	Luxury	5
9	Midsize Wagon	1
10	Large Wagon	1
11	Near Truck	3
12	Compact Van	2
13	Standard Van	3
14	Mini Pickup	1
15	Compact Pickup	2
16	Standard Pickup	3
17	Mini Utility	1
18	Compact Utility	2
19	Standard Utility	4

and the number of makes and models in each subclass were simply summed. Sales price and horsepower were calculated as the sales weighted arithmetic averages. Shoulder room and luggage space were calculated as the make and model weighted arithmetic average. Fuel efficiency was calculated as a sales weighted harmonic average.

$$mpg_p = \frac{\sum s_i}{\sum \left(\frac{s_i}{mpg_i}\right)} \qquad \text{(D–11)}$$

where s is subclass sales and the subscript p indicates the pooled characteristic of i subclasses.

Corporate Average Fuel Economy ratings were adjusted to on-road fuel efficiencies by multiplying by 0.85. Finally, variance of shoulder room was calculated using a formula for pooled variance noted below.

$$\sigma_p = \frac{\sum \sigma_i (n_i - 1)}{n_p - 1} + \frac{\sum n_i (\overline{SR}_i)^2}{n_p - 1} - \frac{\left(\sum n_i \overline{SR}_i\right)^2}{n_p (n_p - 1)} \qquad \text{(D–12)}$$

where σ represents variance in subclass shoulder room, n the number of makes/models in the subclass, $\overline{SR}$ the subclass average shoulder room, and the subscript p indicates the pooled characteristic of i subclasses.

Table D–3 lists the forecast subclasses, and the historical subclasses on which they were based. The subclass criterion in the historical subclasses is not listed if the subclasses were aggregated over this characteristic. For example, for class 1 all domestic and foreign vehicles were aggregated and their vehicle characteristics combined.

Calibration of Marginal Utility

The marginal utility of income is both calculable with CARS and used by CARS for the determination of consumer surplus. To allow more accurate comparison of policy-induced changes in consumer surplus between income groupings, and thus allow a better assessment of the equity impacts of policies, a detailed calculation of marginal utilities by income group (as well as forecast year) was undertaken.

The marginal utility of income (MU_I) and consumer surplus (CS) are related by:

$$CS = \frac{ln \sum_{i}^{0,1,2+} e^{Ui}}{MU_I} \qquad \text{(D–13)}$$

where the numerator on the right-hand side can be interpreted as the average utility of vehicle ownership, dependent on both household and (through the inclusive value term from the vehicle choice models) vehicle characteristics. This is how CARS calculates consumer surplus. In CARS, marginal utility of income is therefore also dependent on forecasts of the characteristics of the

Table D–3. Aggregation of Historical Data to Forecast Subclasses

Forecast Subclass	Class	Perf	Tech	Domestic/ Import	Historical Subclasses	Perf	Tech	Domestic/ Import
1	1	HiPerf	HiTech	Import	1,7	HiPerf	HiTech	
2	1	LoPerf	HiTech	Import	2,8	LoPerf	HiTech	
3	1	VLPerf	HiTech	Import	3,9	VLPerf	HiTech	
4	1	LoPerf	LoTech	Import	4,5,10,11	HLPerf	LoTech	
5	1	VLPerf	LoTech	Import	6,12	VLPerf	LoTech	
6	2	HiPerf	HiTech	Domestic	13	HiPerf	HiTech	Domestic
7	2	LoPerf	HiTech	Domestic	14,15	LoVLPf	HiTech	Domestic
8	2	LoPerf	LoTech	Domestic	16	HiPerf	LoTech	Domestic
9	2	VLPerf	LoTech	Domestic	17	LoPerf	LoTech	Domestic
10	2	HiPerf	HiTech	Import	18	VLPerf	LoTech	Domestic
11	2	LoPerf	HiTech	Import	19	HiPerf	HiTech	Import
12	2	VLPerf	HiTech	Import	20	LoPerf	HiTech	Import
13	2	HiPerf	LoTech	Import	21	VLPerf	HiTech	Import
14	2	LoPerf	LoTech	Import	22,23	HLPerf	LoTech	Import
15	2	VLPerf	LoTech	Import	24	VLPerf	LoTech	Import
16	3	HiPerf	HiTech	Domestic	25	HiPerf	HiTech	Domestic
17	3	LoPerf	HiTech	Domestic	26	LoPerf	HiTech	Domestic
18	3	HiPerf	LoTech	Domestic	27	HiPerf	LoTech	Domestic
19	3	LoPerf	LoTech	Domestic	28,29	LoVLPf	LoTech	Domestic
20	3	HiPerf	HiTech	Import	30	HiPerf	HiTech	Import
21	3	LoPerf	HiTech	Import	31	LoPerf	HiTech	Import
22	3	HiPerf	LoTech	Import	32	HiPerf	LoTech	Import
23	3	LoPerf	LoTech	Import	33	LoPerf	LoTech	Import
24	4	HiPerf	HiTech	Domestic	34	HiPerf	HiTech	Domestic
25	4	LoPerf	HiTech	Domestic	35,36	LoVLPf	HiTech	Domestic
26	4	HiPerf	LoTech	Domestic	37	HiPerf	LoTech	Domestic
27	4	LoPerf	LoTech	Domestic	38,39	LoVLPf	LoTech	Domestic
28	4	HiPerf	HiTech	Import	40	HiPerf	HiTech	Import
29	4	LoPerf	HiTech	Import	41,42	LoVLPf	HiTech	Import
30	4	LoPerf	LoTech	Import	43	LoPerf	LoTech	Import
31	5	HiPerf	HiTech	Domestic	44	HiPerf	HiTech	Domestic
32	5	LoPerf	HiTech	Domestic	45,46	LoVLPf	HiTech	Domestic
33	5	HiPerf	LoTech	Domestic	47	HiPerf	LoTech	Domestic

Table D–3. Aggregation of Historical Data to Forecast Subclasses (continued)

Forecast Subclass	Class	Perf	Tech	Domestic/ Import	Historical Subclasses	Perf	Tech	Domestic/ Import
34	5	LoPerf	LoTech	Domestic	48,49	LoVLPf	LoTech	Domestic
35	5	HiPerf	HiTech	Import	50	HiPerf	HiTech	Import
36	5	HiPerf	LoTech	Import	51	HiPerf	LoTech	Import
37	5	LoPerf	LoTech	Import	52	LoPerf	LoTech	Import
38	6	HiPerf	LoTech	Domestic	53,56	HiPerf		Domestic
39	6	LoPerf	LoTech	Domestic	54,55,57,58	LoVLPf		Domestic
40	7	HiPerf	LoTech	Domestic	59,61	HiPerf		Domestic
41	7	LoPerf	LoTech	Domestic	60,62,63	LoVLPf		Domestic
42	7	HiPerf	HiTech	Import	64	HiPerf	HiTech	Import
43	7	LoPerf	HiTech	Import	65,66	LoVLPf	HiTech	Import
44	7	HiPerf	LoTech	Import	67	HiPerf	LoTech	Import
45	7	LoPerf	LoTech	Import	68	LoPerf	LoTech	Import
46	8	HiPerf	HiTech	Domestic	69	HiPerf	HiTech	Domestic
47	8	LoPerf	HiTech	Domestic	70	LoPerf	HiTech	Domestic
48	8	HiPerf	LoTech	Domestic	71	HiPerf	LoTech	Domestic
49	8	LoPerf	LoTech	Domestic	72,73	LoVLPf	LoTech	Domestic
50	8	HiPerf	HiTech	Import	74	HiPerf	HiTech	Import
51	8	LoPerf	HiTech	Import	75,76	LoVLPf	HiTech	Import
52	8	HiPerf	LoTech	Import	77	HiPerf	LoTech	Import
53	8	LoPerf	LoTech	Import	78,79	LoVLPf	LoTech	Import
54	9	HiPerf	HiTech	Domestic	80	HiPerf	HiTech	Domestic
55	9	LoPerf	HiTech	Domestic	81,82	LoVLPf	HiTech	Domestic
56	9	HiPerf	LoTech	Domestic	83	HiPerf	LoTech	Domestic
57	9	LoPerf	LoTech	Domestic	84,85	LoVLPf	LoTech	Domestic
58	9	HiPerf	HiTech	Import	86	HiPerf	HiTech	Import
59	9	LoPerf	HiTech	Import	87	LoPerf	HiTech	Import
60	10	HiPerf	LoTech	Domestic	89	HiPerf	LoTech	Domestic
61	10	LoPerf	LoTech	Domestic	88,90,91	LoVLPf		Domestic
62	11	LoPerf	HiTech	Domestic	92–5			Domestic
63	11	HiPerf	HiTech	Import	96	HiPerf	HiTech	Import
64	11	LoPerf	HiTech	Import	97–100	LoVLPf		Import
65	13	HiPerf	HiTech	Import	105	HiPerf	HiTech	Import
66	13	LoPerf	HiTech	Import	106,107	LoVLPf	HiTech	Import

Table D–3. Aggregation of Historical Data to Forecast Subclasses (continued)

Forecast Subclass	Class	Perf	Tech	Domestic/ Import	Historical Subclasses	Perf	Tech	Domestic/ Import
67	14,12	LoPerf	LoTech	Import	101,102,108,109	LoPerf		
68	14,12	VLPerf	LoTech	Import	103,104,110	VLPerf		Import
69	15	HiPerf	LoTech	Domestic	111,114	HiPerf		Domestic
70	15	LoPerf	LoTech	Domestic	112,115	LoPerf		Domestic
71	15	VLPerf	LoTech	Domestic	113,116	VLPerf		Domestic
72	15	HiPerf	LoTech	Import	117,120	HiPerf		Import
73	15	LoPerf	LoTech	Import	118,121	LoPerf		Import
74	15	VLPerf	LoTech	Import	119,122	VLPerf		Import
75	16	HiPerf	HiTech	Domestic	123	HiPerf	HiTech	Domestic
76	16	LoPerf	HiTech	Domestic	124	LoPerf	HiTech	Domestic
77	16	VLPerf	HiTech	Domestic	125	VLPerf	HiTech	Domestic
78	16	HiPerf	LoTech	Domestic	126	HiPerf	LoTech	Domestic
79	16	LoPerf	LoTech	Domestic	127	LoPerf	LoTech	Domestic
80	16	VLPerf	LoTech	Domestic	128	VLPerf	LoTech	Domestic
81	16	HiPerf	HiTech	Import	129	HiPerf	HiTech	Import
82	16	LoPerf	HiTech	Import	130	LoPerf	HiTech	Import
83	16	VLPerf	HiTech	Import	131,132	VLPerf		Import
84	17	HiPerf	LoTech	Domestic	133,136	HiPerf		Domestic
85	17	LoPerf	LoTech	Domestic	134,135,137,138	LoVLPf		Domestic
86	17	HiPerf	LoTech	Import	141	HiPerf	LoTech	Import
87	17	LoPerf	LoTech	Import	139,140,142,143	LoVLPf		Import
88	18	HiPerf	LoTech	Domestic	146	HiPerf	LoTech	Domestic
89	18	LoPerf	LoTech	Domestic	144,147	LoPerf		Domestic
90	18	VLPerf	LoTech	Domestic	145,148	VLPerf		Domestic
91	19	HiPerf	LoTech	Domestic	150	HiPerf	LoTech	Domestic
92	19	LoPerf	LoTech	Domestic	151	LoPerf	LoTech	Domestic
93	19	VLPerf	LoTech	Domestic	149,152	VLPerf		Domestic
94	20	HiPerf	LoTech	Domestic	154	HiPerf	LoTech	Domestic
95	20	LoPerf	LoTech	Domestic	153,155–8	LoVLPf		

Perf = performance
Tech = technology

vehicle fleets as well as other demographic characteristics, in addition to income.

For small changes in the price of a good (that induce little change in quantity demanded), the change in consumer surplus is closely approximated by the change in expenditure on that good. For example, an increase in the price of gasoline effectively reduces the income of the household by the price increase times the quantity of gasoline demanded. For small price changes this change in income equals the change in consumer surplus. If a household buys 1,000 gallons of gas per year, a 1-cent increase in the price of gas costs them $10, assuming no change in gas consumption. This $10 is the loss in consumer surplus.

With this fact and equation D–13, the marginal utility of income can be calculated as follows. In previous analyses using CARS, an estimate of 0.001905 (utils per dollar) was used for the marginal utility of income for all income groups in all forecast years, and consumer surplus figures were calculated. Call these the aggregated marginal utility (MU_a) and consumer surplus (ΔCS_a). Because the average utility term does not change between aggregated and disaggregated (with the *d* subscript), we can use equation D–14 to relate the two:

$$MU_a CS_a = \ln \sum_{i}^{0,1,2+} e^{U_i} = MU_d CS_d \qquad \text{(D–14)}$$

adding deltas

$$MU_a \Delta CS_a = MU_d \Delta CS_d \qquad \text{(D–15)}$$

To calculate MU_d, CARS was run twice, once with the baseline and once with a 1-cent increase in the price of gasoline (G) in all regions and years (the smallest price increase that the model as currently coded will recognize). The model provides as output consumer surplus by income group and forecast year. The model also provides gas consumption per vehicle by income group, vehicle group, and forecast year. This must be aggregated over vehicle groups and multiplied by the average number of vehicles per household in each income group, which the output also provides, to arrive at gas consumption by income group and forecast year.

MU_a = 0.001905 is given. Furthermore, ΔCS_d (in 1978 dollars) is very closely approximated by –$0.001 times the gas consumption per household. Therefore the final equation used for calculating the disaggregated marginal utility for each income bracket and forecast year is:

$$MU_d = \frac{0.001905 \times \Delta CS_a}{-0.001 \times G} \qquad \text{(D–16)}$$

Using this approach, the following marginal utilities of income by income group and forecast year were calculated (Table D–4).

These quantities were those used in forecasting. Economic theory forecasts that the marginal utility of income will decrease as income increases. This is strongly evident in cross section (across income groupings) in the above marginal utilities of income, validating the model to some extent. It is not evident over time (the time trend of income growth by income bracket is not consistent).

Table D–4. Marginal Utilities of Income

	Income Group		
Year	**Low**	**Medium**	**High**
1990	0.002111	0.001951	0.001451
1995	0.002105	0.001907	0.001511
2000	0.002272	0.002032	0.001435
2005	0.002264	0.001954	0.001447
2010	0.002289	0.001904	0.001460

Appendix E. Model Input Assumptions

The forecasts of fuel prices and household demographic variables that are input into the Fuel Economy Model (FEM) and the Consumer Automotive Response System (CARS) must be provided exogenously. Although these inputs to a large extent determine model outputs, because the same set of inputs is used in both the baseline and the scenarios, their effects on relative results (for example, the percent improvement in fuel economy over the BASELINE scenario) are secondary. The sensitivity of the model results to these input assumptions was not tested. Although the absolute forecasts are sensitive to changes in fuel prices, especially on the supply side, this sensitivity is mitigated by reporting results as percent changes over the BASELINE scenario. The percent impact of feebates is less dependent on the absolute corporate average fuel economy (CAFE) ratings in the BASELINE scenario. This appendix describes the input assumptions used in this analysis.

Fuel Price Forecast

The Energy Information Administration (EIA) publishes detailed energy supply and demand forecasts annually in the *Annual Energy Outlook*. For this analysis, the reference-case motor-gasoline price forecast in the *Annual Energy Outlook 1992* was used. Table E–1 presents this fuel-price forecast, averaged for the entire United States, in 1990 dollars per gallon and 1978 cents per gallon (the units used by CARS).

Table E–1. Energy Information Administration 1992 Reference-Case Gasoline Price Forecasts

Year	1990$ per Gal	1978¢ per Gal
1990	1.17	58.4
1995	1.19	59.4
2000	1.36	68.0
2005	1.49	74.5
2010	1.58	78.9

Notes: Average price for all grades. Includes Federal and State taxes.
Source: EIA, 1992.

CARS requires fuel-price forecasts by census region. EIA provides such forecasts, but by Federal region, and only for the years 2000 and 2010. To use EPA's forecasts for CARS input, the regions must be reconciled and the years 1995 and 2005 interpolated. Table E–2 shows the results in 1978 cents per gallon.

These prices are consumption-weighted averages of the EIA Federal region prices. These were aggregated into census regions as follows: Northeast—New England, New York/New Jersey; Midwest—Midwest, Central; South—Mid-Atlantic, South Atlantic, Southwest; and West—North Central, West, Northwest. There are several small regional discrepancies in this aggregation: Pennsylvania is included in the South rather than the Northeast census region, New Mexico is in the South rather than the West, and the Dakotas are in the West rather than the Midwest. Because these States would affect the weighted averages only slightly, and correction would be difficult, these discrepancies were ignored.

The years 1995 and 2005 were interpolated by assuming that the 5-year shares of the price increases for each decade were the same in the regions as they were for the United States as a whole (where prices were provided for 1995 and 2005). Using this method, when these census region prices are aggregated into weighted average prices for the entire United States, the results are consistent with the EIA aggregate forecast.

Finally, regional prices were deflated using regional Consumer Price Indexes (CPIs), and fuel prices in intervening years were interpolated assuming constant growth rates in each period.

Table E–2. Regional Gasoline Price Forecasts (1978 cents per gallon)

	Region			
Year	**Northeast**	**Midwest**	**South**	**West**
1990	59.5	59.5	58.9	58.0
1995	60.7	60.5	59.8	59.2
2000	70.2	68.7	67.7	69.3
2005	76.6	75.3	74.3	75.8
2010	80.8	79.7	78.7	80.1

Household Demographics Scenario

This analysis made no changes to the household scenario developed for EPA by RCG/Hagler Bailly, Inc., in coordination with EPA staff. Table E–3 provides the baseline socioeconomic input data for every fifth year in the forecast period.

Because these are model inputs, they are reported with exaggerated precision. The total number of households is projected to increase by 29.1 percent between 1990 and 2010. The population shares of the South are projected to grow at the expense of the North and North Central regions, while the share of the West remains fairly stable until 2010, when it drops suddenly. Households concentrate increasingly in suburban areas, mainly because of decreased settlement in urban areas, but also because of a slightly decreased settlement in rural areas. The number of workers per household is assumed to stay constant

Table E–3. Baseline Socioeconomic Input Data

Input	1990	1995	2000	2005	2010
Number of Households	94,313,672	101,351,582	107,384,999	114,613,599	121,842,223
Northeast	19,064,306	20,056,786	21,389,954	21,983,311	22,424,343
North Central	20,940,905	21,391,857	21,580,196	20,503,886	20,790,785
South	35,756,497	39,757,953	43,506,869	49,202,679	57,118,622
West	18,551,962	20,144,986	20,907,980	22,923,723	21,508,473
Urban	27,492,435	29,928,549	30,162,671	31,081,525	30,928,918
Suburban	44,119,661	50,602,716	55,908,455	61,244,499	68,441,364
Rural	21,701,576	20,820,317	21,313,873	22,287,575	22,471,941
Mean Annual Growth Rate (%)	—	1.4	1.2	1.3	1.2
Mean Household Income (1990$)	32,632	33,998	37,306	40,324	42,718
Mean Annual Growth Rate (%)	—	0.8	1.9	1.6	1.2
Mean Household Size (persons)	2.815	2.735	2.534	2.534	2.534
Mean Workers per Household	1.35	1.35	1.35	1.35	1.35

at 1.35. Real average household income is projected to increase 30.9 percent from 1990 to 2010, at an average annual growth rate of 1.4 percent. Average household size is projected to drop from 2.82 in 1990 to 2.53 by the year 2000 and remain constant thereafter.

Appendix F. State and Federal Feebate Legislation

This appendix provides the details of the legislative feebate proposals summarized in Table 1–1 in Chapter 1.

State Feebate Proposals and Programs

Of the State proposals, California's DRIVE+ program (Demand-based Reductions In Vehicle Emissions plus reductions in carbon dioxide) is the longest running and is the original feebate proposal on which most of the others are based. First introduced in 1990 by State Senator Gary Hart as Senate bill (SB) 1905, it was passed overwhelmingly in the Legislature (31–4 in the Senate and 61–11 in the Assembly), but vetoed by then-Governor George Deukmejian on his last day in office. DRIVE+ legislation was reintroduced by Senator Hart as SB 431 in 1991 and SB 378 in 1993. This legislation is virtually identical to the original SB 1905. SB 378 is a 2-year bill and will be voted on in 1994.

DRIVE+ includes feebates on emissions as well as fuel consumption, applied against the sales tax on new motor vehicles. DRIVE+ feebates are based on a vehicle's tailpipe emissions of air pollutants and carbon dioxide (which are closely linked to fuel economy). Vehicles that are cleaner and more fuel-efficient than the average new car sold in California will be eligible for tax credits that will reduce sales taxes, and vehicles that are less efficient than average new cars will have increased sales taxes. The feebates are based on the average cost of emissions reductions from stationary sources. Senate bill 378 requires the California Air Resources Board to calculate feebates by estimating the sales-weighted average for certified levels of pollutants. The feebates would be based on the difference from the sales-weighted average for each pollutant, multiplied by $1,925 per gram per mile for hydrocarbons, $2,200 per gram per mile for nitrogen oxides, $220 per gram per mile for carbon monoxide, $2.50 per gram per mile for carbon dioxide, and $586 per gram per mile for particulates. These feebate rates are based on the average cost of emissions reductions from stationary sources.

The DRIVE+ proposal is designed to be revenue-neutral. The legislation establishes a new DRIVE+ fund to collect fees and distribute rebates; State and local taxes are unaffected. The program also provides for a reserve account and several other mechanisms to ensure it remains revenue-neutral even if sales projections are inaccurate. The proposal establishes a reserve of 30 percent of the estimated DRIVE+ rebates. Assuming that credits would total half of the current sales tax revenue, this would amount to a reserve of approximately $160 million. In addition, the program's startup and administrative costs are fully offset by the fees from the sales tax surcharges. The DRIVE+ program is estimated to have preparatory costs of $67,000 during 1994–95, and administrative costs of $840,000 during 1995–96 and $750,000 annually thereafter.

A feebate program actually passed the Maryland Legislature in 1992, the only feebate legislation yet to do so in the United States. This program is designed to be introduced in two stages. For cars purchased in 1993 and 1994, there is a tax surcharge of $100 if fuel efficiency is below 21 miles per gallon (mpg), and a $50 rebate if it is above 35 mpg. For cars purchased in 1995 and later, the fee for inefficient cars is $50 times the number of mpg less than 27, and the rebate is $50 times the number of mpg above 35. A cap of 1 percent of the car price applies. This program is designed to be revenue-generating, and will help finance Maryland's share of the cost for expanding the Washington, D.C., area's Metrorail system.

Maryland's feebate law is being challenged by the U.S. Departments of Transportation and Justice on the grounds that States are preempted by the corporate average fuel economy (CAFE) legislation from establishing regulations that "relate to fuel economy standards."

A gasoline-guzzler/sipper tax assessment was proposed in Massachusetts in 1990 and reintroduced by Representative Cohen in 1991. The current 5 percent sales tax would have been assessed variably (from 0 to 10 percent) based on vehicle fuel efficiency relative to cars in the same size class. The Maine legislation is similar, except that it applies to new vehicles only and is not intended to be revenue-neutral. This proposal did not pass in Maine in 1991 when it was first introduced. In 1993, Maine considered introducing feebate legislation that was virtually identical to California's DRIVE+ program. The Arizona feebate, introduced by Representative McCune-Davis, is efficiency-based, comparing the Environmental Protection Agency (EPA) composite fuel-economy rating with other vehicles in the same size class. Alternative-fuel vehicles would also be treated separately.

Federal Feebate Proposals

The proposed Safe and Efficient Vehicles Incentive Act was introduced by then-Senator Wirth in 1991 and subsequently included in the proposed

National Energy Efficiency and Development Act of 1991 (S. 741), an omnibus energy bill introduced in the 102nd Congress (first session) by Senators Wirth, Hatfield, Daschle, Jeffords, Bryan, Fowler, Bingaman, and Adams. The legislation would have introduced feebates based on fuel consumption and a composite safety factor, as measured by the National Highway Traffic Safety Administration, to avoid the criticism that fuel-economy legislation could reduce the size and thus the safety of vehicles.

The composite safety factor is based on injury criteria specified in Department of Transportation regulations using crash test data from tests conducted according to the test protocol also set forth in the same regulations. The formula for the composite safety factor (also called the "Gillis Factor") is:

$$0.1 \times [\text{Driver's Injury Factor} + (0.5 \times \text{Passenger's Injury Factor})]$$

where:

Driver's and Passenger's Injury Factor $= H + (12.525 \times T) + (0.11 \times L) + (0.11 \times R)$

(as measured for a dummy positioned in the driver's and passenger's seats, respectively) where:

H = Head acceleration as specified in Department of Transportation regulations,
T = Thorax acceleration, and
L, R = Left and right leg force, respectively.

The Secretary of Transportation can revise the formula and add terms to account for other safety factors, including side impact collisions and collision-avoidance equipment such as antilock brake systems.

Senate bill (S.) 741 was not actively considered by the Senate Energy and Natural Resources Committee. Instead, S. 341, the National Energy Security Act of 1991, sponsored by Senators Johnston and Wallop (based on the Bush Administration's National Energy Strategy) was selected as the primary legislative vehicle on energy policy in the 102nd Congress. S. 341 did not include any feebate proposal. Although S. 341 was passed by the Senate Energy and Natural Resources Committee, the full Senate voted not to invoke cloture in October 1991, thereby allowing a filibuster on the bill, and ultimately defeating the legislation.

The proposed Clean Domestic Fuels Enhancement Act of 1991, House bill (H.R.) 2960 introduced by Representative Synar, considered both alternative fuels and automotive fuel economy. Alternative fuels are defined to include natural gas, methanol, ethanol or other alcohol, electricity, liquefied petroleum gas, and hydrogen. A feebate provision is included in Section 215 of the legislative proposal. Feebates would be established based on how close the vehicle model's volume-adjusted carbon dioxide (CO_2) emissions are to established target levels. Table F–1 shows this proposal's CO_2 emissions target levels for passenger cars in grams of CO_2 per mile per cubic foot of passenger interior volume, starting in 1993.

Emissions target levels would be established for light trucks beginning with model year 1993 through model year 2001, taking into account vehicle size, payload weight, or a similar measure of vehicle utility. Emissions levels in 1993 would be established at 1988 emissions levels, and reduced by 3.6 percent annually thereafter until 2001.

Additional rebates would be included for vehicles that operate exclusively on alternative fuels. The target CO_2 emissions would consider "fuel-cycle emissions" including production, transmission, and combustion of the fuel(s)

Table F–1. Proposed Carbon Dioxide Emissions Target Levels Under H.R. 2960

Model Year	Target Levels (gm/mi/cu.ft.)
1993	4.06
1994	3.915
1995	3.77
1996	3.625
1997	3.48
1998	3.335
1999	3.19
2000	3.045
2001	2.90

being used. For the purposes of the established target levels in this legislation, gasoline-powered vehicles are assumed to generate fuel-cycle CO_2 emissions of 10,360 grams per gallon (22.8 pounds per gallon). The alternative-fuel rebate would be based on the net air-quality benefits of the alternative fuel including fuel-cycle CO_2 emissions, ozone-forming emissions, emissions of air toxics and of carbon monoxide, and the domestic content of the alternative fuel.

Beginning with model year 1993, consumers of new vehicles that emit more than the established CO_2 emission targets would be assessed a fee of $10 for every hundredth of a gram of CO_2 per mile per cubic foot of passenger interior volume by which the vehicle's emissions are in exceedence. The same $10 valuation applies in establishing rebates for those buyers of new vehicles with CO_2 emissions below the target level. No committee action was taken on this legislation in 1991.

Title V of the proposed *World Environment Policy Act* of 1991 (S. 201—Senators Gore and Wirth) included increases to the rates applicable to the gas guzzler tax, payable by vehicle manufacturers, and would have instituted a consumer gas-sipper rebate. Accordingly, vehicle manufacturers would pay a gas guzzler tax based on the vehicle's fuel economy starting in model year 1992. Table F–2 shows the actual gas guzzler tax that would have been levied on manufacturers of automobiles achieving less than 23.5 mpg.

Table F–2. Model Year 1992 Gas Guzzler Tax

Fuel Economy (mpg)	Tax ($)
>23.5	0
23.5	1,000
22.5	1,300
21.5	1,700
20.5	2,200
19.5	2,800
18.5	3,500
17.5	4,300
16.5	5,200
15.5	6,200
14.5	7,200
13.5	8,200
<12.5	9,200

Tax rates would have increased each year until 2000. The fuel-economy cutoff for each tax level increases by 1 mpg every year from 1992. Table F–3 shows what manufacturers of automobiles achieving less than 31.5 mpg would have paid in taxes in model year 2000.

At the program's planned inception in 1992, consumers that bought vehicles that were at least 15 percent more efficient than average would have received an income tax credit in the year the vehicle was purchased. Tax credits would have been based on the percentage that a specific vehicle's efficiency was greater than the average of all comparable models in its size class. There were two schedules for credits: one for model years 1993–94 and a second for 1995–2000, as shown in Table F–4. If the fuel economy of the vehicle exceeded the fuel economy of the model type of the vehicle by the percentage shown in Table F–4, the tax credit the purchaser of the vehicle would receive is shown in the table. The program was not designed to be revenue-neutral.

Table F–3. Proposed Model Year 2000 Gas Guzzler Tax Under S. 201

Fuel Economy (mpg)	Tax ($)
>31.5	0
31.5	1,000
30.5	1,300
29.5	1,700
28.5	2,200
27.5	2,800
26.5	3,500
25.5	4,300
24.5	5,200
23.5	6,200
22.5	7,200
21.5	8,200
20.5	9,200
19.5	10,200
18.5	11,400
17.5	12,400
16.5	13,400
15.5	14,400
14.5	15,400
<13.5	16,400

Table F–4. Proposed Tax Credits for Vehicle Fuel Economy Under S. 201

Program (%)	Credit ($)
1993–94	
<15	0
15–20	250
20–25	400
>25	750
1995–2000	
<20	0
20–25	400
25–30	750
30–50	1,000
50–75	1,500
>75	2,000

S. 201 was introduced on January 14, 1991, and referred to the Senate Committee on Environment and Public Works. No action was taken on this bill.

The proposed Fuel-Efficient Vehicle Purchase Incentive Act (H.R. 1583—Congressman Scheuer) would have established a revenue-neutral feebate system based on new-vehicle CO_2 emission levels. For model year 1993 and beyond, standards for the vehicle's tailpipe CO_2 emissions would be established by size class, as shown in Table F–5 (for the purposes of H.R. 1583, the table gives the CO_2 emission standards for motor vehicles). Consumers buying a new vehicle with CO_2 emissions exceeding the standard for its size class would have been assessed a fee of $10 for every gram of CO_2 per mile that their vehicle exceeded the standard. Likewise, those purchasing new vehicles that emitted less CO_2 than the standard would have received comparably calculated rebates.

H.R. 1583 was introduced on March 21, 1991, and referred to the House Committee on Energy and Commerce. No action was taken on this proposed legislation.

Table F-5. Proposed Carbon Dioxide Emissions Standards for Vehicle Size Classes Under H.R. 1583

Size Class	Standard (gram CO_2/mile)
Mini	223
Subcompact	271
Compact	298
Midsize	331
Large	365
Two-seater	298

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