Economic analysis of feebates to reduce greenhouse gas emissions from light vehicles for California

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Economic Analysis of Feebates to Reduce Greenhouse Gas Emissions from Light Vehicles for California

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1 Executive Summary

A growing majority of climate scientists are convinced that unless emissions are reduced, global warming would cause a number of adverse effects throughout the United States. In California, rising temperatures would reduce the snow pack in the Sierra—the state's primary source of water—and lead to less water for irrigating farms in the Central Valley. Global warming would increase the number of extreme heat days and greatly increase the risk of poor air quality across the state. California's 1,100 miles of coastline and coastal communities are vulnerable to rising sea levels. Concerted action could curb global warming, but all sectors would need to take immediate steps to reduce heat-trapping pollution.

In California, the transportation sector consumes well over half the oil used statewide, and passenger cars and trucks emit 20 to 30 percent of the state's global warming pollution. Vehicles therefore are a central focus of the immediate action required to reduce global warming.

The state of California's regulatory approach involves phasing in limits to average global warming emissions from passenger cars and trucks beginning in 2009 and culminating in 2016. This regulation is often called "Pavley," after its author, Assemblywoman Fran Pavley.

The federal government's approach provides tax incentives to buyers of hybrid vehicles, which emit significantly lower amounts of global warming pollution than most conventional vehicles. However, the hybrid incentive affects only a small portion of the vehicle market.

A third approach that could be used to enhance or replace existing regulations would be a feebates program. A feebates program creates a schedule of both fees and rebates that reflects the amount of global warming pollution that different vehicles emit. Purchasers of new vehicles that emit larger amounts of heat-trapping emissions pay a one-time surcharge at the point of purchase. These surcharges are then used to provide rebates to buyers of new vehicles that emit less pollution. A feebates program has several advantages over other approaches:

Market-oriented: A feebates program recognizes the power of price signals to change consumer behavior. That is, incentives spur consumers to purchase and manufactures to produce cleaner vehicles.

Self-financing: A feebates program can be designed so that the surcharges collected equal the rebates paid.

Affects entire market: A feebates program applies to all new vehicles—clean and dirty—spurring a transformation of the entire market.

Consumer choice: A feebates program can be designed so that consumers have the option to buy vehicles that carry no surcharge in each vehicle class, such as cars, trucks, sport utility vehicles (SUVs), and minivans.

This study explores the economic impacts on consumers and manufacturers of the existing Pavley regulation and a feebates program by analyzing four alternative scenarios, using information from 2002 as the base year.

Our findings show that a feebates program is an effective strategy to reduce global warming pollution by up to 25% more than Pavley alone. Also, under a feebates program consumers will save thousands of dollars and retailers will see their revenue rise by as much as 6%.

Our Approach

As part of the Pavley regulation, the California Air Resources Board (CARB) reviewed 39 emission-reducing technologies. CARB then used modeling to determine how much pollution these technologies would actually eliminate, as well as the cost of different technology packages. In our study, we created marginal cost curves for these technology packages to determine the cost of reducing various amounts of global warming pollution.

In addition to this supply-side analysis, we also modeled how the demand for specific vehicles depends on how consumers value vehicle attributes, such as performance, size, and fuel economy. To estimate the value to consumers of reducing the heat-trapping emissions of vehicles, we used California market data to revise a model developed by the University of Michigan Transportation Research Institute's (UMTRI) Automotive Analysis Division.

The Feebates Program

We also needed to define a hypothetical feebates program. As noted, such a program entails charging buyers of vehicles that emit large amounts of global warming pollution one-time fees, which are used to provide rebates to buyers of vehicles with lower emissions.

The graph below shows one potential feebates schedule. The horizontal axis measures the amount of global warming pollution that a vehicle produces in grams of carbon dioxide–equivalent per mile. The vertical axis measures surcharges (positive values) and rebates (negative values). The example schedule preserves consumer choice by incorporating a "zero-band": a range of emissions levels that do not require surcharges on vehicles that fall within the range.

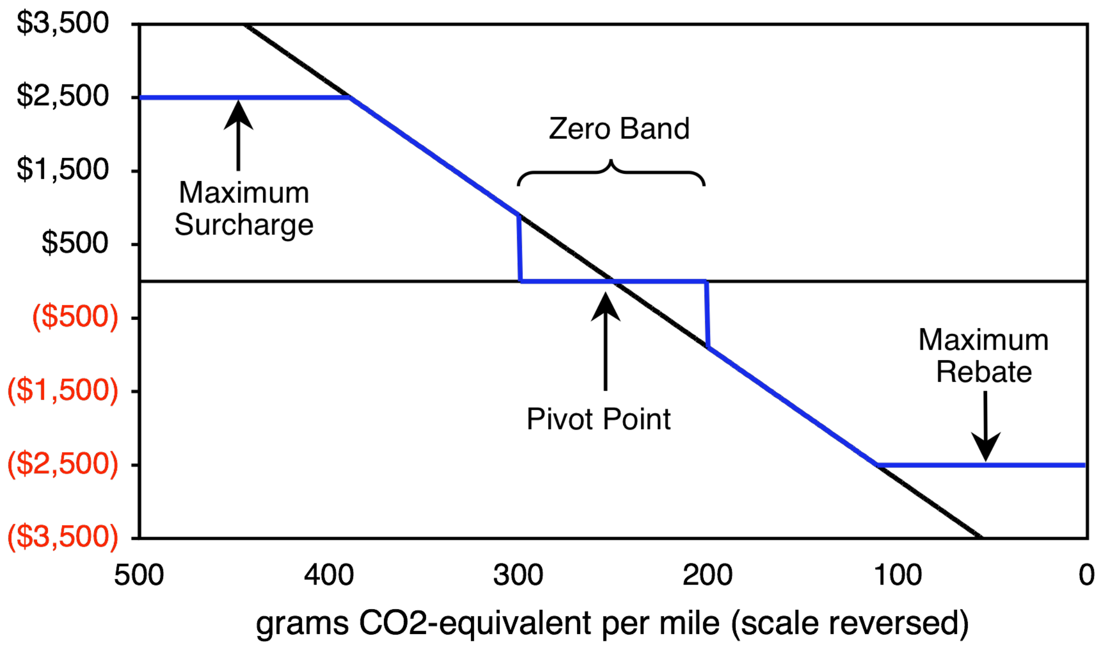
A feebates program is usually defined according to the change in surcharge or rebate for each additional amount of pollution a vehicle produces. In Figure 1, this amount is $18 per gram of CO_2-equivalent emissions per mile. This is known as the slope of the feebates schedule. The pivot point, another element defining a program, is the point on the schedule where it crosses the horizontal (emissions) axis.

For the program shown in Figure 1, the pivot point is 250 grams per mile. Thus a vehicle that produces 350 grams per mile would incur a surcharge of $1,800. As the slope of a feebates program increases, the incentive to reduce emissions also increases. For example, if the slope were $25 per gram per mile, the surcharge for that vehicle would be $2,500.

The feebates program in our study has three constraints:

- Surcharges and rebates are limited to $2,500.
- The program is self-financing.
- The zero-band—where vehicles neither incur a surcharge nor earn a rebate—includes 20–25 percent of the fleet.

Figure 1: Hypothetical Feebates Program with Slope of $18 Gram of CO_2 Equivalent per Mile



The Four Scenarios

We compared four different scenarios with the 2002 baseline:

Pavley alone: Each automaker meets its Pavley target.

Feebates alone ($18 per gram of CO_2-equivalent per mile): The feebates program has an $18 slope.

Feebates alone ($36 per gram of CO_2-equivalent per mile): The feebates program has a $36 slope. (This program is designed to achieve the same overall emission reductions as Pavley alone.)

Pavley plus feebates ($18 per gram of CO_2-equivalent per mile): Automakers meet their Pavley targets, and vehicles are subject to a feebates program with an $18 slope.

Under the Pavley scenario, we assume that each automaker installs technologies on its vehicles to exactly meet the average fleet wide emissions required in 2016, at the lowest-possible cost. Under a feebates program, we assume that automakers install emission-reducing technologies until the cost of those technologies, plus the feebates, equals the value to consumers (marginal cost equals marginal revenue). <u>That is, the prospect of lower fees encourages manufacturers of dirtier vehicles to make them cleaner, while the prospect of higher rebates encourages manufacturers of cleaner vehicles to make them even cleaner.</u>

We then simulated the impacts of these scenarios on the light vehicle market in California. We assumed that the cost of the additional technologies designed to reduce emissions, lower fees, and raise rebates changes the cost of the vehicles. This, in turn, changes consumer demand for the vehicles and retailers' revenue, according to UMTRI's market model. We then evaluated the impact of the four scenarios on emission reductions, retailers, and consumers—including lifetime savings to consumers from more fuel-efficient and thus cleaner vehicles.

The model used a fuel price of $1.74 per gallon—the average in 2002—and a 5 percent discount rate, to estimate the present value of future savings to consumers. However, the U.S. Department of Energy reported an average retail gasoline price of $3.30 in California in April 2007. <u>If our study had used today's higher fuel prices, it would have found significantly higher demand for more fuel-efficient vehicles. Such a market shift would reduce emissions even further, and improve lifetime savings to consumers.</u>

Results

Reductions in Emissions

Our study shows that a feebates program is effective in reducing global warming pollution from vehicles.

The amount of such emission cuts depends on the slope of the feebates curve. Thus the reductions ranged from a market average of 17 percent under the modest feebates program ($18 per grams of CO_2-equivalent per mile) to 33 percent under Pavley and feebates combined (see
Table 1). In fact:

The combination of Pavley plus feebates achieves a 33% reduction in global warming pollution—25 percent more than Pavley alone.

Table 1: Emissions Reductions under Different Scenarios and Their Source

	Fleet-wide Emissions (g CO^2-eq/mi)	Reduction in Emissions (g CO^2-eq/mi)	Total %Change in Emissions	% Change in Emissions from Technology	% Change in Emissions from Market Shift
Base	352				
Pavley Only	258	-94	-26.7%	101.0%	-1.0%
Feebates Only ($18 slope)	292	-60	-17.1%	98.2%	1.8%
Feebates Only ($36 slope)	258	-94	-26.7%	98.8%	1.2%
Pavley plus Feebates ($18)	235	-117	-33.3%	100.1%	-0.1%

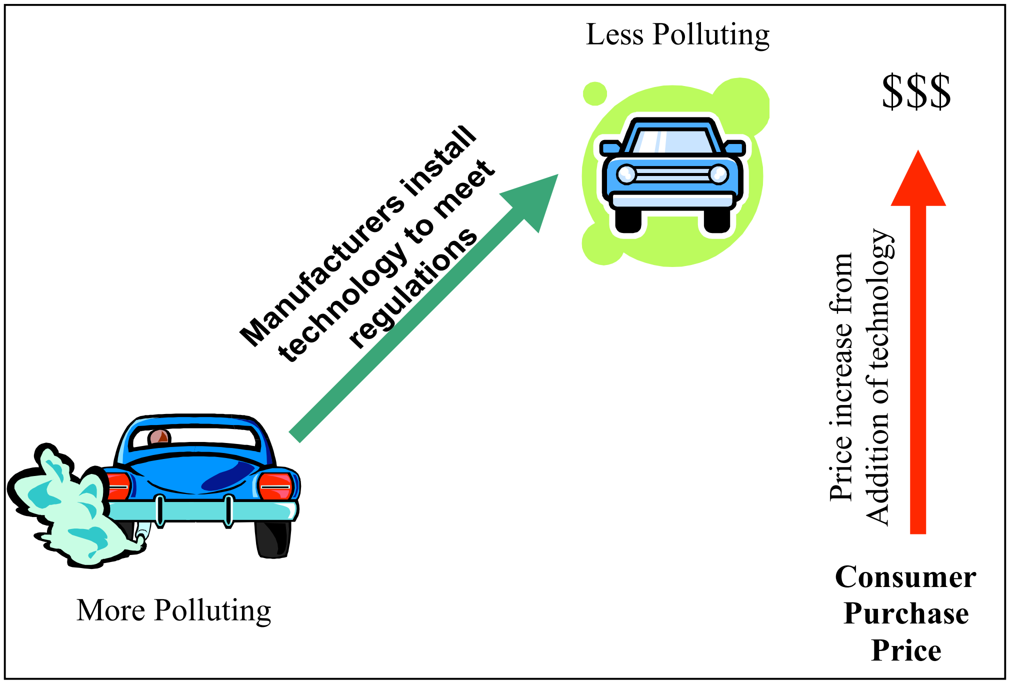
Emission reductions can stem from the addition of technologies by automakers, or from a market shift that occurs as feebates spur consumers to buy cleaner vehicles. The two right-hand columns in

Table 1 show that at full implementation nearly all the emissions reductions in our scenarios come from the addition of technologies, and not from a significant change in the types of vehicles consumers buy.

Under closer examination, the market in the two scenarios with Pavley regulations actually shifts a small fraction of consumers' purchases (<2%) toward vehicles with higher emissions after new technologies have been applied. This results in a change of emissions from technology greater than 100 percent. However, in the feebates-only scenarios, the market shifts toward cleaner vehicles.

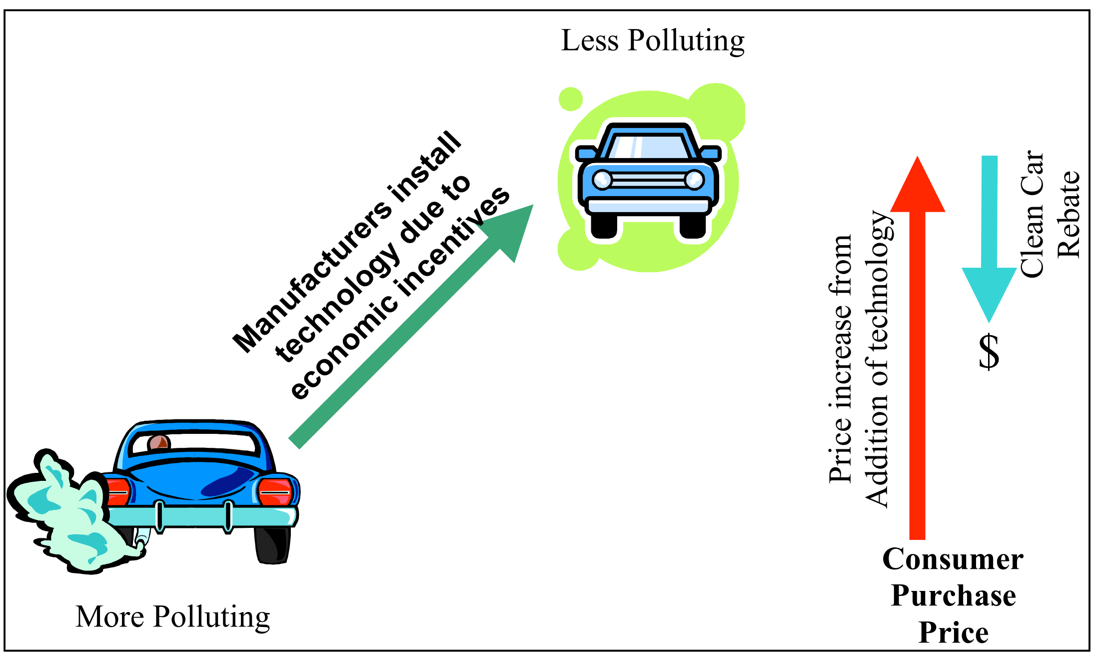
This is one advantage of a feebates program. Under a regulation scenario (Pavley Only) in our model, vehicle manufacturers install technologies on all vehicles, clean and dirty, to reduce global warming pollution to the required level. The prices consumers pay to purchase the vehicles rise, because of the cost of the additional technologies (Figure 2).

Figure 2: Effect of Regulations on Emissions and Consumer Purchase Prices



However, under a feebates scenario in our model, manufacturers install technologies on all vehicles, clean and dirty, to reduce emissions *and* to reduce surcharges and increase rebates. Rebates compensate consumers for some of the costs of the technologies, making clean vehicles less expensive (Figure 3). Surcharges on high-polluting vehicles increase the cost of those vehicles even further. This accounts for the small market shift.

Figure 3: Effect of Feebates Program on Emissions and Consumer Purchases



More importantly:

Although emission-reducing technologies raise the cost of vehicles, a feebates program makes cleaner vehicles more affordable to consumers.

1.1.1 Impact on Consumers

The price of vehicles, including feebates, is just one aspect of how a feebates policy would affect consumers' pocketbooks. Some technologies that reduce global warming pollution also improve the efficiency of vehicles, thereby reducing fuel costs over their lifetime. Table 2 combines retail prices with vehicle lifetime fuel savings to show the full impact on consumers.

Under all scenarios and for all vehicle types, consumers save (up to $2,544) over the lifetimes of their vehicles. The greatest overall market savings, $1,793 is realized under Feebates alone with $36 per gram per mile slope.

Table 2: Vehicle Lifetime Savings to Consumers under Each Scenario and Vehicle Type

Scenario		Car	Van	Pickup	SUV	Market
Pavley Alone	Lifetime Fuel Cost	($2,432)	($3,090)	($3,712)	($3,786)	($2,928)
	Retail Price	$1,253	$989	$1,367	$1,242	$1,275
	Total Change	($1,178)	($2,100)	($2,344)	($2,544)	($1,652)
Feebates Alone ($18 g per g/mi)	Lifetime Fuel Cost	($1,428)	($2,117)	($2,456)	($2,429)	($1,892)
	Retail Price	$536	$743	$959	$920	$658
	Net Feebates	($652)	$172	$1,187	$928	$0
	Total Change	($1,544)	($1,203)	($311)	($581)	($1,234)
Feebates Alone ($36 g per g/mi)	Lifetime Fuel Cost	($2,281)	($3,254)	($3,812)	($3,817)	($2,957)
	Retail Price	$979	$1,270	$1,633	$1,516	$1,164
	Net Feebates	($877)	$235	$1,444	$1,353	$0
	Total Change	($2,179)	($1,748)	($735)	($948)	($1,793)
Pavley plus Feebates ($18 g per g/mi)	Lifetime Fuel Cost	($2,904)	($3,949)	($4,817)	($4,770)	($3,670)
	Retail Price	$2,618	$2,726	$3,514	$3,227	$2,866
	Net Feebates	($541)	$280	$966	$673	$0
	Total Change	($287)	($1,222)	($1,303)	($1,543)	($804)

1.1.2 Impact on Retailers

We also examined the impact of the different scenarios on retailers. Although sales decline no more than 4 percent because of higher costs stemming from additional technology:

Retailers' revenue rises under all scenarios, and the feebates program boosts the sale of cleaner vehicles.

Table 3: Retailers' Revenue under Different Scenarios

	Retailers' Revenue ($ Billions)	Revenue Change from Base ($ Billions)	% Change Revenue from Base
Base	$52.2		
Pavley Only	$54.9	$2.8	5.3%
Feebates Only ($18 slope)	$53.2	$1.1	2.1%
Feebates Only ($36 slope)	$54.1	$1.9	3.7%
Pavley plus Feebates ($18)	$55.7	$3.5	6.7%

Overall, while policy designers can adjust a feebates program to achieve different reductions in global warming pollution:

We found that a feebates program is an effective strategy to reduce global warming pollution while benefiting both consumers and retailers. The combination of the existing Pavley regulation with a modest feebates program would achieve a 25 percent greater drop in emissions than a regulatory system alone. Feebates create incentives to both manufacturers and consumers to produce and purchase cleaner vehicles. <u>Furthermore, consumers can save thousands of dollars over the lifetime of their vehicles because of lower operating costs</u>. Also, retailers' revenues can rise more than 6 percent when feebates are combined with the existing Pavley regulation.

2 Theory

This section describes the analytical approach and methods we used in this research. The theory section has four parts. In the first part we describe the models of the cost of reducing greenhouse gas emissions and of the consumer value of reducing greenhouse gas emissions. The cost functions were derived from documents published by the California Air Resources Board (CARB) in support of regulating greenhouse gas emissions from light vehicles (CARB August 2004 and CARB September 2004)[i]. The value to a consumer of reducing the greenhouse gas emissions of his/her own vehicle is derived from UMTRI's model of consumer demand for vehicles and attributes (see McManus (2006) for a recent description of the model).

In part two of this section we describe the analytics of meeting the greenhouse reductions that are mandated under California's Vehicle Global Warming Law (AB 1493), which is also known as Pavley. Under Pavley, automakers must meet some very aggressive targets by 2016, and can do so through a combination of technological improvements and sales-mix changes. The automakers face the constrained optimization problem of minimizing the cost of reducing greenhouse gas emissions by choosing how much to improve each vehicle in their portfolio subject to the requirement to meet Pavley for its fleet overall.

In part three of this section we introduce the concept of feebates that can supplement or substitute for Pavley. Under a feebates program, the buyers of dirtier vehicles are charged fees that finance rebates to buyers of cleaner vehicles. By raising the full price of dirtier vehicles and lowering the full price of cleaner vehicles, a feebates shifts market demand toward cleaner vehicles and gives automakers strong incentives to shift their products in the same direction.

The fourth part of this section is a brief overview of the UMTRI Consumer Choice Model. Using the UMTRI model we simulate the impacts on the light vehicle market in California of several alternative scenarios involving Pavley and/or feebates programs. We originally developed the UMTRI model for the national market, so for this study we calibrated the UMTRI model to the 2002 California market.

2.1 Cost and Value Functions

Cost and value are central to evaluating programs to reduce greenhouse gas emissions. Pavley sets aggressive emissions targets, but leaves the automakers free to choose the technologies and market offerings it uses for that purpose. Pavley requires each automaker to achieve a target sales-weighted average in grams of CO2-equivalent per mile across the automaker's light-duty vehicle lines. The target can be different for each automaker since the target is defined using the distribution of the automaker's light-duty vehicle sales and product offerings.

Costs and consumer values drive the technology and product choices of economically rational automakers as they respond to both consumers and governments. The economic analysis of alternative programs we report here is also based on the costs and consumer values.

2.1.1 Costs

We embedded cost functions for reducing greenhouse gases in the UMTRI model using the assumptions in CARB (September 2004). We fit exponential functions to CARB's cost estimates for five types of vehicles (as defined by CARB): small cars, small trucks, minivans, large cars, and large trucks. Consider the process used for small cars as an example.

The figure below is a screenshot of CARB's cost and CO_2 reduction assumptions for small cars. We focused this study on the 2016 model year, at which time, according to CARB, all of the technology options listed in the figure would be available for use by automakers.

Addendum to Initial Statement of Reasons
September 10, 2004

Revised Table 5.2-5. Potential Carbon Dioxide Emissions Reductions from Small Car (NESCCAF, 2004)

Small Car	Combined Technology Packages	CO_2 (g/mi)	Potential CO_2 reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO_2 reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	DVVL,DCP,A5 (2009 baseline)	285	-2.6%	$308	0%	$0
	DCP,CVT,EPS,ImpAlt	269	-7.8%	$561	-5.4%	$253
	DCP,A4,EPS,ImpAlt	269	-7.8%	$351	-5.4%	$43
	DCP,A5,EPS,ImpAlt	260	-10.9%	$486	-8.5%	$178
	DCP,A6	260	-11.0%	$346	-8.6%	$38
	DVVL,DCP,AMT,EPS,ImpAlt	233	-20.1%	$456	-18.0%	$148
	GDI-S,DCP,Turbo,AMT,EPS, ImpAlt	215	-26.5%	$1120	-24.6%	$812
Mid Term 2013-2015	gHCCI,DVVL,ICP,AMT,EPS,ImpAlt	229	-21.8%	$665	-19.7%	$357
	CVVL,DCP,AMT,ISG-SS,EPS, ImpAlt	216	-25.9%	$1022	-24.0%	$714
	gHCCI,DVVL,ICP,AMT,ISG, EPS,eACC	204	-30.1%	$1767	-28.3%	$1459
Long Term 2015-	dHCCI,AMT,ISG,EPS,eACC	224	-23.4%	$3055	-21.4%	$2747
	ModHEV	159	-45.6%	$2546	-44.2%	$2238
	HSDI,AdvHEV	133	-54.4%	$6060	-53.2%	$5752
	AdvHEV	136	-53.4%	$4009	-52.2%	$3701

Notes: Costs are included here to place the technology benefits in context. Costs and their derivation are discussed in greater detail in Section 5.3; Reductions and costs for all scenarios except the baseline include benefits and costs listed in Table 5.2-4 and benefits and costs from improved air conditioning systems from NESCCAF (2004).

The columns "CO_2 (g/mi)" and "Retail Price Equivalent 2009" in the small car table were used to fit the total cost of improvements ("Retail Price Equivalent 2009") as an exponential function of the level of emissions ("CO_2 (g/mi)"). The total cost and marginal cost functions, defined in terms of the amount by which CO_2 (g/mi) is reduced, are:

$$\text{Cost} = ae^{b(g_0 - g)}$$

$$\text{MC} = abe^{b(g_0 - g)}$$

In the cost and marginal cost function, g_0 is the 2009 level of emissions, g is the level of emissions at which cost is being measured, e is the exponential function, and a and b are parameters that we estimated by regression analysis.[ii]

Our regression estimates of the a- and b-parameters for the five vehicle types are shown in the table below. The b-parameter is the percentage increase in cost that results from a one-gram per mile reduction in emissions. For example, reducing large car emissions by one gram per mile would increase total cost by 1.41%. The a-parameter is the intercept of the total cost function and can be interpreted as the fixed cost of emissions-reduction technologies. Appendix A contains graphs of the CARB assumptions and fitted exponential curves for the five vehicle types.

Parameters of Cost Functions

	a	***b***
LARGE CAR	292	0.0141
LARGE TRUCK	235	0.0131
MINIVAN	254	0.0132
SMALL CAR	271	0.0185
SMALL TRUCK	231	0.0116

It is important to remember that CARB's cost estimates are simply the engineering costs (plus a mark up) for applying the technologies ***in a manner that is optimized for CO_2 reduction***. Most of the technologies are fungible—they could be used either to enhance performance (or other attributes) ***or*** to reduce emissions of CO_2. CARB's estimates of technical costs ignore these trade offs and isolate CO_2 emissions from all other attributes of vehicles (horsepower per ton and weight are constant). This makes CARB's cost estimates lower than would be the case if they measured the *opportunity cost* of applying the technology to maximize CO_2 reduction rather than simply the engineering cost. The opportunity cost would incorporate the value of the technologies in enhancing the performance (or other attribute) of vehicles.

2.1.2 Value

The value to a consumer of reducing the greenhouse gas emissions of his/her own vehicle is derived from UMTRI's model of consumer demand for vehicles and the attributes of vehicles (McManus (2006) has a detailed description of the model). McManus (2006) examined the costs and benefits of adding specific, identified bundles of technologies to vehicles. This study, in contrast, examines actions that continuously vary the reductions in emissions (along the cost curve).

In McManus (2006) the consumer value of incremental changes in emissions was assumed to be a constant that did not depend on the level of emissions (within a vehicle segment). In this study of Pavley and feebates, the UMTRI model was changed to allow the consumer value of emission reductions to fall with the level of emissions. This change in the model is justified on at least two grounds. Diminishing marginal value, common in economics, comes from the assumption that a resource is allocated to the most valuable uses first when little of the resource is available, and is allocated to less and less valuable uses as the amount available increases. This could apply to almost any resource, and thus could apply to automotive emission reduction. Another justification for diminishing marginal value comes from a distinctive characteristic of automotive emissions and fuel consumption. The technologies that reduce emissions generally do so by reducing the fuel necessary to drive a given distance (although there are other options to reduce emissions). This lowers the cost per mile of driving to the consumer, and this in turn gives the consumer an incentive to drive more miles. The Law of Demand (in economics) states that when the price of a good falls, the quantity of the good demanded rises.

The significance of diminishing marginal value by consumers has implications that need to be considered in designing programs to reduce emissions from automobiles. The goal of Pavley is to reduce the **aggregate** level of greenhouse gas emissions, not simply to reduce the level of emissions per mile of driving, even though the standard is stated in terms of emissions per mile of driving. The more that the lower costs per mile induce consumers to drive more miles, the less the aggregate reductions can be predicted simply from the reductions per mile. If the effect of such offsetting behavior (or "rebound effect") were large, then CARB would need to set a higher per-mile standard to attain a given aggregate reduction in emissions than if this effect were small. The UMTRI model does not explicitly account for a rebound effect.

In McManus (2006), we identified opportunities for automakers to increase fuel economy between now and 2010. In theory, and in the long run, unexploited opportunities would not exist in a competitive market. The opportunities identified in McManus (2006) result from strongly held prior beliefs by domestic U.S. automakers that based on inaccurate models of consumer preferences. Because of federal regulations and the adversarial position in which they have put domestic U.S. automakers, the automakers appear to have underestimated consumer preferences for fuel economy. One effect of this underestimate was their failure to predict the impact of rising fuel prices on demand for vehicles in 2002-2005.

In this study we have estimated two marginal revenue functions for each vehicle. The true MR is derived from the UMTRI Consumer Choice Model. The assumed marginal revenue (MR) is derived by a parallel shift of the true MR to equate assumed MR to marginal cost (MC) at the baseline level. Manufacturers optimize by equating MC to MR across all vehicles in their portfolios, and, if they incorrectly estimate the value of greenhouse gas (GHG) reductions to consumers, then the assumed MR would differ from the true MR, but the manufacturers would believe themselves to be optimizing.

We defined the true and assumed marginal revenues:

$$\text{True MR} = \alpha_0 - \beta g^{-2}$$
$$\text{Assumed MR} = \alpha_1 - \beta g^{-2}$$

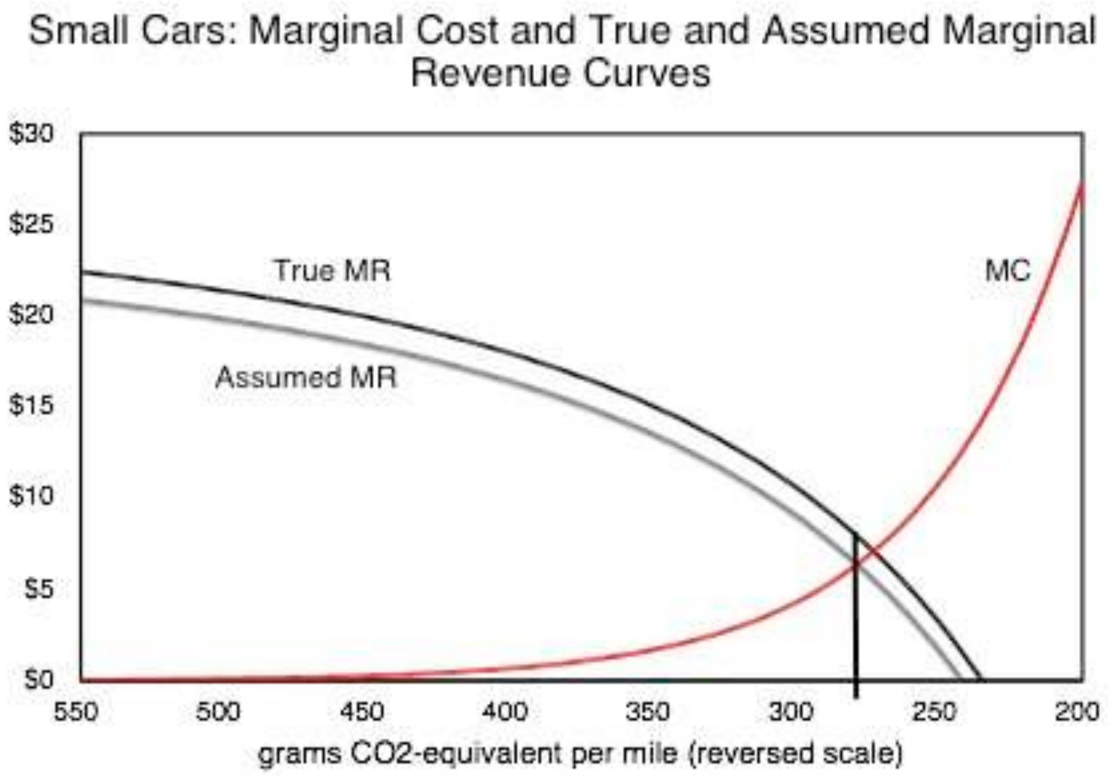
The intercept of the true MR curve, α_0, is an estimate of the value to the consumer of reducing emissions by one gram CO_2-equivalent per mile. The intercept of the assumed MR curve, α_1, equates assumed MR and MC at the base emissions level. The true and assumed MR curves are parallel to each other and decrease at an increasing rate as emissions are reduced. The parameters of the marginal revenue curves were estimated separately for each individual vehicle. Their sales-weighted average values are: α_0=34.66; α_1=27.87; β=2,916,777.

2.2 Marginal Cost and Marginal Revenue Graphs

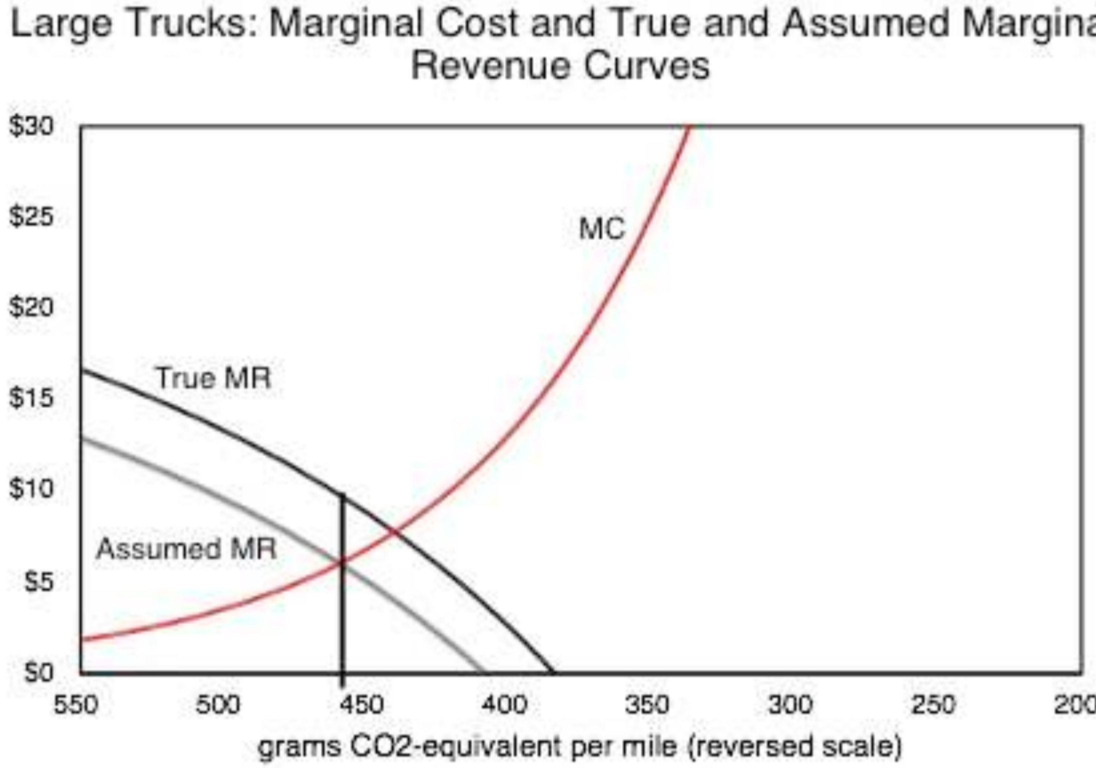
In this section we show the marginal cost and marginal revenue for the two segments that define the extremes (small cars and large trucks). We also comment on the marginal cost and marginal revenue for the three other segments (minivans, small trucks, and large cars) and show them in the appendix. In each graph we use the same scales for the x-axis and y-axis so that the graphs can be directly compared to each other.

Marginal cost and marginal revenue are measured on the vertical axes in dollars per gram reduction of CO_2-equivalent per mile. The range of the vertical axes is $0 per gram to $30 per gram. Greenhouse gas emissions are measured in grams of CO2-equivalent per mile on the horizontal axes. The scales are reversed so that movements to the right are reductions in greenhouse gases. The horizontal axes limits are 550 grams of CO2-equivalent per mile to 200 grams of CO2-equivalent per mile.

Small cars have the lowest MC curve and the highest MR curves. The result is that the base emissions level for small cars is lower than for any other segment. The difference between the assumed and the true MR for small cars is less than $2 per grams of CO2-equivalent per mile, implying that automakers have more accurate estimates of the value of emissions reduction for small cars than they have for any other segment.



Small car cost and revenue are at one extreme in most measures and large trucks are generally at the other extreme. Large trucks have the highest MC curve and the lowest MR curves. These produce the highest base level of emissions per mile. The gap between the true and the assumed MR is about $4 per grams of CO2 equivalent per mile, roughly the same as it is for small trucks, meaning that automakers have the biggest underestimates of the value of emissions-reduction for these two segments.



The other three segments (minivans, small trucks, and large cars) have MR and MC curves that fall between those of small cars and large trucks. The MC curve for large cars is the second lowest, after that of small cars. The MC curves for minivans and small trucks are nearly identical and are higher than that of large cars but lower than that of large trucks. The MR curves of small trucks are second lowest, after large trucks. The gap between true and assumed MR is nearly the same for large trucks and small trucks. These gaps are larger than the gap in any other segment implying that the automakers estimate the value of emissions in the vehicles poorly. MR curves for minivans are the next higher MR after MR curves for small trucks (and more accurately estimated by automakers). MR curves for large cars are the next higher MR after the curves for minivans (and are also more accurately estimated by automakers).

2.3 Meeting AB 1493 (Pavley)

California AB 1493, commonly referred to as Pavley for author Assemblywoman Fran Pavley, was signed into law by Governor Gray Davis on July 22, 2002. The law requires that the California Air Resources Board (CARB) develop and implement greenhouse gas emissions limits for light vehicles sold in California beginning in model year 2009. In August 2004, CARB released its initial statement of reasons (ISOR) supporting the law (CARB August 2004), and in September 2004 released an addendum (CARB September 2004) with revisions to the ISOR. Also in September 2004, CARB approved light vehicle greenhouse gas emissions limits for model year 2009. The table below shows the emissions limits CARB approved (officially for 2009, anticipated for 2010-2016). The automotive industry sued in Federal court, and the case is working its way through the court system. We do not address the question of whether or not Pavley is ultimately likely to be approved by the courts.

Tier	Year	CO2-equivalent emission standard (g/mi)	
		PC/LDT1 (Passenger cars and small trucks/SUVs)	LDT2 (Large trucks/SUVs)
Near-term	2009	323	439
	2010	301	420
	2011	267	390
	2012	233	361
Mid-term	2013	227	355
	2014	222	350
	2015	213	341
	2016	205	332

For this study we estimated the 2016 Pavley target by automaker as the 2002 sales-weighted average of the separate requirements for PC/LDT1 and LDT2. The use of 2002 data was dictated by availability. The vehicle mix has probably changed toward lower GHG emissions since 2002, and is likely to change in that direction more by 2009, so using the 2002 mix overstates the changes needed. Results need to be used with this in mind.

Separate targets were set for the two vehicle types, but Pavley allows the automakers to substitute across the types to meet the requirement. The effect is that Pavley effectively imposes a single target on each automaker. Each automaker has a unique Pavley target determined by its sales mix. The table below gives the hypothetical targets for the manufacturers that we computed using the sales mix in 2002.

The automaker targets we use are applied to a single year's sales (2016) and do not necessarily match the overall improvement that CARB estimates Pavley would produce. Our single-year target calls for a 27% reduction in emissions of greenhouse gases per mile in 2016, but CARB estimates that Pavley would produce a 30% reduction in that year. The difference is that CARB is adding up the improvements made each year between now and 2016, whereas we are counting only the improvements made to new vehicles sold in 2016. Thus, our single-year target and CARB's overall target are consistent with each other.

Assumed Model Year 2016 Pavley Targets

(grams CO2-equivalent per mile)

	Target	Sales Mix* 2002		
		PC/LDT1	LDT2	Toal
DaimlerChrysler	262	55%	45%	100%
Ford Motor Co.	274	45%	55%	100%
General Motors	270	49%	51%	100%
Honda	235	77%	23%	100%
Nissan	252	63%	37%	100%
Others	226	84%	16%	100%
Toyota	260	57%	43%	100%
Total	**258**	**58%**	**42%**	**100%**
Targets by Class		**205**	**332**	

*Based on the UMTRI California Database

We identify the six largest automakers by sales in California, and treat the residual (Others) as a seventh automaker. We assume that the hypothetical seventh automaker must also meet a Pavley target. This simplification facilitates computation but does not significantly alter our conclusions.

This study is as concerned about feebates as it is about Pavley. To understand the separate and combined effects of Pavley and feebates, we defined four alternative scenarios for model year 2016.

- Pavley alone: each automaker meets its Pavley target.
- Feebates alone ($18 per grams of CO2-equivalent per mile): a feebates program with $18 slope.
- Feebates alone ($36 per grams of CO2-equivalent per mile): a feebates program with $36 slope; designed to achieve the same market-level reduction in emissions as Pavley alone.
- Pavley plus feebates ($18 per grams of CO2-equivalent per mile): Both Pavley and a feebates program with $18 slope.

In the remainder of this section we explain the analytics of meeting Pavley, the operation of a feebates program in our model, and how the two would work together. The automakers compete for market share and profits by offering highly differentiated products to consumers.

We assume that each automaker installs technologies on their vehicles to exactly meet Pavley's requirements in 2016, at the smallest possible net cost. Since we have assumed that initially MC = MR for each market entry, technologies that reduce greenhouse gas emissions add more in costs than they add in consumer value. We define the net cost of greenhouse gas reductions as the change in costs minus the change in consumer value. For each automaker, choosing the reduction in emissions for each of its market entries that minimizes the net cost of meeting the Pavley requirements is a constrained optimization problem.

The automaker's problem can be stated as choosing how much to improve each entry to minimize technology cost minus consumer value subject to meeting its overall Pavley target.

Minimize $\sum_{i=1}^{I}(c_i - v_i)q_i$

Subject to $H = \sum_{i=1}^{I} s_i h_i$

Where i indexes the automaker's vehicles (of the total number I), c_i is the cost of improving the i^{th} vehicle's emissions, v_i is the value to consumers of the improvement of the i^{th} vehicle, h_i is the improvement in emissions (in grams of CO2-equivalent per mile), q_i is the i^{th} vehicle's unit sales, s_i is the i^{th} vehicle's share of the automaker's total unit sales, and H is the improvement in the automaker's average emissions (in grams of CO2-equivalent per mile) required by Pavley. The first order conditions for the automaker's optimum are given by the I equations (one for each vehicle):

$mc_i - mv_i = \lambda$

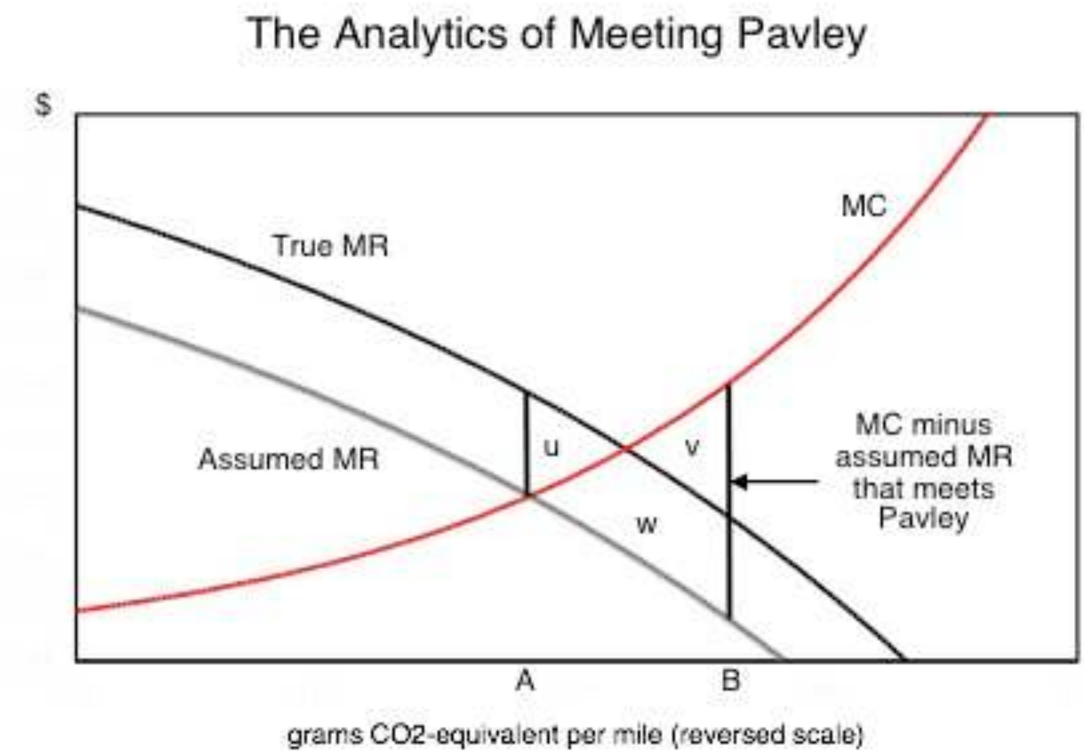
Where mc_i is marginal cost, mv_i is marginal value (or marginal revenue) and λ is the marginal cost of increasing H.

The solution to the automaker's constrained optimization problem under Pavley is thus to reduce greenhouse gas emissions for each of its market entries such that all entries have the same difference between marginal cost and marginal revenue. This difference equals the automaker's overall marginal cost of reducing its average emissions.

To understand this solution, consider an automaker that must reduce its greenhouse gas emissions by 100 grams of CO2-equivalent per mile. The automaker can get the required reduction at the lowest net cost by an iterative process:

(1) For each entry compute the reduction in emissions by that entry that would result in a 1.0 unit reduction in the automaker's overall average emissions;
(2) For each entry compute the change in cost and consumer value that would result from the change;
(3) Implement the change for the entry that has the smallest cost minus consumer value;
(4) If the average has not yet improved by 100, then go to (1), else end.

The solution, equal MC-MR across all of the automaker's vehicles, assumes that automakers do not trade emissions reduction credits. Pavley permits them to trade early credits, but by the time Pavley is fully implemented (2016) any early credits are likely to have already been used or traded. Pavley also allows each automaker to trade credits between classes of vehicles, which is why we set the target based on the automaker's car-truck sales split but do not distinguish between cars and trucks in the optimization.



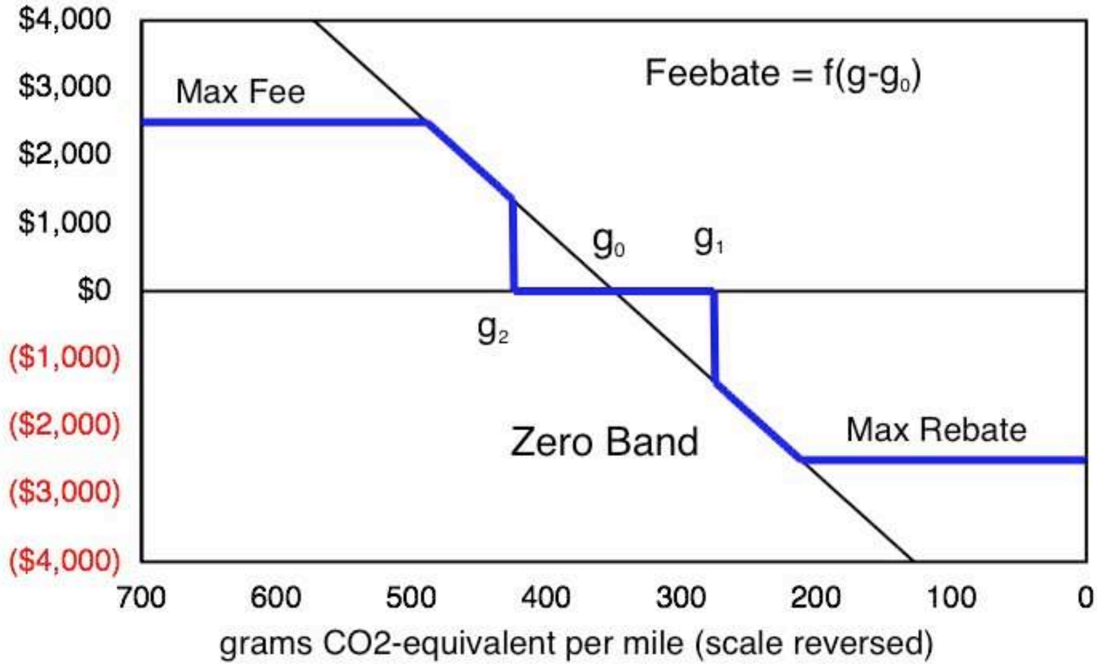
The graph above shows the impact of meeting Pavley for a single market entry. The arrow points to the vertical line that is equal to λ in length (the difference between MC and assumed MR). The graph illustrates the change in economic (consumer plus producer) surplus that results from Pavley. Reducing this entry's emissions from the base level (A) to the level that equates MC and true MR) increases economic surplus by the area (u). If Pavley requires the automaker to reduce emissions to (B), then reducing emissions from the level that equates MC and true MR to (B) lowers economic surplus by the area (v). The net impact on economic surplus is (v) minus (u). The automaker makes decisions based on the assumed MR, and therefore assumes that the change in economic surplus is negative and equal to (v) plus (w).

The efficiency loss arises from the allocation of more resources toward reducing vehicle emissions than new-vehicle buyers would choose on their own. The loss is measured from a purely private point of view. However, not all of the costs of vehicle emissions are borne by new-vehicle buyers. Greenhouse gas emissions from new vehicles impose costs on all of us through global warming. The efficiency losses from reducing greenhouse gas emissions (measured in this study) have to be compared to the externality costs of greenhouse gas emissions (not measured in this study).

2.4 Feebates

A feebates program gives incentives to consumers to buy, and to manufacturers to produce and sell cleaner products by combining a fee on dirtier products with a rebate on cleaner products. See Greene et al. 2005 and Johnson 2006 for examples of feebates programs applied to vehicles. Two features of feebates programs have made them attractive to policy makers. By addressing choices across the full range of alternatives, feebates programs have the potential to stimulate more significant changes than one-sided approaches. Probably more important is that a feebates program can be structured so that the fees collected equal the rebates paid, making the program self-financing. The figure below can be used to explain the parameters of a feebates program for vehicle emissions.

The Parameters of a Feebates Program

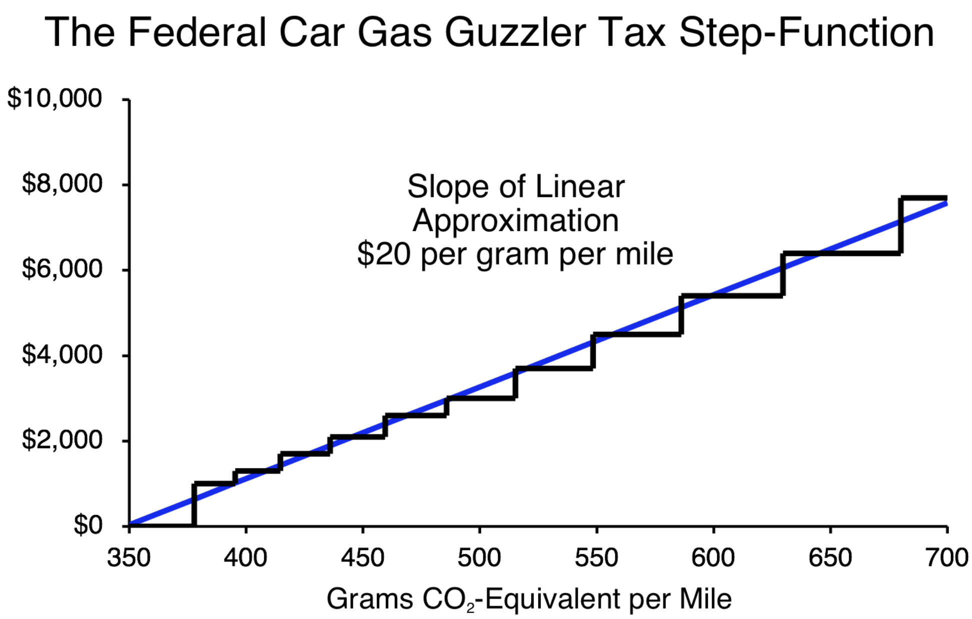


The basic feebate function (fee if positive, rebate if negative) is defined by an emissions-level pivot point and a slope in dollars. The fee or rebate for a particular market entry is larger (in absolute value) the greater the difference between the market entry's emissions and the pivot point. For example, with an slope of $18 per grams of CO2-equivalent per mile and a pivot point of 350 grams of CO2-equivalent per mile, the fee due for a vehicle with emissions of 425 grams of CO2-equivalent per mile would be $18x(425-350) = $1,350. The fee due for a vehicle with emissions of 450 grams of CO2-equivalent per mile would be $18x(450-350) = $1,800. Optional elements include a "zero band" for which fees or rebates are zero (defined by upper and lower emissions levels) and limits on the maximum fee and maximum rebate.

$$Feebate = f(g - g_{pivot}) \quad \text{if } g > g_{upper} \text{ or } g < g_{lower}$$

$$Feebate = 0 \quad \text{if } g_{lower} \leq g \leq g_{upper}$$

For this study the feebates was defined with a slope of $18 or $36 per grams of CO2-equivalent per mile. We further constrained the absolute value of the feebates to be not more than the smaller of $2,500 or 7.7% of the vehicle's transaction price (7.7% is the sales tax rate). The $18 slope is comparable to the Federal Gas Guzzler tax, which has an implicit slope of $20 per grams of CO2-equivalent per mile. The Federal Gas Guzzler tax applies to cars but not to trucks, and very few consumers are required to pay the tax.

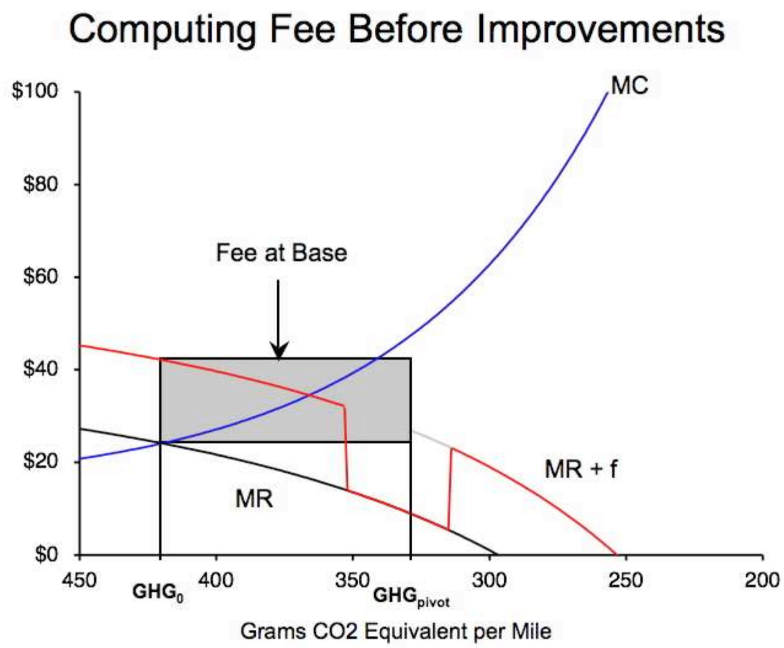


The upper and lower limits of the zero band were set so that at least 20% of sales fell between them. The pivot point was found through iteration to make the program revenue-neutral, with total fees collected equal total rebates paid. The steps that were iterated to find the pivot point was as follows:

(1) Once the upper and lower limits were set, the pivot point was initially set equal to the midpoint between them.
(2) The model was solved for this pivot point and total fees and total rebates were computed.
(3) If fees exceed rebates then the pivot is moved toward the upper limit, if rebates exceed fees then the pivot is moved toward the lower limit.
(4) Loop back to (2).
(5) Continue (using progressively smaller changes in the pivot) until the difference between fees and rebates is less than ±$0.05.

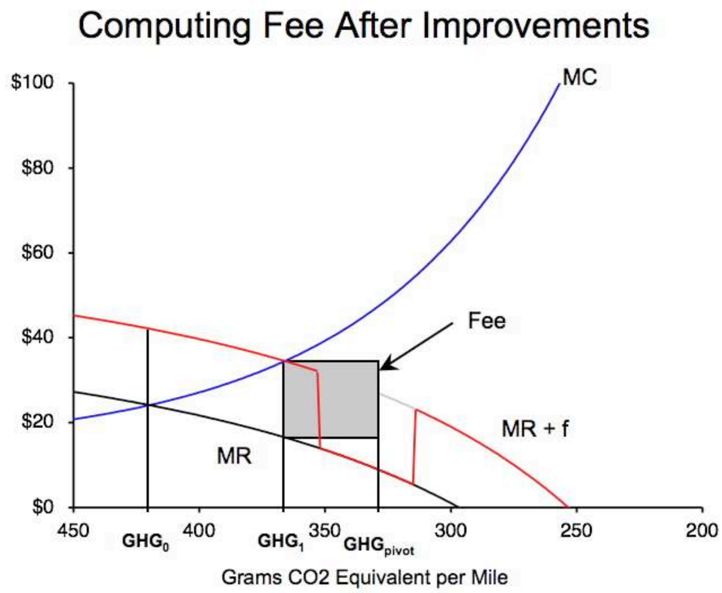
It should be mentioned that integer values were used for the upper and lower limits of the zero band, but the pivot point had up to 12 digits to the right of the decimal point. It would be much easier to ensure that fees would exceed rebates (or rebates would exceed fees) than to ensure that the program was revenue neutral.

The incentives for consumers to demand and automakers to supply vehicles with reduced greenhouse gas emissions can be seen by comparing the situation after feebates are imposed and before a technology response with the situation after the technology response.



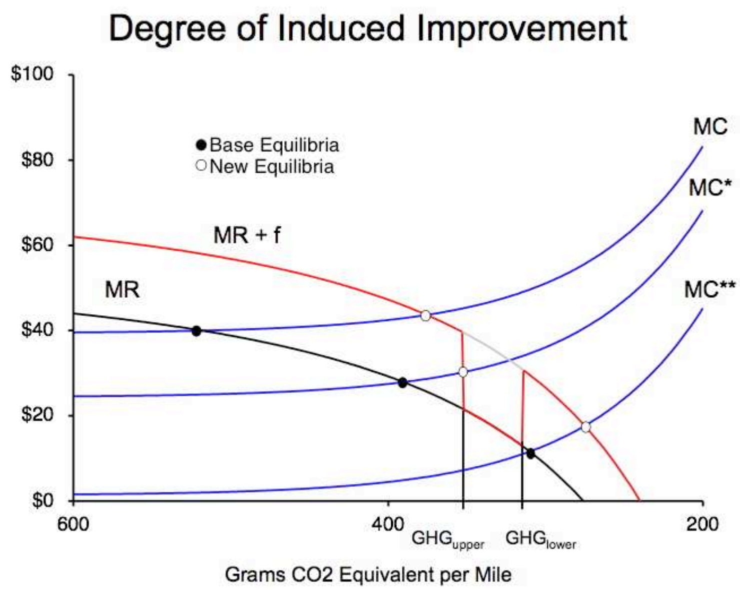
Initially, the MR and MC curves for a vehicle intersect at the base (GHG_0), and the system is in equilibrium. A feebates program is introduced that has the effect of shifting the MR curve to MR + f. At GHG_0 a buyer of a high polluting vehicle would now have to pay[iii] a fee of $f(GHG_0-GHG_{pivot})$, the shaded area in the figure. The next graph shows what would happen to the fee if the automaker were to reduce the vehicle's greenhouse emissions to GHG_1, the point at which the MC curve intersects the MR + f curve. At GHG_1 a buyer of the vehicle would now have to pay a fee of $f(GHG_1-GHG_{pivot})$, the new shaded area in the figure. Since the heights of the shaded areas in the two figures are equal (to f), and the pivot point is unchanged, the fee is lower in the second figure.

A feebates program results in a parallel shift of the effective marginal revenue curve (from the consumer's point of view) from MR to MR + f, except in the zero band. To either side of the zero band, the effective MR becomes MR + f. If a vehicle's emissions earn a rebate for the consumer, then reducing emissions even further would increase the rebate. If a vehicle's emissions require the consumer to pay a fee, then reducing emissions would reduce the fee. Thus, the MR + f curve is parallel to the MR curve, and MR + f > MR at every point not in the zero band.



The reduction in fees (or the increase in rebates) is what makes consumers demand (and automakers supply) cleaner vehicles. The incentive to move to cleaner technologies applies at all levels of current emissions. Just as the prospect of lower fees encourages makers of dirtier vehicles to make them cleaner in the above example, the prospect of higher rebates encourages makers of cleaner vehicles to make them even cleaner. Simulations were completed for this study under two alternative assumptions about whether automakers would respond to the feebates by changing the technologies in their vehicles. In every case we examined, the automakers would gain if they were to respond by adding technology. Therefore, in this report, we show only scenarios in which automakers respond by applying technology.

The inclusion of a zero band in the feebates program limits the improvement that would be induced for some vehicles. In particular, vehicles that have MC curves that intersect the MR + f curve in the vertical segment at the upper limit of the zero band, would be improved only to the upper limit of the zero band. If we eliminated the zero band, then vehicles in this situation would be improved up to the intersection of MC and MR + f. Our feebates simulations have a substantial number of vehicles "stacking up" at the upper limit of the zero band. However, the additional improvements to each vehicle that would be possible without the zero band were very small, so the aggregate effect of the zero band's improvement limits were also small.



2.5 UMTRI Consumer Choice Model

This study's aim is to assess the potential of alternative policies to reduce California's greenhouse gas emissions from vehicles. The reaction of California's new vehicle buyers is central to this assessment. We developed a model of California's vehicle market from UMTRI's Consumer Choice Model (McManus et al. 2005 and McManus 2006). The model uses a nested multinomial logit to describe the choice process that consumers follow when choosing among different vehicles. The demand for a specific vehicle in the model depends on the vehicle's "loadings" of performance (horsepower per ton), size (weight in pounds), and fuel economy (fuel cost per mile) and the values that consumers place on these attributes.

For this study we derived California-specific estimates consumers' willingness to pay for vehicle attributes from a hedonic price regression (Espey and Nair 2005 and McManus 2006) on the California 2002 data (described below). According to this analysis, the implicit market value of fuel economy in California in 2002 was in the range of $400 to $600 per mile per gallon. The U.S. national-level implicit value of fuel economy with the same data (but with U.S. 2002 prices and sales) was consistently lower by 5% to 7%. Californians valued fuel economy more highly than residents of other states in 2002. The magnitude of our estimates of the value of fuel economy to consumers is consistent with McManus [2006] and Espey and Nair [2005], both of which used similar hedonic approaches.

In the workings of the model we used the value of fuel economy to calibrate a discount rate that we applied to fuel cost savings. Assuming (along with Espey and Nair [2005] and CBO [2003]) a 14-year useful life for the average vehicle and assuming annual miles driven decline at 5.2% per year of vehicle age, the discount rate implied by the national-level analysis in McManus [2006] would be negative, (0.35%). For California, our current analysis implies a negative discount rate of -3% to -5%. The discount rate can be thought of as the real market rate of interest minus the expected rate of inflation in fuel prices (over and above general price inflation). Economists usually assume that the real market rate of interest is on the order of 4% to 8%, so a negative discount rate implies that consumers expect inflation in fuel prices to be higher than the real rate of interest. Espey and Nair [2005] also found very low or negative discount rates, and suggested that consumers value reductions in greenhouse gases and other emissions. This is a plausible interpretation, but we believe expected inflation in fuel prices is a more likely cause of negative discount rates.

Even though we have evidence that a negative discount rate would be appropriate for valuing fuel cost savings, we wanted to be conservative, and used 5% as the discount rate in our scenarios. This is lower than rates used in other studies. CBO [2003] and McManus et al. (2005) used 14%. Santini and Vyas (2005) used 10%. Greene, Duleep, and McManus (2004) used 0.0%, but assumed that new vehicle buyers value only about the first three years of cost savings.

Choosing the discount rate to use in our analysis is more than a mere technicality. The discount rate summarizes an assumption about the value consumers place on future benefits and costs and their expectations of future fuel prices. Consumer demand for automobiles is derived from the value consumers put on current and future services (transportation, fashion) offset by current and future costs. The higher the discount rate, the less value put on future services and costs relative to current services and costs.

The table below summarizes this section by giving our estimates of demand elasticities for price, performance, size, and fuel cost per mile (using either 0% and 5% discount rates).

UMTRI Consumer Choice Model: Demand Elasticities

Vehicle Segment	Vehicle Price ($)	Performance (HP per Ton)	Size (Curb Weight)	Fuel Cost per Mile	
				Discount Rate 0%	Discount Rate 5%
Car-Luxury	(1.90)	1.51	0.86	(0.12)	(0.09)
Car-Midsize	(2.00)	2.43	1.51	(0.24)	(0.18)
Car-Small	(2.30)	2.66	1.61	(0.26)	(0.19)
CUV-Luxury	(1.90)	1.36	1.24	(0.18)	(0.13)
CUV-Midsize	(2.00)	1.97	1.57	(0.26)	(0.19)
CUV-Small	(2.30)	2.08	1.72	(0.25)	(0.19)
Minivan	(2.00)	1.79	1.85	(0.27)	(0.20)
Pickup-Large	(1.40)	2.15	1.93	(0.37)	(0.27)
Pickup-Small	(2.00)	2.23	1.97	(0.37)	(0.28)
SUV_Large Luxury	(1.90)	0.93	1.16	(0.19)	(0.14)
SUV-Large	(2.00)	1.36	1.56	(0.27)	(0.20)
SUV-Midsize	(2.10)	1.60	1.60	(0.29)	(0.22)
SUV-Midsize Luxury	(1.90)	1.00	1.14	(0.17)	(0.13)
SUV-Small	(2.30)	1.93	1.59	(0.27)	(0.20)
Van-Large	(1.50)	1.87	2.33	(0.42)	(0.31)

The demand elasticity of an attribute meaures the percentage change in unit sales for a one (1.0) percent change in the attribute (all other attributes being held constant). For example, increasing the prices of all luxury cars by one percent would cause a 1.9% drop in unit sales.

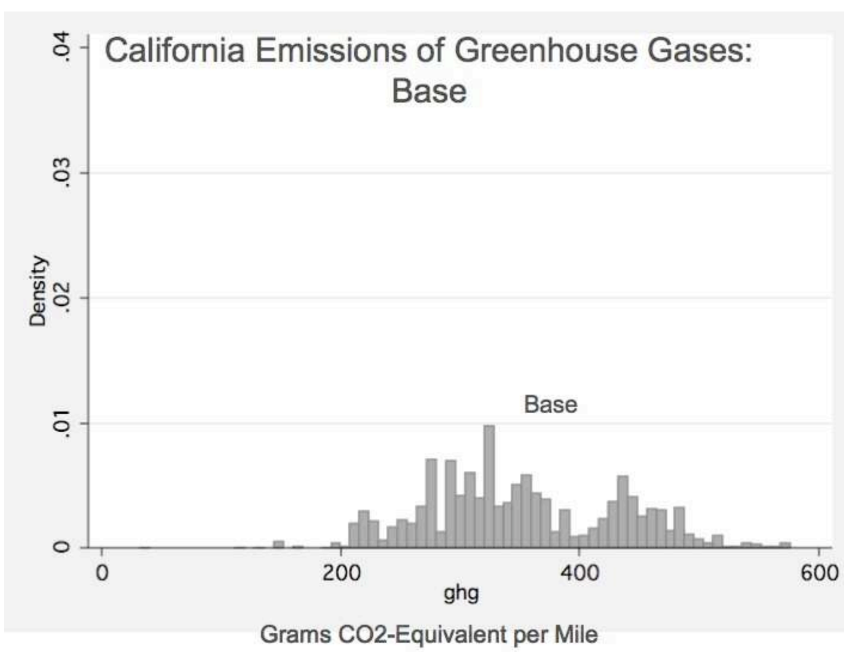
The relative magnitudes of the elasticities with respect to performance, size, and fuel cost per mile indicate that consumer demand is more responsive to performance than to size, and consumer demand is significantly more responsive to performance and size than to fuel cost per mile. For example, consider the luxury car segment. A 1.0 percent increase in performance of luxury cars would increase the number of luxury car demanded by 1.51 percent, and a 1.0 percent increase in size would increase the number of luxury cars demanded by 0.86 percent. Fuel cost per mile would need to be improved by 9.5 percent to get the same impact on demand as a 1.0 percent improvement in size, and fuel cost per mile would need to be improved by 17 percent to get the same impact on demand as a 1.0 percent increase in performance (using the 5% discount rate).

3 Data

We have data on model year 2002 sales of vehicles in California by make and model. We matched these data with California-specific transaction price data and national-level splits of each model into engine, transmission, body style, and drive type configurations (used in Greene, Duleep, and McManus [2004]). Information on vehicle attributes (horsepower, weight, fuel cost per mile) also came from the national-level data. Our California data covers 895 market entries for 2002.[iv] The table below shows average price, horsepower, curb weight, and GHG by Pavley class and automaker for California in 2002.

	Pavley Class 1 (PC/LDT1)				Pavley Class 2 (LDT2)			
	Price	Horse-power	Curb Weight	GHG	Price	Horse-power	Curb Weight	GHG
DaimlerChrysler	$28,033	181	3460	319	$26,143	215	4412	452
Ford Motor Co.	$24,640	179	3213	319	$26,496	214	4463	427
General Motors	$21,528	174	3153	304	$27,778	251	4843	443
Honda	$20,905	154	2894	268	$27,700	200	4223	350
Nissan	$22,480	192	3031	303	$24,446	177	4191	418
Others	$26,471	170	3137	310	$28,459	191	4329	400
Toyota	$25,397	172	3095	284	$26,730	202	4179	389
Total	**$24,433**	**173**	**3153**	**302**	**$26,828**	**217**	**4461**	**423**

Averages can cover considerable variability in attributes. The figure below plots the base distribution of greenhouse gas emissions by new vehicles sold in California in 2002.



This distribution has at least two modes. The part of the distribution above 400 grams of CO2-equivalent per mile represents most midsize and large trucks, while the part below

400 grams of CO2-equivalent per mile represent smaller trucks and cars. The vertical scale was chosen for displaying changes in the distribution that we will show later.

The table below shows the unit sales in California for model year 2002 by automaker and UMTRI vehicle type.

California Sales by Automaker and UMTRI Vehicle Type, Model Year 2002

	Cars	CUVs	Minivans	Pickups	SUVs	Large Vans	All Types
DaimlerChrysler	159,531	0	33,683	40,281	93,110	2,693	329,298
Ford Motor Co.	186,932	22,562	17,784	83,870	104,360	8,392	423,900
General Motors	183,021	8,083	18,399	85,268	82,731	8,735	386,237
Honda	169,137	26,944	24,651	0	0	0	220,732
Nissan	76,605	0	3,857	17,157	24,106	0	121,725
Others	196,639	18,011	7,380	0	24,131	0	246,161
Toyota	183,845	53,696	18,981	45,000	21,312	0	322,834
All Automakers	**1,155,710**	**129,296**	**124,735**	**271,576**	**349,750**	**19,820**	**2,050,887**

Ford and General Motors are the only "full-line" automakers with products of every type. Honda has the most concentrated product range (we classify the Ridgeline pickup as a crossover CUV).

4 Results

This section presents the results of our simulations. We highlight changes in greenhouse gas emissions, unit sales of light vehicles, prices to consumers, revenues to retailers, and cash flows of the feebates program. We assessed the potential impacts of Pavley and feebates on California's vehicle market and greenhouse gas emissions by simulating the outcome under four alternative situations for model year 2016:

- **Pavley alone:** assumes that each automaker meets its 2016 Pavley requirement by applying technologies to vehicles so that the loss of consumer plus producer surplus is minimized.
- **Feebates alone ($18 per grams of CO2-equivalent per mile):** assumes that the state adopts a feebates program with a slope of $18 per grams of CO2-equivalent per mile. Automakers apply technologies so that for each vehicle, the marginal cost equals the marginal revenue plus $18 (except in the zero band).
- **Feebates alone ($36 per grams of CO2-equivalent per mile):** assumes that the state adopts a feebates program with a slope of $36 per grams of CO2-equivalent per mile. Automakers apply technologies so that for each vehicle, the marginal cost equals the marginal revenue plus $36 (except in the zero band). This program is designed to achieve the same overall reduction in emissions as Pavley alone.
- **Pavley plus feebates:** assumes that each automaker meets its 2016 Pavley requirement, at a minimum. The state also adopts a feebates program with a slope of $18 per grams of CO2-equivalent per mile, motivating automakers to exceed Pavley.

We compared these situations to the 2002 baseline. To meet Pavley, or in response to the feebates program, we assume that automakers use technology to improve the emissions individual vehicles. We assume this adds cost according to CARB's cost curves, and changes consumer demand and automakers' revenue according to UMTRI's market model. CARB's cost curves overstate the ability of automakers to reduce greenhouse gas emissions and also assume that vehicle performance and weight are not affected. We do not change the attributes of hybrid or diesel vehicles in the simulations because these vehicles do not have room for much improvement. Total vehicle sales in California are allowed to vary by scenario, based on demand elasticities and changes in the average value of attributes, such as emissions.

In scenarios without feebates, the price of each vehicle is defined as the baseline price plus the cost of new technology used. Feebates create a wedge between the price a consumer pays and the price (revenue) the auto retailer receives. We define price and variable profit in the feebates scenarios as:

Price to consumer: $P_1 = P_0 + C + F$

Price to auto retailer: $P_2 = P_0 + C$

$\Pi = \pi P_2$

Where P_0 = baseline price of vehicle, C = cost of technology, F = value of fee or rebate, Π = variable profit, and π = variable profit rate.

4.1 Summary of Key Results

The table below summarizes the results of our simulation by examining the differences between the base case and the scenarios according to five key variables: average greenhouse gas emissions for the overall California market (grams of CO2-equilavent per mile), the total numbers of vehicles sold, the average retail price, retailers' total revenue (in billions of dollars), and the consumer price plus the lifetime fuel savings (a negative value equals savings to the consumer). The first panel of the table provides the levels of the key variables under each scenario. The second panel shows the difference from the base of those variables. The third panel shows the percent difference from the base of each variable.

Summary of Key Results by Scenario

	Base	Pavley alone	Feebates alone ($18 per gram per mile)	Feebates alone ($36 per gram per mile)	Pavley plus feebates ($18)
Emissions (g CO2-eq/mi)	**352**	**258**	**292**	**258**	**235**
Sales	2,050,887	2,057,040	2,040,778	2,033,128	1,967,327
Retail Price	$25,429	$26,704	$26,086	$26,593	$28,295
Retailers' Revenue (billions)	$52.2	$54.9	$53.2	$54.1	$55.7
Price plus Lifetime Fuel Cost	$36,435	$34,782	$35,201	$34,642	$35,631
	Difference from Base				
Emissions (g CO2-eq/mi)	**0**	**(94)**	**(60)**	**(94)**	**(117)**
Sales	0	6,153	(10,109)	(17,759)	(83,560)
Retail Price	$0	$1,275	$658	$1,164	$2,866
Retailers' Revenue (billions)	$0.0	$2.8	$1.1	$1.9	$3.5
Price plus Lifetime Fuel Cost	$0	($1,652)	($1,234)	($1,793)	($804)
	Percent Difference from Base				
Emissions (g CO2-eq/mi)	**0.0%**	**-26.7%**	**-17.1%**	**-26.7%**	**-33.3%**
Sales	0.0%	0.3%	-0.5%	-0.9%	-4.1%
Retail Price	0.0%	5.0%	2.6%	4.6%	11.3%
Retailers' Revenue (billions)	0.0%	5.3%	2.1%	3.7%	6.7%
Price plus Lifetime Fuel Cost	0.0%	-4.5%	-3.4%	-4.9%	-2.2%

By construction, Pavley alone and Feebates alone (at $36) have the same impact on average greenhouse gas emissions per mile statewide—reducing that average from 352 to 258 grams of CO2-equivalent per mile (down 26.7%). However, these two scenarios have very different impacts on vehicle sales, consumer prices, and revenues for retailers. Under Pavley alone, vehicles cost an average of 5.0% more than under the base scenario, while under Feebates alone (at $36), vehicles cost an average of 4.6% more than under the base scenario.

Under Pavley alone, lower emissions combined with higher prices result in slightly higher vehicle sales than base (up 0.3%). However, under Feebates alone (at $36), lower emissions combined with a higher price result in a slight reduction in sales (down 0.9%). Although the average price of vehicles rises under both scenarios because of new technology, only under Feebates alone (at $36) does the price of dirtier vehicles rise and that of cleaner vehicles fall. This shifts sales toward cleaner vehicles, and lower overall sales are one result.

Retailers' revenue rises more under Pavley alone than under Feebates alone (at $36). Lower fuel costs over vehicle lifetimes more than compensate consumers for increases in purchase price. The average consumer ends up saving $141 more under Feebates alone (at $36) than under Pavley alone, because feebates generate more economically efficient reductions in emissions, and automakers pass at least part of these efficiency gains on to consumers.

Feebates alone (at $18) have about two-thirds as strong an impact on greenhouse gas emissions as Pavley alone, reducing average emissions from 352 grams of CO2-equivalent per mile to 292 grams of CO2-equivalent per mile (down 17.1%). Under Feebates alone (at $18), the average price of a vehicle increases less than under Pavley alone or Feebates alone (at $36), sales fall relative to base but less than they do under Feebates alone (at $36), and revenue rises less than under Pavley alone. Consumers end up saving more money over the lifetime of their vehicles because of lower operating costs. Because automakers install fewer technologies under Feebates alone (at $18), consumers end up saving less than under Pavley alone and Feebates alone (at $36).

The biggest reduction in greenhouse gas emissions occurs under Pavley plus feebates (33%). In this scenario, the average price of a vehicle is higher, and thus sales are lower, relative to base than under Pavley alone. However, the higher price of vehicles more than compensates automakers for lower sales, pushing market revenue to $55.7 billion. What's more, consumers' savings from lower lifetime fuel costs exceed the cost of added technology under Pavley plus feebates—although consumers save less than under the other scenarios.

4.2 Sources of Change in Emissions

For each scenario, the table below shows the change in greenhouse gas emissions per mile, and how much of that change is due to technology and how much is due to market shifts reflecting changes in the vehicle mix . We assumed that automakers would apply technologies to their vehicles to meet Pavley and in response to feebates as long as the marginal value to consumers exceeded the marginal cost to automakers. Technology is the primary source of changes in emissions, indicating that the costs of improving emissions to meet the Pavely requirements are reasonable.

Impact on Greenhouse Gas Emissions by Scenario and Source

	Grams CO2-Equiv per Mile	Change Compared to Base					
		G CO2-Equil per Mile			Percent of Base		
		Tech-nology	Market Shift	Total	Tech-nology	Market Shift	Total
Base	**352**	0	0.0	0	0.0%	0.0%	0.0%
Pavley alone	258	(95)	0.9	(94)	-26.9%	0.26%	-26.7%
Feebates alone ($18 slope)	292	(59)	(1.1)	(60)	-16.7%	-0.31%	-17.1%
Feebates alone ($36 slope)	258	(93)	(1.1)	(94)	-26.4%	-0.32%	-26.7%
Pavley plus Feebates ($18)	235	(117)	0.1	(117)	-33.3%	0.03%	-33.3%

In Pavley alone and in Pavley plus feebates, the shift in sales mix slightly offsets cuts in emissions produced by technology. Thus automakers would have to use additional technology to fulfill the Pavely standards than is needed in these scenarios than would be the case if there were no market shift. In contrast, in Feebates alone (at $18) and Feebates alone (at $36), a shift in sales mix toward cleaner vehicles slightly reduces the need for technology improvements to reduce emissions. This illustrates a key difference between market-based mechanisms (feebates) and mandates (Pavley). In both strategies, technologies that clean up vehicle emissions add cost. However, in the Feebates strategies, feebates for the cleanest vehicles offset those costs, shifting sales toward cleaner vehicles. Still, in all the scenarios, changes in emissions stemming from changes in the sales mix were small.

4.3 *Changes in Emissions by Scenario and Segment*

The table below shows the impact of the scenarios on greenhouse gas emissions in different segments of the vehicle market. The first panel shows the level of greenhouse gas emissions by segment and scenario, and the second panel shows percent differences relative to the base.

California Greenhouse Gas Emissions
by CARB Segment and Scenario

(grams CO2 equivalent per mile)

	Base	Pavley alone	Feebates alone ($18 slope)	Feebates alone ($36 slope)	Pavley plus Feebates ($18)
Car	302	220	254	225	204
Van	370	275	305	270	249
Pickup	436	323	361	320	289
SUV	419	303	344	302	273
Total	**352**	**258**	**292**	**258**	**235**

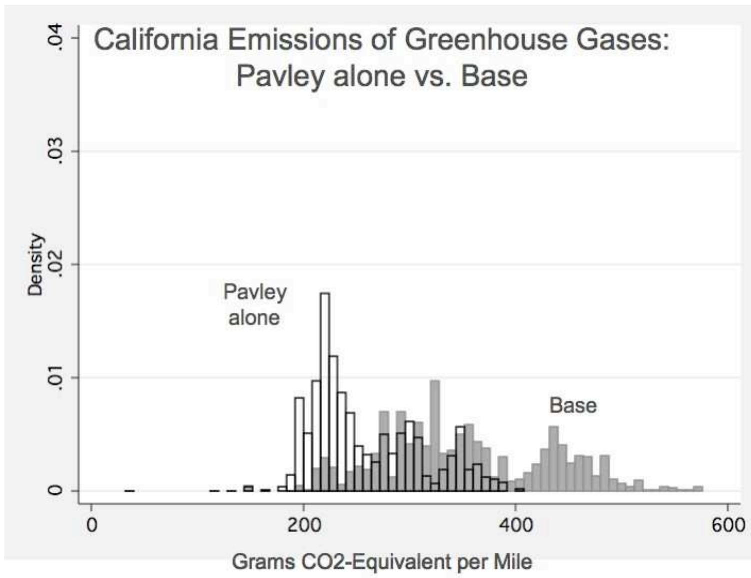
Relative to Base (percent change)

	Base	Pavley alone	Feebates alone ($18 slope)	Feebates alone ($36 slope)	Pavley plus Feebates ($18)
Car	0%	-27%	-16%	-25%	-32%
Van	0%	-26%	-18%	-27%	-33%
Pickup	0%	-26%	-17%	-27%	-34%
SUV	0%	-28%	-18%	-28%	-35%
Total	**0%**	**-27%**	**-17%**	**-27%**	**-33%**

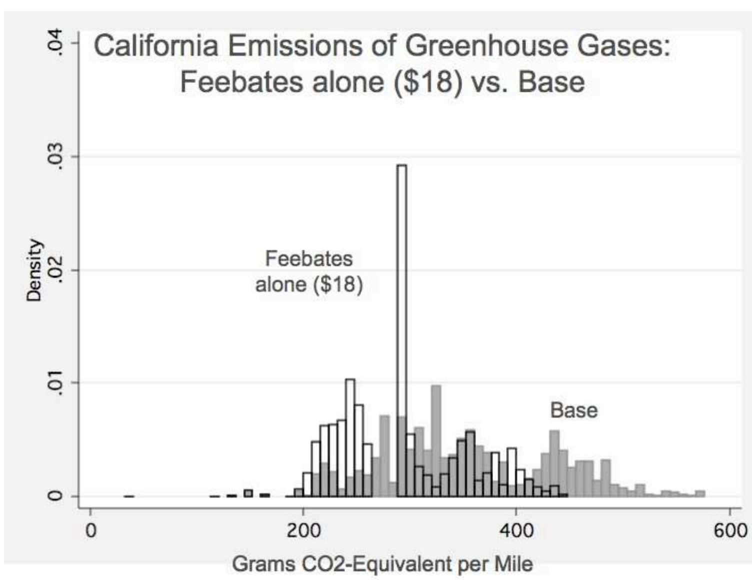
Both Pavley alone and Feebates alone (at $36) reduce emissions in the overall vehicle market by 27%. Both scenarios also reduce emissions of SUVs by 28%. However, Pavley alone reduces emissions for cars slightly more—and reduces emissions for vans and pickups slightly less—than Feebates alone (at $36)

4.4 Changes in the Distribution of Emissions

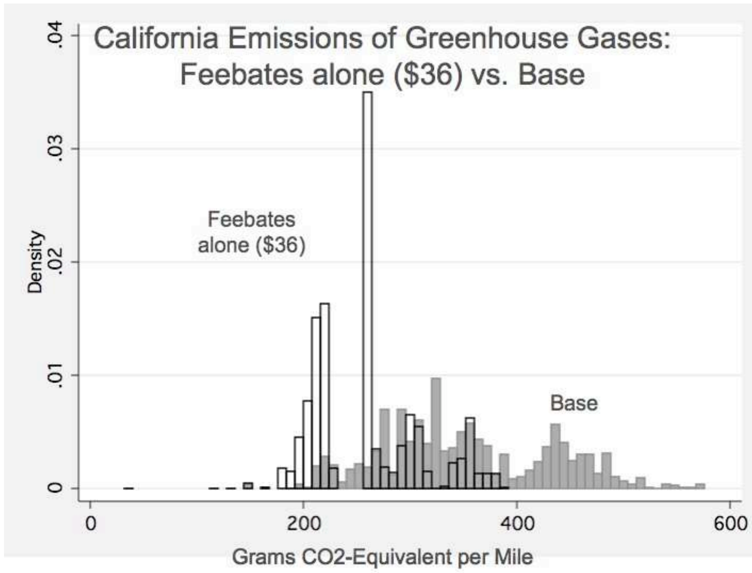
The graphs below compare the distribution of greenhouse gas emissions under each scenario superimposed over the base distribution. Pavley alone creates a new emission peak at 225 grams of CO2-equivalent per mile, with a cluster between 180 and 250 grams of CO2-equivalent per mile.



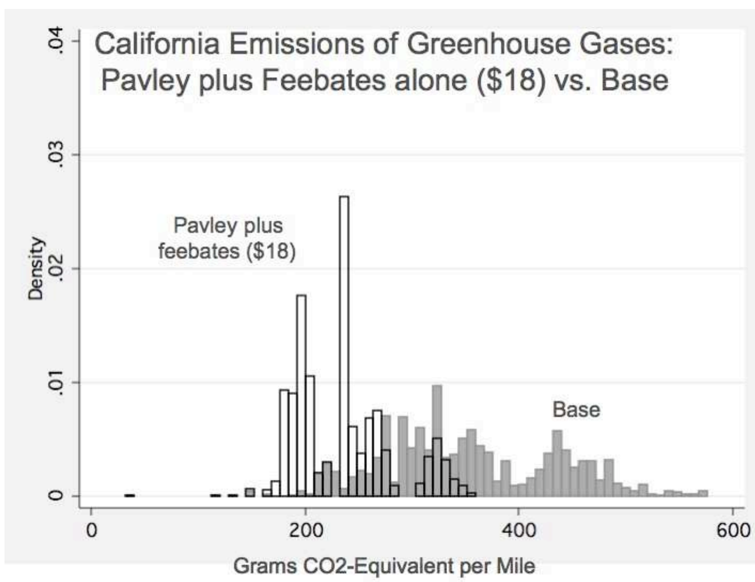
Feebates alone (at $18) create a smaller but similar cluster between 200 and 230 grams of CO2-equivalent per mile. The tallest spike occurs at the upper limit (293 grams of CO2-equivalent per mile) of the zero band (261 to 293 grams of CO2-equivalent per mile).



Feebates alone (at $36) create a tight cluster between 180 and 220 grams of CO2-equivalent per mile. The tallest spike occurs at the upper limit (256 grams of CO2-equivalent per mile) of the zero band (225 to 256 grams of CO2-equivalent per mile).



Pavley plus Feebates (at $18) creates a very tight cluster between 170 and 210 grams of CO2-equivalent per mile. The tallest spike occurs at the upper limit (236 grams of CO2-equivalent per mile) of the zero band (205 to 236 grams of CO2-equivalent per mile).



The histograms qualitatively show that all scenarios achieve significant reductions in emissions compared to the base scenario.

4.5 Changes in Consumer Expenditures

The overall cost of a vehicle to a consumer has two elements: acquisition and operation. Acquisition costs would include price plus fees minus rebates, licensing, and the present value of financing. Operation costs include fuel, maintenance, and insurance. The table below shows the impact of the scenarios on major portions of acquisition and operation costs: retail price, feebates, and lifetime fuel cost. Negative values represent savings for consumers, while positive values represent higher expenditures for consumers. The estimates of lifetime fuel savings are based on CARB's estimates of vehicle miles traveled, which are 202,329 for cars and 233,418 for trucks.[v]

Change in Price and Lifetime Fuel Cost by Scenario

Scenario		Car	Van	Pickup	SUV	Market
Pavley alone	Lifetime Fuel Savings	($2,432)	($3,090)	($3,712)	($3,786)	($2,928)
	Retail Price Change	$1,253	$989	$1,367	$1,242	$1,275
	Total Change	($1,178)	($2,100)	($2,344)	($2,544)	($1,652)
Feebates alone ($18 per gram per mile)	Lifetime Fuel Savings	($1,428)	($2,117)	($2,456)	($2,429)	($1,892)
	Retail Price Change	$536	$743	$959	$920	$658
	Net Feebate	($652)	$172	$1,187	$928	$0
	Total Change	($1,544)	($1,203)	($311)	($581)	($1,234)
Feebates alone ($36 per gram per mile)	Lifetime Fuel Savings	($2,281)	($3,254)	($3,812)	($3,817)	($2,957)
	Retail Price Change	$979	$1,270	$1,633	$1,516	$1,164
	Net Feebate	($877)	$235	$1,444	$1,353	$0
	Total Change	($2,179)	($1,748)	($735)	($948)	($1,793)
Pavley plus feebates ($18)	Lifetime Fuel Savings	($2,904)	($3,949)	($4,817)	($4,770)	($3,670)
	Retail Price Change	$2,618	$2,726	$3,514	$3,227	$2,866
	Net Feebate	($541)	$280	$966	$673	$0
	Total Change	($827)	($943)	($337)	($870)	($804)

Negative values represent reductions in consumer expenditure.
Lifetime Fuel Cost = present value at 5% discount of fuel saved assuming CARB life and VMT.
Retail Transaction Price = change in price from the retailer's point of view.
Net Feebate = impact of feebate on price from the consumer's point of view.
Total Change= the total change in consumer expenditure.
Price of gasoline = $1.74/gallon

The average vehicle price is higher in every scenario than in the base, because the price includes the cost of technologies used to improve emissions. The average feebates is a rebate (negative) for cars and a fee (positive) for trucks in all scenarios. The analysis in the table are weighted by sales, showing that the changes shown are driven by technologies.

In every scenario and for every vehicle type, the present value of fuel savings over the lifetime of the vehicle more than compensates for increases in the vehicle's price. Under all the Feebates scenarios, the feebates lowers the average consumer price of cars while raising the average price of other types of vehicles. In the overall market, consumers' expenditures to purchase and fuel their vehicles are lower in all scenarios compared to the base.

4.6 Changes in Sales by Scenario and Segment

The table below shows the impact of the scenarios on vehicle sales in different segments of the market. The first panel shows sales by segment and scenario, and the second panel shows percent differences relative to the base.

California Light Vehicle Sales by CARB Segment and Scenario

(Thousands of Units)

	Base	Pavley alone	Feebates alone ($18 slope)	Feebates alone ($36 slope)	Pavley plus Feebates ($18)
Car	1,155	1,135	1,173	1,172	1,109
Van	145	148	143	143	140
Pickup	272	278	263	261	263
SUV	480	495	462	457	455
Total	**2,051**	**2,057**	**2,041**	**2,033**	**1,967**

Relative to Base (percent change)

	Base	Pavley alone	Feebates alone ($18 slope)	Feebates alone ($36 slope)	Pavley plus Feebates ($18)
Car	0.0%	-1.7%	1.6%	1.5%	-3.9%
Van	0.0%	2.7%	-1.0%	-1.0%	-3.3%
Pickup	0.0%	2.3%	-3.1%	-4.0%	-3.1%
SUV	0.0%	3.2%	-3.9%	-4.8%	-5.2%
Total	**0.0%**	**0.3%**	**-0.5%**	**-0.9%**	**-4.1%**

Under Pavley alone, total sales are up 0.3%, while sales of cars are down 1.7% and sales of trucks are up. In contrast, under Feebates alone (at $18) and Feebates alone (at $36), total sales are down, while sales of cars are up and sales of trucks are down. Under Pavley plus feebates (at $18), sales are down in all segments. This shows that the consumer demand shifts toward cleaner vehicles in the feebates alone scenarios.

4.7 Changes in Retailers' Revenue by Scenario and Segment

The table below shows the impact of the scenarios on the revenue of California retailers stemming from different segments of the market. The first panel shows the level of revenue by segment and scenario, and the second panel shows percent differences relative to the base.

Retailers' Revenue by CARB Segment and Scenario

($billions)

	Base	Pavley alone	Feebates alone ($18 slope)	Feebates alone ($36 slope)	Pavley plus Feebates ($18)
Car	$28.4	$29.3	$29.4	$29.9	$30.1
Van	$3.4	$3.6	$3.5	$3.5	$3.7
Pickup	$6.0	$6.5	$6.1	$6.2	$6.7
SUV	$14.4	$15.5	$14.3	$14.4	$15.1
Total	**$52.2**	**$54.9**	**$53.2**	**$54.1**	**$55.7**

Relative to Base (percent change)

	Base	Pavley alone	Feebates alone ($18 slope)	Feebates alone ($36 slope)	Pavley plus Feebates ($18)
Car	0.0%	3.3%	3.8%	5.6%	6.3%
Van	0.0%	7.0%	2.1%	4.3%	7.9%
Pickup	0.0%	8.7%	1.1%	3.1%	12.4%
SUV	0.0%	7.4%	-0.9%	0.0%	4.9%
Total	**0.0%**	**5.3%**	**2.1%**	**3.7%**	**6.7%**

In all the scenarios, retailers' revenue is larger than in the base. Under Feebates scenarios, cars contribute relatively more to total revenue, while trucks contribute less, again showing a shift toward cleaner vehicles.

5 Summary and Directions for Further Research

Concern over climate change is growing in America and the debate over policies to regulate the emissions that contribute to global warming is proceeding faster than anyone imagined just a few years ago. The recent U.S. Supreme Court decision in Mass. V. EPA has given new momentum to federal actions as well as to additional state actions.

In California, Assembly Bill 1493 (commonly referred to as Pavley) orders the California Air Resources Board (CARB) to "develop and adopt regulations that achieve the maximum feasible and cost-effective reduction of greenhouse gas emissions from motor vehicles." Based upon an evaluation of near and mid-term emissions reducing technologies and their costs, CARB has developed annual fleet-wide emissions targets for passenger cars and light duty trucks.

In addition to establishing mandatory emissions limits, there are other possible means of reducing global warming pollutants, such as creating economic incentives for consumers to buy and manufacturers to produce cleaner vehicles. A feebates program provides such incentives by combining a fee on vehicles with high emissions along with a rebate on cleaner vehicles. This study estimated impacts of feebates and Pavley (separately and in combination) on California's greenhouse gas emissions for model year 2016.

We estimated the impact of different policy combinations on emissions, prices, and vehicle sales using an economic model we developed for California. We examined the cost and value to the consumer of reducing greenhouse gas emissions. Our cost estimates were based on CARB's projections of the costs of technologies that automakers could apply to reduce greenhouse gas emissions. CARB's estimates assume that all technology changes would be applied to reduce greenhouse gas emissions. We fitted exponential functions to CARB's technology packages to specify the cost of reducing emissions in our model. Exponential cost functions have more rapidly rising marginal costs than quadratic cost functions would, and offset the assumption that all improvements would be applied to reducing emissions.

We derived the value to a consumer of reducing his vehicle's greenhouse gas emissions from UMTRI's model of consumer demand for vehicle attributes. The demand for a specific vehicle depends on the vehicle's "loadings" of performance (horsepower per ton), size (weight in pounds), and fuel economy (fuel cost per mile) and the values that consumers place on these attributes. To meet Pavley or in response to the feebates program, we assume that automakers respond by using technology to improve individual vehicles. We further assume that this adds cost according to CARB's cost curves and changes demand and revenue according to UMTRI's market model. We allowed total vehicle sales in California to vary by scenario, based on market-level demand elasticities and changes in the average market values of attributes.

We assessed the impacts of Pavley and feebates on California's vehicle market and greenhouse gas emissions by simulating the outcome under four alternative situations for model year 2016: Pavley alone, Feebates alone (at $18 slope), Feebates alone (at $36 slope), and Pavley plus feebates (at $18 slope).

In Pavley alone the price is defined as the baseline price plus the cost of technology used. Feebates alone (at $36) and Pavley alone would each reduce the market average greenhouse gas emissions per mile by 26.7%. Pavley alone has a 5.0% higher average price than base, while Feebates alone (at $36) has a 4.6% higher average price than base. Under Pavley alone, lower emissions combined with a higher price result in slightly higher sales than base (up 0.3%). However, under Feebates alone (at $36) lower emissions combined with a higher price result in a slight reduction in sales (down 0.9%). Both scenarios have price increases from new technologies, but under Feebates alone (at $36) the fees and rebates make prices of dirtier vehicles rise and those of cleaner vehicles fall. This shifts sales toward cleaner vehicles, and lower overall sales are one result. However, the lower fuel costs over the lifetime of the vehicle more than compensates the consumer for the increase in purchase price. Among the simulations, the biggest reduction in greenhouse gas emissions occurs in Pavley plus feebates (33%). Sales are lower and average price is higher relative to base than under Pavley alone.

In Pavley alone and in Pavley plus feebates, a market shift slightly offsets the improvements produced by technology. In both strategies technologies are added that clean up vehicle emissions adding cost, but in the feebates strategies these costs are offset by feebates for the cleanest vehicles..

There are several enhancements that were suggested by our analysis for this study.

- We are pursuing an update using more current California market data.
- CARB's cost estimates were based on NAS and NESCAAF—studies that are now a few years old. It would be valuable to update them.
- Adding more vehicle attributes to the model would make it capable of greater precision.
- It would be preferable to model the technical trade-offs directly rather than summarize them in cost functions. We are pursuing this approach in another study of the U.S. market.
- We are also enhancing the model to allow us to analyze other policies at the national market level (CAFE, cap and trade, rebates alone, fuel taxes, manufacturer incentives for investing in technology).

6 Bibliography

Alson, J., B. Ellies, and D. Ganss, 2005. *Interim Report: New Powertrain Technologies and Their Projected Costs*. EPA420-R-05-1012. U.S. Ann Arbor, MI: U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Transportation and Climate Division. August.

Bento, Antonio M., Lawrence H. Goulder, Emeric Henry, Mark R. Jacobsen, And Roger H. Von Haefen (2005) *"Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically-Based Multi-Market Study," American Economic Association Papers And Proceedings* May 2005

Berry, Steven, James Levinson, and Ariel Pakes. (1995) *"Automobile Prices in Market Equilibrium."* Econometrica, 1995, 63(4), pp. 841–90.

Berry, S., J. Levinsohn, and A. Pakes. (2004) *"Differentiated Products Demand Systems from a Combination of Micro and Macro Data: The New Vehicle Market*," Journal of Political Economy 112, 68-105.

California Air Resources Board (CARB) August 2004. *AB 1493 Draft Staff Report: Maximum Feasible and Cost-Effective Reduction of Greenhouse Gas Emissions from Motor Vehicles*, August 2004

California Air Resources Board (CARB) September 2004. *Addendum to AB 1493 Draft Staff Report: Maximum Feasible and Cost-Effective Reduction of Greenhouse Gas Emissions from Motor Vehicles*.

Congressional Budget Office, (2003) "*The Economic Costs of Fuel Economy Standards Versus a Gasoline Tax".* Congressional Budget Office, Washington, DC.

DeCicco, J., F. An, and M. Ross, ACEEE, 2001. "*Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015,"* American Council for an Energy Efficient Economy.

DOE 1995. "*Energy Conservation Trends: Understanding the Factors Affecting Conservation Gains and Their Implications for Policy Development*." Report DOE/PO-0034. Washington, DC: U.S. Department of Energy, Office of Policy. April.

EEA 2005. *"Fuel Economy Potential for 2010 Light Duty Trucks*," prepared for DOE and DOT, Energy and Environmental Analysis.

Ellerman, A.D., Jacoby, H.D., and Zimmerman M. (2006) "Bringing Transportation into a Cap-and-Trade Regime", The MIT Joint Program on the Science and Policy of Global Change , Report No. 136, June .

Espey, M. and Nair, S., *"Automobile Fuel Economy: What is it Worth*?" Contemporary Economic Policy (Western Economic Association). Vol. 23, No. 3, July 2005, 317-323.

Espey, M. (2005), *"Do Consumers Value Fuel Economy?"* Regulation (Cato Institute), Winter 2005-2006, 8-10.

Fudenberg, Drew and Jean Tirole (1991) "*Game Theory*," MIT Press.

Fullerton, Don and Gan, Li, 2005. "Cost-Effective Policies to Reduce Vehicle Emissions," *American Economic Review*, vol. 95(2), pages 300-304, May.

David L. Greene (2001) *"TAFV: Alternative Fuels And Vehicles Choice Model Documentation"* Center for Transportation Analysis Oak Ridge National Laboratory July 2001

Greene, D.L., and Y. Fan, ORNL 1994. "*Transportation Energy Efficiency Trends, 1972-1992."* Report ORNL-6828. Oak Ridge, TN: Oak Ridge National Laboratory, Center for Transportation Analysis. December.

Greene, D.L., Duleep, K.G., and McManus, W.S., *"Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market,"* ORNL Report, August 2004.

Grene, David L., Patterson, Philip D., Singh, Margaret, and Li, Jia 2005. "Feebates, Rebates, and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy," *Energy Policy*, 33: 757-775.

Griliches, Z. (1961). *"Hedonic Price Indexes for Automobiles: An econometric Analysis of Quality Change"*, in The Price Statistics of the Federal Government, New York, the National Bureau of Economic Research.

Hammett, P. Flynn, M., and Sims, M., *"Fuel-saving Technologies and Facility Conversion: Costs, Benefits, and Incentives,"* Office for the Study of Automotive Transportation, University of Michigan Transportation Research Institute, November 2004.

Heavenrich, R.M, EPA 2005. *Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2005*. Ann Arbor, MI: U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Advanced Technology Division. July.

Johnson, David S., Reed, Stephen B., and Stewart, Kenneth J. *"Price measurement in the United States: A decade after the Boskin Report,"* Monthly Labor Review, May 2006.

Johnson, Kenneth C. 2006. "Feebates: An Effective Regulatory Instrument for Cost-Constrained Environmental Policy," *Energy Policy*, 34: 3965-3976.

Kleit, A. *, "Impacts of Long-Range Increases in the Corporate Average Fuel Economy (CAFE) Standard,"* Economic Inquiry 42:2 (April 2004) 279-294. (Published version of "Short- and Long-Range Impacts of Increases in the Corporate Average Fuel Economy (CAFE) Standard," report for the General Motors Corporation, January 2002.)

Kurani, K.S., and T. Turrentine, 2004, *"Automobile Buyer Decisions about Fuel Economy and Fuel Efficiency,"* ITS-RR-04-31, University of California Institute of Transportation Studies Report, Sept. 1.

McFadden, D., *"Conditional Logit Analysis of Qualitative Choice Behavior,"* in P. In Zarembka, Frontiers in Econometrics (New York: Academic Press, 1973).

McManus, Walter S., Alan Baum, Roland Hwang, Daniel D. Luria, and Gautam Barua, *"IN THE TANK How Oil Prices Threaten Automakers' Profits and Jobs,"* Office for the Study of Automotive Transportation, University nof Michigan Transportation Research Institute, July 2005.

McManus, W.S., *"The Effects of Higher Gasoline Prices on U.S.Light Vehicle Sales, Prices, and Variable Profits by Segment and Manufacturer Group, 2001 and 2004,"* Office for the Study of Automotive Transportation, University of Michigan Transportation Research Institute, May 23, 2005.

McManus, Walter, September 2006. *Can Proactive Fuel Economy Strategies Help Automakers Mitigate Fuel-Price Risks?* University of Michigan, UMTRI Automotive Analysis Division, Research Report.

McManus, W.S., *"The Link Between Gasoline Prices and Vehicle Sales,"* Business Economics, Forthcoming April 2007.

NAS 2002. *Effectveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,* report by the National Research Council, Washington, DC, National Academy Press.

Nash, John (1950) *"Equilibrium Points in N-person Games"* Proceedings of the National Academy of Sciences.

National Commission on Energy Policy, *"Ending the Energy Stalemate, A Bipartisan Strategy to Meet America's Energy Challenges,"* December 2004.

NESCCAF 2004. *"Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles."* Northeast States Center for a Clean Air Future. September.

NRC, 2002. *"Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards."* National Research Council, Washington, DC, National Academy Press.

Parry, Ian 2006. "On the Costs of Policies to Reduce Greenhouse Gases from Passenger Vehicles" Resources for the Future, DP 06-14, March.

Parry, Ian W.H., Carolyn Fischer, and Winston Harrington (2004) *"Should Corporate Average Fuel Economy (CAFE) Standards Be Tightened?"* December 2004 RFF DP 04-53

Rawls, John, (1971) "*A Theory of Justice,"* The Belknap Press of Harvard University Press.

Santini, D. and Vyas, A., (2005) *"Suggestions for a New Vehicle Choice Model Simulating Advanced Vehicles Introduction Decisions (AVID): Structure and Coefficients,"* Argonne National Laboratory, August 2005.

Sweeney, J.L. 1979. Effects of federal policies on gasoline consumption. Resources and Energy 2: 3-26.

Train, K.E. and Winston, C., (2006) *"Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers"* (2006) Forthcoming, International Economic Review.

Train, Kenneth E. (2003). *"Discrete Choice Methods with Simulation."* Cambridge, UK: Cambridge University Press.

Weiss, M., et al, MIT 2000.., *On the Road in 2020: A Life-cycle analysis of new automobile technologies.* Cambridge, MA: Massachusetts Institute of Technology. October.

Kenneth E. Train Clifford Winston (2004) *"Vehicle Choice Behavior And The Declining Market Share Of U.S. Automakers,"* U.C. Berkeley Brookings Institution July 2004

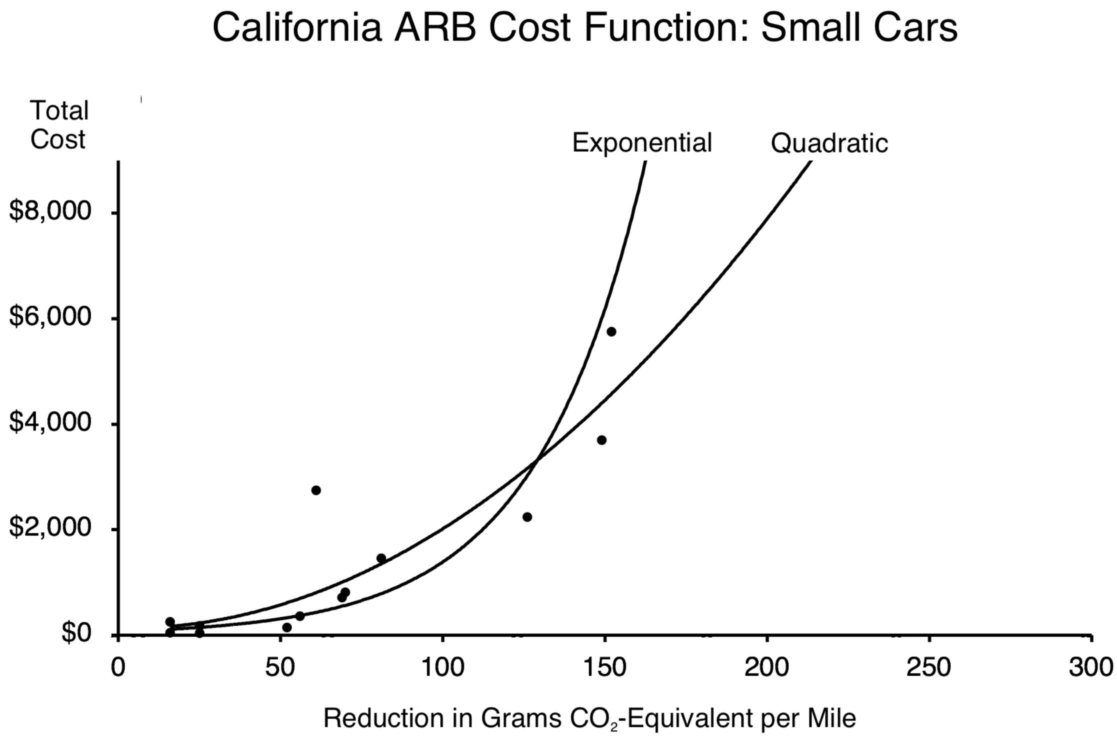
Williams, H.C.W.L., (1977) *"On the Formulation of Travel Demand Models and Economic Evaluation Measures of User Benefit,"* Environment and Planning, 9A, No.3, pp.285-344, 1977.

Feng, Ye; Fullerton, Don; and Gan, Li. (2004) *"Vehicle Choices, Miles Driven and Pollution Policies,"* Working paper, University of Texas at Austin, July 2004.

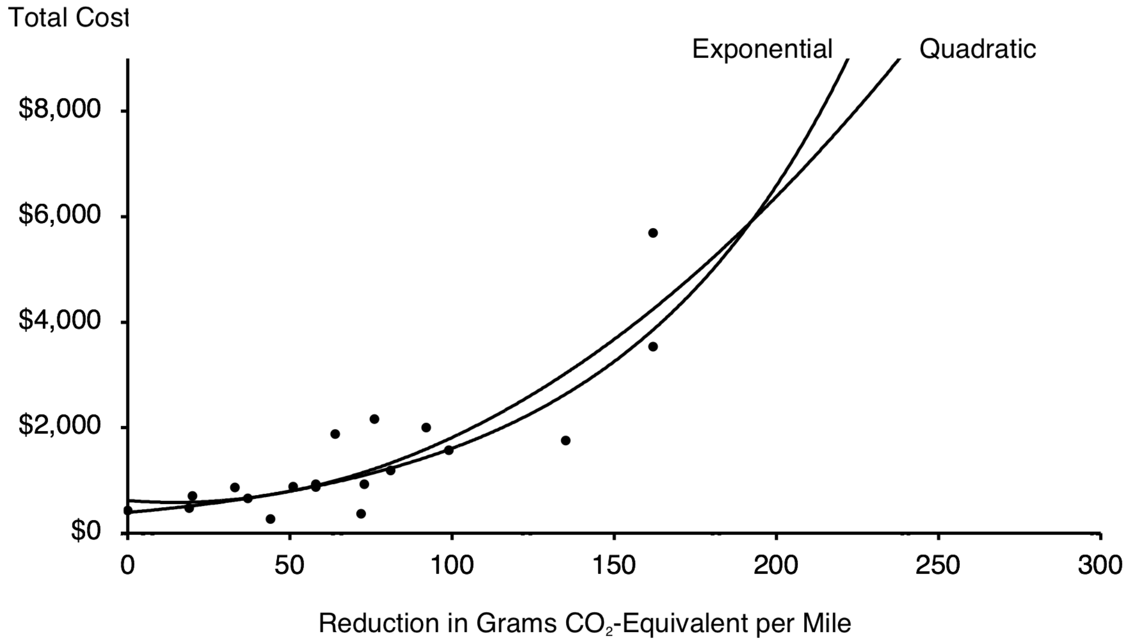
Ye Feng Don Fullerton Li Gan (2005) *"Vehicle Choices, Miles Driven And Pollution Policies,"* Working Paper 11553 National Bureau Of Economic Research August 2005.

7 Appendix A: Exponential Cost Functions

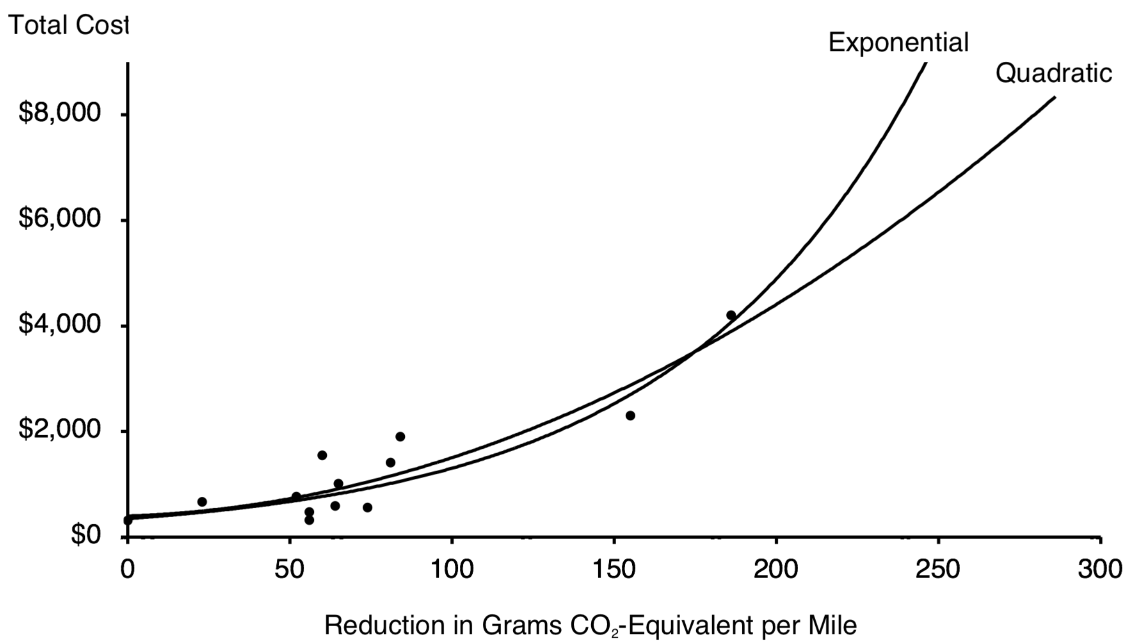
The graphs below display the California ARB cost assumptions for five types of vehicles: small cars, large cars, minivans, small trucks, and large trucks. In each graph the CARB assumptions on total cost and reduction in emissions are plotted as dots and two alternative fitted functions (exponential and quadratic) are plotted as curves. Quadratic cost functions imply linear marginal cost functions and exponential cost functions imply exponential marginal cost functions. We chose to use exponential cost functions for this study as the more conservative choice. Rising marginal costs are more conservative than are linear marginal costs, especially as we simulate large reductions in emissions. Cubic total cost functions (quadratic marginal cost functions) would have produced results similar to what the exponential functions produced in our simulations.



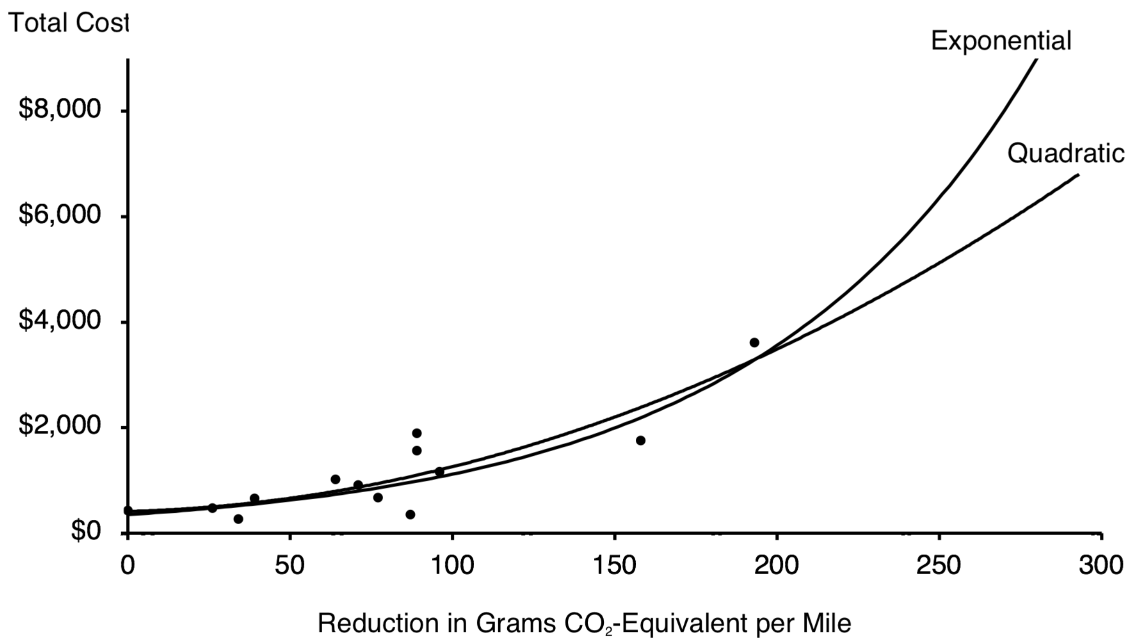
California ARB Cost Function: Large Cars



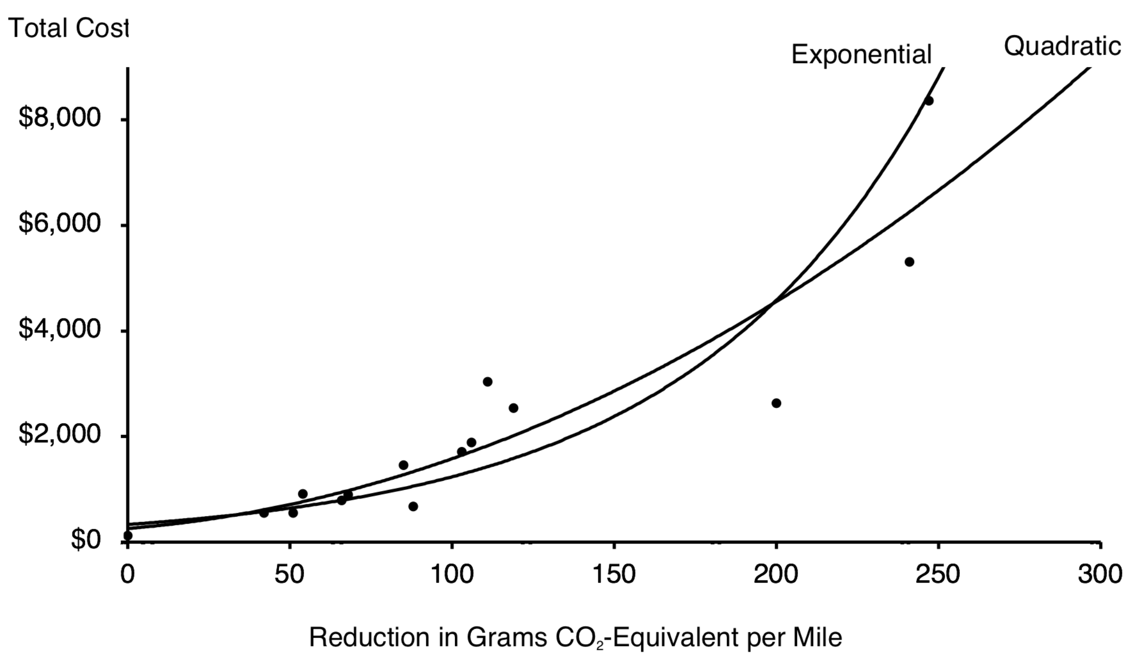
California ARB Cost Function: Minivans



California ARB Cost Function: Small Trucks



California ARB Cost Function: Large Trucks



8 Appendix B: Hedonic Regressions

Regressions were run on the 2002 vehicle data separately for California and the U.S. in which the dependent variable was the retail price. Independent variables were horsepower per ton, curb weight, gallons per mile, and dummy variables for manufacturers. The basic results are shown below. The table below shows the parameter estimates, means, and elasticities. The model was fit with gallons per mile, but the table also shows three alternative specifications of interest (all simple transformations of the coefficient on gallons per mile): grams of CO2-equivalent per mile, cents per mile, and miles per gallon.

Determinants of Retail Price: Hedonic Regressions

	California			United States		
	Parameters	Means	Elasticities	Parameters	Means	Elasticities
Horsepower/Ton	$311	104	1.27	$243	102	1.01
Curbweight (lb)	$9.21	3697	1.34	$8.66	3774	1.32
Gallons per Mile	($254,691)	0.04	(0.41)	($258,358)	0.04	(0.43)
Grams CO2-eq/mile	($29.96)	344	(0.41)	($30.40)	349	(0.43)
Cents per Mile	($1,682)	6.12	(0.41)	($1,921)	5.53	(0.43)
Miles per Gallon	$417	24.73	0.41	$436	24.33	0.43
R-Squared	55%			57%		
Vehicle Price		$25,429			$24,675	
Gas Price (cents/gal)		151.4			134.5	

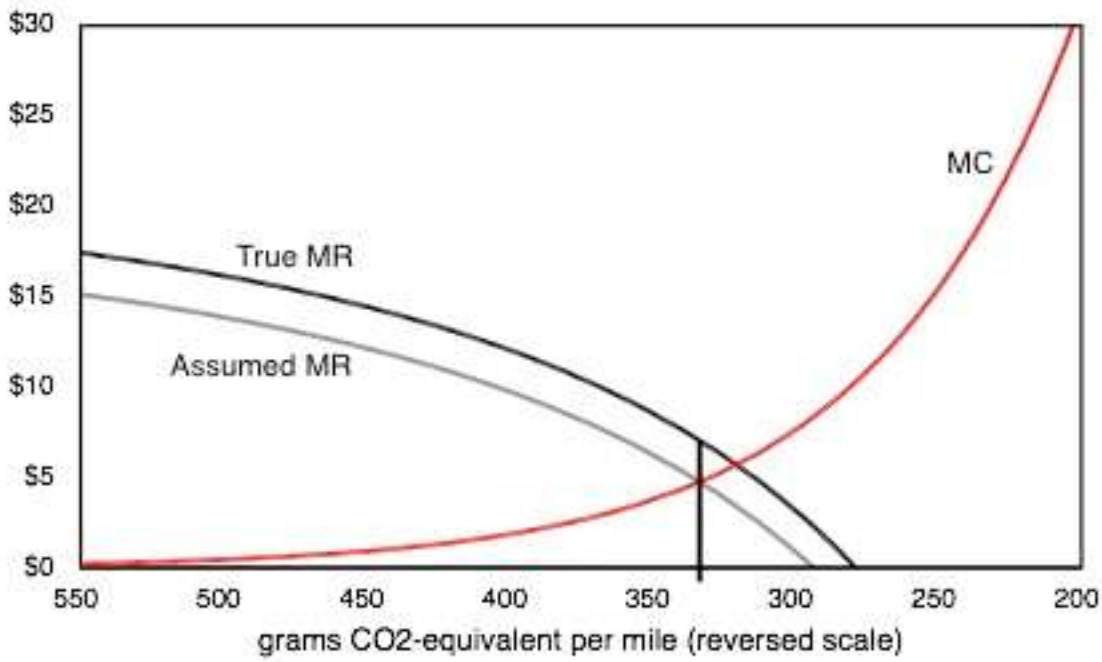
The hedonic regressions also included dummy variables for manufacturers. The table below uses the hedonic results to calculate a price premium for each manufacturer compared to GM.

Retail Price Premium by Manufacturer

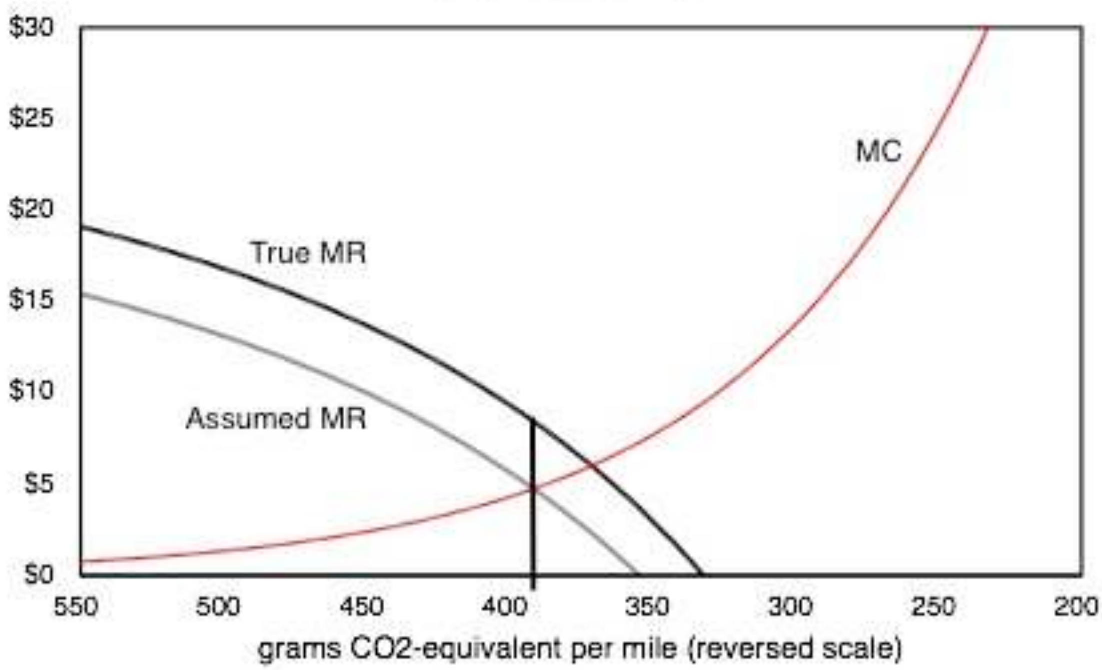
	Calif.	U.S.
DaimlerChrysler	17%	6%
Ford	11%	7%
GM	**0%**	**0%**
Honda	12%	4%
Nissan	5%	-1%
Toyota	16%	10%
Other	28%	17%

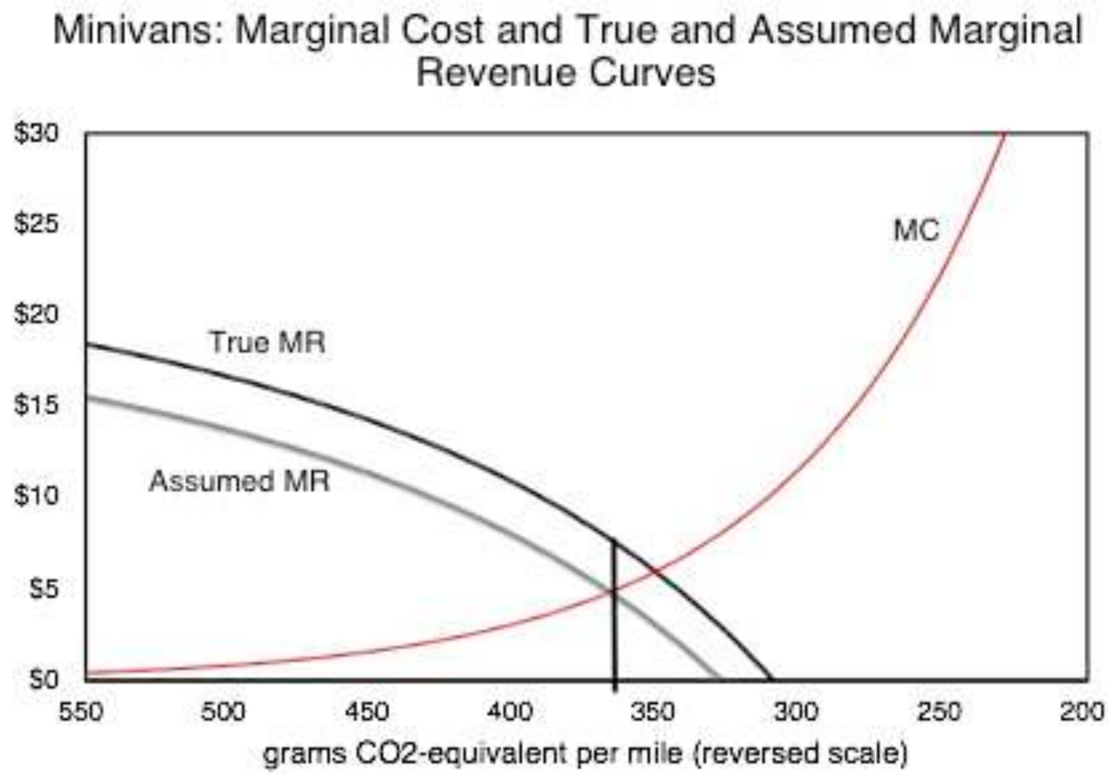
9 Appendix C: Marginal Revenue and Marginal Cost

Large Cars: Marginal Cost and True and Assumed Marginal Revenue Curves



Small Trucks: Marginal Cost and True and Assumed Marginal Revenue Curves




Minivans: Marginal Cost and True and Assumed Marginal Revenue Curves
$30
$25
$20
$15
$10
$5
$0
MC
True MR
Assumed MR
550
500
450
400
350
300
250
200
grams CO2-equivalent per mile (reversed scale)

10 Appendix D: Alternative VMT Estimates

In the text of the report we used CARB's estimates of VMT to compute the change in total lifetime expenditure by consumers to purchase and fuel their vehicles. This appendix applies our own estimates of VMT that are smaller than CARB's. Our estimates of VMT by segment are: Car 144,286; Van 168,810; Pickup 169,096; and SUV 167,228.

Change in Price and Lifetime Fuel Cost by Scenario

Scenario		Car	Van	Pickup	SUV	Market
Pavley alone	Lifetime Fuel Cost	($1,820)	($2,467)	($2,969)	($2,995)	($2,260)
	Retail Price	$1,253	$989	$1,367	$1,242	$1,275
	Total Change	($567)	($1,478)	($1,602)	($1,753)	($985)
Feebates alone ($18 per gram per mile)	Lifetime Fuel Cost	($1,069)	($1,690)	($1,965)	($1,922)	($1,470)
	Retail Price	$536	$743	$959	$920	$658
	Net Feebate	($652)	$172	$1,187	$928	$0
	Total Change	($1,185)	($776)	$180	($74)	($813)
Feebates alone ($36 per gram per mile)	Lifetime Fuel Cost	($1,707)	($2,598)	($3,050)	($3,019)	($2,295)
	Retail Price	$979	$1,270	$1,633	$1,516	$1,164
	Net Feebate	($877)	$235	$1,444	$1,353	$0
	Total Change	($1,606)	($1,093)	$27	($151)	($1,131)
Pavley plus feebates ($18)	Lifetime Fuel Cost	($2,174)	($3,153)	($3,853)	($3,773)	($2,842)
	Retail Price	$2,618	$2,726	$3,514	$3,227	$2,866
	Net Feebate	($541)	$280	$966	$673	$0
	Total Change	($97)	($147)	$626	$126	$25

Negative values represent reductions in consumer expenditure.
Lifetime Fuel Cost = present value at 5% discount of fuel saved assuming AAD life and VMT.
Retail Transaction Price = change in price from the retailer's point of view.
Net Feebate = impact of feebate on price from the consumer's point of view.
Total Change= the total change in consumer expenditure.
Price of gasoline = $1.74/gallon

11 Endnotes

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[i] Visit http://www.arb.ca.gov/cc/ccms/ccms.htm for additional documents and information.
[ii] The function estimated was $\ln(\text{Cost})_i = a + b(g_0 - g)_i + u_i$ in which *ln* is the natural logarithmic function, *i* indexes rows in the CARB table, and *u* is the error term.
[iii] We model the feebates as a shift upward of the MR curve. We could also have modeled the feebates as a shift downward in the MC curve. The important thing is that there is a difference between what the buyer pays and what the automaker receives.
[iv] The UMTRI database is available upon request.
[v] The appendix presents estimates of changes in consumer expenditures using alternative estimates of vehicle miles traveled.