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Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy☆

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Abstract

US fuel economy standards have not been changed significantly in 20 years. Feebates are a market-based alternative in which vehicles with fuel consumption rates above a "pivot point" are charged fees while vehicles below receive rebates. By choice of pivot points, feebate systems can be made revenue neutral. Feebates have been analyzed before. This study re-examines feebates using recent data, assesses how the undervaluing of fuel economy by consumers might affect their efficacy, tests sensitivity to the cost of fuel economy technology and price elasticities of vehicle demand, and adds assessments of gas-guzzler taxes or rebates alone. A feebate rate of $500 per 0.01 gallon per mile (GPM) produces a 16 percent increase in fuel economy, while a $1000 per 0.01 GPM results in a 29 percent increase, even if consumers count only the first 3 years of fuel savings. Unit sales decline by about 0.5 percent but sales revenues increase because the added value of fuel economy technologies outweighs the decrease in sales. In all cases, the vast majority of fuel economy increase is due to adoption of fuel economy technologies rather than shifts in sales.

Keywords: Feebates; Fuel economy; Automobile policy

1. Introduction

Despite a continuing need to reduce dependence on oil and curb the growth of carbon dioxide emissions, the United States has not implemented major policies to increase the energy efficiency of passenger cars and light trucks since the Energy Policy and Conservation Act was passed in 1975. That act established Corporate Average Fuel Economy (CAFE) standards, which helped to nearly double passenger car miles per gallon (MPG) by 1985 (National Research Council (NRC), 2002). Since then, the fuel economy of light-duty vehicles has not increased and in recent years has actually declined as consumers increasingly favored greater performance and weight over saving gasoline (Hellman and Heavenrich, 2002).

A number of policies could produce higher fuel economy, reduced oil use and lowered greenhouse gas (GHG) emissions. Higher gasoline taxes would provide an incentive both to increase fuel economy and reduce vehicle travel, but strong public opposition has so far made this option politically unacceptable (CBO, 2002). Opposition to CAFE standards from the automobile industry, both corporations and labor union, has blocked any significant increases in fuel economy standards despite consistent support for such action by two-thirds to three-quarters of the public (Greene, 1998). The goal of the Partnership for a New Generation of Vehicles (PNGV),[1] to transform the market by developing revolutionary technologies that could double or triple fuel economy without policy intervention, has

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[1] The PNGV partnership has been superseded by the FreedomCAR partnership, with a shift in focus toward more basic, higher-risk research with applicability to passenger vehicles, but with an emphasis on fuel cells.

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so far produced no change in the average MPG of new vehicles sold in the United States.

An explanation for the stagnation of new vehicle MPG may lie in imperfections in the market for fuel economy. The NRC (2002) evaluation of the CAFE standards suggested that consumers may reckon only the first 3 years of fuel savings when considering the value of higher fuel economy. This would understate the true economic value of fuel savings over the typical 14-year life of a vehicle by about 60 percent. Honda of America has reported market research indicating the average consumer counts only the first 50,000 miles of fuel savings (German, 2002). A survey by the US Department of Energy found that on average consumers want to be paid back in 2.8 years for an investment in fuel economy (Patterson, 2002).[2] The US Energy Information's National Energy Modeling System (NEMS) used a 4-year payback with a 10 percent annual discount rate to estimate the value of fuel economy improvements to consumers until last year when they switched to a 3-year payback and 30 percent discount rate (Maples, 2003). These examples do not prove that consumers under-value fuel economy; in fact, surprisingly little is known about how consumers estimate the value of improved fuel economy and factor that information into their car-buying decisions. It could well be that the apparent undervaluing of fuel economy is a result of bounded rational behavior. Consumers may not find it worth the effort to fully investigate the *costs* and benefits of higher fuel economy (Greene, 1996, Chapter 4). The above examples strongly suggest, however, that there may be an important market failure with respect to consumers' decision-making about fuel economy.[3]

If consumers do under-value fuel savings, there are several important implications for policy making. Increasing the price of gasoline would have a smaller impact on MPG. Setting fuel economy standards would be a more effective approach because regulation circumvents the market failure. Shifting the price signal from gasoline to the price of the vehicle should also be more effective than a fuel tax. Consumers appear to accurately reckon vehicle prices in their purchase decisions and it seems certain that manufacturers would accurately weigh the costs and benefits of increasing MPG so as to avoid fees and capture rebates.

[2]The survey cited asked respondents what payback period was acceptable for a fuel economy increase that also increased vehicle price. The average response was 2.8 years, but 12.5 percent of respondents would accept 5 or more years and 2.2 percent would accept 10 years, or more. In another survey by the same source, consumers were asked what they would be willing to pay for a doubling of fuel economy. The responses implied a much greater payback period: 5 years.

[3]A useful discussion of how individuals actually make energy efficiency decisions can be found in Stern and Aronson (1984), particularly Chapter 4.

This suggests that a system of rebates for high fuel economy vehicles combined with a system of fees levied on lower fuel economy vehicles should be an effective fuel economy policy. To date, feebate systems have been widely considered but little used. Ontario, Canada and Austria are exceptions (Michaelis, 1997, Part 1). The essential elements of a "feebate" system are a pivot point that divides vehicles charged fees from those receiving rebates and a rate that specifies the fee or rebate as a function of distance from the pivot point. A single pivot point can be used for all vehicles or vehicles can be divided into classes (e.g., passenger cars and light trucks) and different pivot points assigned to each class. The simplest and most interesting, types of feebate systems are those that set a constant dollar rate per gallon of fuel consumed per mile driven (GPM). If vehicles travel approximately the same number of miles per year, constant rates per GPM should lead manufacturers to equate the marginal cost of saving a gallon of gasoline across all vehicle types.

A key advantage of feebates over fuel economy standards is that they provide a continuing incentive to increase fuel economy as new technologies are developed (Gordon and Levenson, 1989). Once fuel economy standards are met, there is no incentive for manufacturers to make further increases.[4] The feebate schedule provides an ever-present extra incentive to increase fuel economy whenever new, more cost-effective technologies become available. Disadvantages of feebates include the possibility that they will be perceived as a kind of tax and that they will undoubtedly confer different benefits and costs on different manufacturers. The first disadvantage can be mitigated by designing feebates to be revenue neutral: to pay out as much in rebates as they collect in fees. The second disadvantage can be mitigated by establishing different feebate schedules for different vehicle classes, a topic that will be considered below.

Policies such as gas-guzzler taxes on low fuel economy vehicles or rebates (e.g., tax incentives) for higher MPG vehicles can be seen as partial feebate systems. They do not provide an incentive for all vehicles to increase fuel economy. The US "Gas-Guzzler Tax" implemented in 1980 and revised in 1991 applies only to passenger cars getting less than 22.5 MPG. There is no comparable gas-guzzler tax for light trucks. Surprisingly, the impacts of that tax on light-duty vehicle markets do not appear to have been analyzed. The method used here to analyze feebates is also applied to estimate the impacts of rebates and gas-guzzler taxes.

[4]Assuming the standards are a binding constraint, that is, they require fuel economy levels above what market forces would produce in the absence of the standards. If the standards are not binding they are irrelevant.

This paper presents an analysis of feebates using a model of the US market for automotive fuel economy that estimates the private costs and benefits of feebates, as well as impacts on government revenues and relative impacts on automobile manufacturers. The model trades off increases in retail price as a result of adopting fuel economy technologies against the value of fuel saved, as perceived by the car buyer. The analysis applies to a single year approximately 10–15 years in the future, by which time manufacturers have had an opportunity to redesign all their product lines at normal rates of retooling. Because of the uncertainties about certain premises of the analysis, sensitivity analyses are also presented.

1.1. Previous studies of feebates

Feebates are not a new idea. They were proposed at least as long ago as 1989 as part of a concept called "DRIVE+", which attempted to use feebates to stimulate demand for cleaner and more fuel-efficient vehicles in California (Gordon and Levenson, 1989). The DRIVE+ system included criteria pollutants as well as carbon emissions. Gordon and Levenson (1989) analyzed the potential impacts of DRIVE+, but considered only the impacts on the mix of vehicles sold and not on the use of technology. It turns out that technological changes are approximately an order of magnitude more important than sales mix changes, in the long run.

In the most thorough study of feebates for the United States, Davis et al. (1995) analyzed six alternative feebate systems using the Automobile Use, Technologies and Ownership (AUTO) model (Train, 1986) to represent consumer choice, and the Fuel Economy Model (FEM) developed by Energy and Environmental Analysis (EEA), Inc. (Duleep, 1992) to represent manufacturer behavior. The AUTO model predicts the vehicle type choice, ownership and use decisions of individual households conditional on household and vehicle characteristics. The model's underlying behavioral parameters were estimated using 1978 survey data. Forecasts were based on a sample of households from a 1988 survey. The model's predictions were calibrated to 1990 national sales data. The FEM model uses data on the costs and fuel economy improvement potentials of proven fuel economy technologies together with a model of manufacturers' decisions to adopt technologies as a function of their cost-effectiveness. Both models used data for model year 1990 vehicles, aggregated into 95 classes depending on vehicle type, domestic or foreign origin, acceleration performance, and technology status (high or low).

Davis et al. did not attempt to insure that manufacturers' assumptions about the value of fuel economy improvements as embodied in the FEM were consistent with consumers' valuation as reflected in the AUTO model. This led the models to predict that revenue-neutral feebates would *increase* consumers' surplus. This result could occur in reality if manufacturers believed that consumers value fuel economy less than they actually do or if consumers recognized the true value of higher fuel economy once they purchased the vehicle. In the model used here, consumers' and producers' views on the value of fuel economy are the same by assumption.[5]

Among the important findings of Davis et al. was the consistent result that manufacturers' adoption of fuel economy technologies accounted for about 90 percent of the overall increase in fuel economy brought about by feebate systems. Changes in consumers' choices (shifting sales toward higher fuel economy vehicles) were always a minor factor. This result supports the view that sales mix shifting is in general a more expensive way to increase fuel economy than the adoption of fuel economy technology, for moderate ranges of fuel economy increase (Greene, 1991). Given the choice between adjusting vehicle prices to increase the new vehicle fleet average MPG via sales mix shifts and increasing the use of fuel economy technologies, manufacturers will nearly always opt for the technological solution. Davis et al. called for future analyses to test the sensitivity of this conclusion to the cost of fuel economy technologies, an issue addressed by this study.

A potential feebate system for Canadian vehicles based on GHG emissions was assessed in a study for the Canadian government (HLB, 1999). As in Davis et al. (1995) vehicles were grouped into 95 subclasses and 19 classes, and EEA Inc.'s FEM data for 1990 were used but calibrated to match 1998 Canadian sales data. Unlike Davis et al., vehicle demand and supply were represented by a set of simultaneous equations. A focus of the analysis was estimating the effect of a Canada-only feebate system vs. a harmonized US–Canada system. The study concluded that a Canada-only system would be much less cost-effective, resulting in a marginal cost of $60 per metric ton of GHG reduced while a harmonized US–Canada system would have a marginal benefit of $2 per ton.

Feebates were among a suite of policies for reducing CO_2 emissions from cars in Europe evaluated by Koopman (1995) using the EUCARS model (Denis and Koopman, 1998). The model broke cars into five classes: small, medium and large gasoline vehicles, plus diesel and LPG. Feebates of 300–500 ECU/l/100 km were tested with the goal of achieving fleet average

[5] This is not intended to imply that one view is correct and the other incorrect. It is certainly possible that manufacturers' and consumers' views on the value of fuel economy are inconsistent, however, this would imply a market failure. A manufacturer discovering the correct consumer view could increase it profits.

emissions targets of 179 g/km. Assuming approximately 1 ECU per US dollar, this would be equivalent to about \$700–1175 per 0.01 GPM. The feebates produced an estimated reduction in fuel use per kilometer of -11.8 percent and in CO_2 emissions of -10 percent, due to a slight increase in kilometers traveled. There was also a small loss of consumers' surplus and of government tax revenue.

A feebate system and a gas-guzzler tax were evaluated by DRI/McGraw-Hill (1991) using a combination of fuel economy technology cost schedules (again provided by EEA, Inc.) and their own proprietary model of vehicle and fuel demand. The cost schedules described the cumulative cost of increasing fuel economy for 14 passenger car classes (seven size classes and import vs. domestic). Light trucks costs were assumed to be proportional to those of cars. Because the gas-guzzler taxes specified covered the entire range of vehicle fuel economy (the same range as the feebates), the only difference between the two is that the guzzler tax is always a fee, whereas the feebate schedule switches from fee to rebate at a pivot point. A single pivot point was used in all cases. Like Davis et al. (1995), DRI/McGraw-Hill found that the overwhelming majority of the fuel savings from feebates came from the adoption of fuel-efficient technology by manufacturers (mix shifting never accounted for more than 18 percent of the increase).

2. Theory and model

For this study, an aggregate national nested multinomial logit (NMNL) model of vehicle choice has been calibrated to model year 2000 sales data and is used to represent consumers' choice among vehicles as a function of changes in prices and fuel economy. The increase in retail prices as a result of adopting fuel economy technologies was obtained from the NRC (2002) analysis of the impacts of CAFE standards. The model does not include the phasing in of a feebate system over time, but considers only a single future year, by which time manufacturers have had time to make fuel economy increases in the normal course of vehicle redesign and retooling.

Manufacturers are assumed to adjust the fuel economy of each vehicle by adopting fuel economy technologies so as to provide consumers with the greatest possible net benefits (measured by the change in consumers' surplus). The decision variables are the percent changes in fuel economy for each make and model. Fuel economy changes determine fuel savings (using a discounted present value formula), vehicle price changes (by means of technology cost functions) and simultaneously determine the feebate, rebate or gas-guzzler tax (through a rebate formula). The effects of all three are taken into account in maximizing consumers' surplus. Consumers simultaneously select the mix of makes and models that maximizes their surplus. The result is a combination of technological fuel economy improvements and sales mix shifts that maximizes consumer satisfaction, subject to the availability of technology to improve MPG and the incentives created by the rebate system.

Fuel economy/price relationships developed by the NRC (2002) were used to represent the cost of increasing fuel economy by technological means. The NRC fuel economy study provides three sets of fuel economy technology and price curves for each of 11 vehicle classes, intended to span a reasonable range of uncertainty from high-cost/low-improvement to low-cost/high-improvement. This allows us to fulfill the Davis et al. (1995) recommendation that future research address the sensitivity of the manufacturers' response to feebates to the costs of fuel economy technologies. The NRC (2002) study also considered two alternative assumptions for valuing fuel savings: (1) full lifetime discounted present value, and (2) simple (undiscounted) payback over a 3-year period. These two possibilities are also considered in this study.

A national, "typical consumer" Nested Multi-Nominal Logit model of vehicle choice was calibrated to the National Highway Traffic Safety Administration's 2000 model year fuel economy data at the most detailed carline/configuration level (831 vehicle types). This preserves a rich diversity of choices for consumers, allows the impacts of feebates on individual vehicle manufacturers to be estimated, and permits distinguishing between domestic and imported vehicles. The estimated impacts on manufacturers should be interpreted with caution. Simplifying assumptions make the results generally indicative of the kinds of impacts likely to occur, rather than definitive estimates of the impacts on specific manufacturers.

Three key assumptions of the analysis are: (1) vehicle attributes other than fuel economy and price remain unchanged; (2) there is no technological progress over the analysis period; and (3) manufacturers neither introduce new makes and models nor retire existing ones. The first assumption does not allow technology that could be used to improve fuel economy to be used instead to increase vehicle weight or power. This would tend to make the estimated fuel economy increases an upper bound on the fuel economy impact, since some of the technological potential is likely to be used to increase vehicle weight or performance. But, technological progress over a 10–15 year period is virtually certain, implying that MPG impacts will be underestimated. To what extent these effects might cancel each other is not addressed here. The third assumption makes it necessary to use caution in interpreting impacts of feebate policies on particular manufacturers. Manufacturers' market positions will change over time and that will change the impacts on them.

The mathematics of the model can be found in Appendix A.

3. Structure of analysis

The number of possible feebate, rebate and gas-guzzler tax systems is infinite. The form used here, assigning a constant value per vehicle-GPM, has the desirable property of providing the same incentive to save a gallon of fuel for all vehicles. Two rates, \$500 and 1000 per 0.01 GPM are used for all but the gas-guzzler analysis. If consumers value fuel savings over the full life of the vehicle, and discount to present value, a rebate rate of \$500 would have the same impact as a tax of \$0.43/gal of gasoline. But if consumers value only the first 3 years of fuel savings and ignore the rest, \$500 per 0.01 GPM looks to the consumer like a tax of \$1.13 per gallon, because the same up-front charge is distributed over fewer gallons. This relationship magnifies the effectiveness of feebates in the presence of this particular kind of market failure. The \$1000 rate implies twice the value per gallon of fuel saved.

For valuing fuel savings, passenger cars and light trucks are assumed to be driven 15,600 miles per year when new, with usage decreasing at the rate of 4 percent per year. Gasoline is assumed to cost \$1.50 per gallon (of which approximately \$0.40 is highway user tax). Two rules are used to estimate the value consumers will associate with increased fuel economy. Following the method of the NRC CAFE study, one method assumes that consumers add up the first 3 years of undiscounted fuel savings. This 3-year payback method does account for decreasing vehicle use with age but does not discount future fuel savings. The second method calculates the discounted present value of lifetime fuel savings (see Appendix A). Both passenger cars and light trucks are assumed to have expected lifetimes of 14 years. Consumers are assumed to demand a 6 percent annual return on an investment in fuel economy technology, a depreciating asset (for a discussion of this formulation, see Greene and DeCicco, 2000, Appendix). The 3-year simple payback implies a market failure and is used for most cases.

Manufacturers' ability to increase fuel economy is described by three alternative fuel economy—price curves corresponding to the Average, low-cost/high-MPG and high-cost/low-MPG fuel economy cost curves developed by the NRC (2002) CAFE study. These curves relate an increase in retail price to a fractional increase in MPG. Different cost curves were used for each of the NRC's 11 vehicle classes as shown in Appendix A. The 11 size-based classes consist of four passenger car classes (subcompact, compact, midsize and large) and seven light truck classes (small, medium and large SUVs, minivan, large van, and small and large pick-up trucks).[6]

Pivot points are specified for three alternative classifications of vehicles: (1) a single pivot point for all light-duty vehicles, (2) two pivot points, one each for passenger cars and light trucks, and (3) 11 pivot points corresponding to the vehicle classes used in the NRC (2002) study. For feebate cases, pivot points were chosen to be the average fuel economy levels achieved after the feebate system has been imposed. This makes all of the feebate systems approximately revenue neutral.

For all but the case in which elasticities are doubled, price elasticities of vehicle choice are assumed to be -10 at a market share of 1.5 percent for choice among vehicles within a class. The price elasticity of choice among classes was assumed to be -5 at a market share of 10 percent. The overall price elasticity of light-duty vehicle sales was assumed to be -1.0. To test sensitivity to price elasticity, these values were doubled.

In all, 18 cases were evaluated. Two cases estimated the future fuel economy levels in the absence of any policy, given the technology described by the NRC cost curves and assuming the 3-year payback and full lifetime present value methods for valuing fuel savings. Eleven different feebate cases were run, testing \$500 and 1000 feebate levels, the three schemes for pivot points, alternative fuel economy cost curves, and double price elasticities. Four rebate only cases were run, testing alternative pivot points. Two gas-guzzler cases were run, testing \$1000 and 2000 per 0.01 GPM tax rates.

4. Results

Policy cases must be compared with a "no policy" case in which the technologies represented by the NRC "average" fuel economy/price curve can be adopted over time (or not) in the absence of fiscal policies to induce their use. Assuming just the first 3 years of fuel savings are counted, little fuel economy technology would be adopted in the "no policy" case.[7] Passenger car fuel economy increases to 28.3 from 28.2; somewhat more technology is adopted by light trucks, whose MPG grows from 20.7 to 21.8. Overall light-duty MPG thus increases modestly, from 24.3 to 25.0. If consumers recognize fuel savings over the full life of a vehicle the results are strikingly different. Passenger car MPG jumps to 35.1 and average light truck MPG increases to 29.2, for a sales-weighted harmonic average of 32.0 (almost a one-third increase in MPG) (Tables 1A and 1B). Roughly speaking, in the 3-year payback case,

[6] The NRC study did not include a separate class for large vans. The NRC's large pick-up cost curves were used for that class.

[7] This result is consistent with the findings of the NRC (2002) panel reported in their Table 4-3.

Table 1A
Summary of analyses of feebates, rebates and gas-guzzler taxes (2000 US$)

Policy case assumptions				Feebate/rebate/guzzler tax analysis results						
				Fuel economy				Government expenditures (2000 US$)		
Policy/rate	NRC technology price curve	Pivot points	Method of valuing fuel economy	Cars (MPG)	Light trucks (MPG)	Total (MPG)	Consumers' surplus (billions)	Cars (billions)	Light trucks (billions)	Total (billions)
1 Base year	NA	NA	NA	28.2	20.7	24.3	NA	NA	NA	NA
2 No policy	Average	NA	3-year payback	28.3	21.8	25.0	$0.1	$0.0	$0.0	$0.0
Feebate cases										
3 Feebate/$500	Average	Car and light truck	3-year payback	31.8	26.0	28.9	−$2.0	$0.1	$0.1	$0.2
4 Feebate/$500	Average	Single pivot	3-year payback	31.8	26.0	29.0	−$2.1	−$1.3	$1.6	$0.3
5 Feebate/$500	Average	11 classes	3-year payback	31.8	25.9	28.9	−$2.0	$0.1	$0.0	$0.1
6 Feebate/$1000	Average	Car and light truck	3-year payback	35.2	29.2	32.3	−$6.4	$0.3	$0.3	$0.6
7 Feebate/$500	Low-cost/high-MPG	Car and light truck	3-year payback	34.7	27.4	31.0	−$1.1	$0.1	$0.1	$0.2
8 Feebate/$500	High-cost/low-MPG	Car and light truck	3-year payback	28.9	23.7	26.3	−$1.5	$0.2	$0.1	$0.3
9 Feebate/$1000	High-cost/low-MPG	Car and light truck	3-year payback	32.0	27.1	29.7	−$6.7	$0.4	$0.3	$0.7
10 No policy	Average	Car and light truck	Full 14-year life	35.1	29.2	32.0	$12.1	$0.0	$0.0	$0.0
11 Feebate/$500	Average	Car and light truck	Full 14-year life	37.8	31.7	34.6	$11.2	$0.0	−$0.1	−$0.1
12 Feebate/$1000	Average	Car and light truck	Full 14-year life	40.2	33.9	36.9	$9.0	$0.1	$0.0	$0.1
Rebate cases										
13 Rebate/$500	Average	Car–truck feebate average	3-year payback	28.7	22.4	25.5	$0.6	−$0.4	−$0.4	−$0.8
14 Rebate/$500	Average	Single pivot feebate average	3-year payback	31.1	22.2	26.4	$2.1	−$2.5	−$0.2	−$2.8
15 Rebate/$500	Average	Car–truck 10% > base	3-year payback	28.8	24.6	26.7	$1.6	−$0.5	−$1.8	−$2.4
16 Rebate/$500	Average	11 class 10% > base	3-year payback	29.1	24.9	27.0	$1.3	−$0.5	−$1.8	−$2.3
Gas-guzzler tax										
17 Guzzler/$1000	Average	Car and light truck	3-year payback	31.6	25.1	28.3	−$2.2	$0.2	$0.0	$0.2
18 Guzzler/$2000	Average	Car and light truck	3-year payback	31.8	25.1	28.4	−$2.2	$0.2	$0.0	$0.2
Double elasticities										
19 Feebate/$1000	High-cost/low-MPG	Car and light truck	3-year payback	32.5	27.4	30.2	−$6.9	$0.8	$0.6	$1.4

Table 1B
Summary of analyses of feebates, rebates and gas-guzzler taxes

	Feebate/rebate/guzzler tax analysis results											
	Change in sales		Change in shares		Fuel savings			Manufacturers' revenues				
			Cars	Light trucks	Per vehicle	Total (including tax)	Societal value	Gross price increase	Net price increase	Price increase	Lost sales	Net change
Policy case	(%)	(units)	(percentage points)		(gallons)	(billions $)		($/vehicle)		(billions $)		
1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	0.0	5607	−0.1	0.1	126	$3.1	$2.3	$65	−$8	$1.1	$0.3	$1.4
Feebate cases												
3	−0.5	−86,027	0.2	−0.2	773	$19.1	$14.0	$529	$118	$8.7	−$7.2	$1.5
4	−0.5	−88,608	2.3	−2.3	790	$19.5	$14.3	$520	$117	$8.6	−$8.4	$0.2
5	−0.5	−85,272	0.2	−0.2	767	$19.0	$13.9	$531	$118	$8.8	−$6.2	$2.6
6	−1.6	−266,775	0.7	−0.7	1195	$29.2	$21.4	$987	$363	$16.1	−$15.7	$0.4
7	−0.3	−46,566	0.0	0.0	1046	$25.9	$19.0	$632	$62	$10.4	−$5.4	$5.0
8	−0.4	−63,311	0.8	−0.8	375	$9.3	$6.8	$256	$81	$4.2	−$8.3	−$4.1
9	−1.7	−280,118	1.6	−1.6	876	$21.4	$15.7	$802	$372	$13.0	−$18.1	−$5.1
10	3.1	509,705	−3.8	3.8	1159	$29.6	$21.7	$1151	−$757	$19.6	$20.5	$40.2
11	2.8	470,891	−3.7	3.7	1437	$36.7	$26.9	$1585	−$692	$27.0	$15.7	$42.7
12	2.3	379,045	−3.5	3.5	1648	$41.8	$30.7	$1989	−$558	$33.7	$10.0	$43.7
Rebate cases												
13	0.2	25,461	0.0	0.0	223	$5.5	$4.1	$131	−$38	$2.2	−$0.5	$1.7
14	0.5	87,383	1.0	−1.0	385	$9.6	$7.1	$243	−$130	$4.0	−$1.8	$2.2
15	0.4	66,225	−0.6	0.7	433	$10.8	$7.9	$288	−$98	$4.8	$0.1	$4.9
16	0.3	54,792	−0.7	0.7	489	$12.2	$8.9	$340	−$81	$5.6	$0.7	$6.4
Gas-guzzler tax												
17	−0.6	−91,755	0.0	0.0	684	$16.9	$12.4	$486	$128	$8.0	−$6.9	$1.1
18	−0.6	−94,388	−0.1	0.1	694	$17.1	$12.6	$498	$130	$8.2	−$7.5	$0.7
Double elasticities												
19	−3.5	−579,635	3.1	−3.1	940	$22.5	$14.1	$751	$352	$12.0	−$35.8	−$23.8

consumers are counting only three-eighths of the full lifetime present value of fuel savings that will accrue from a fuel economy increase, a serious market failure.

4.1. $500 feebate cases

Even if consumers count only the first 3 years of fuel savings, feebates appear to be able to induce significant increases in fuel economy. Adding a $500 per 0.01 GPM feebate with two pivot points one for passenger cars and another for light trucks causes average light-duty vehicle fuel economy to increase to 28.9 MPG. Light truck MPG increases by 19 percent, while passenger car MPG is 12 percent higher. This is consistent with the general finding of the NRC study that the technological potential to increase MPG is greater for light trucks than for cars (NRC, 2002, Chapter 4).

The $500 feebate system produces $2 billion per year in apparent consumers' surplus losses because the fuel economy increases do not seem economically justified to consumers who count only the first 3 years of fuel savings. The pivot points of case 3 were chosen to be the harmonic mean MPG of cars and light trucks *after* the $500 feebate is imposed, and so net government expenditures on the program are relatively small, $200 million, and evenly divided between cars and light trucks.

The impact of the $500 feebate system on vehicle sales is also relatively modest, a loss of −0.5 percent, or 86,000 units out of 16.5 million. Sales decrease only a little because the average *net* price increase (price increase-feebate-perceived value of future fuel savings) is $118 per car relative to an average price of $23,800 (0.5 percent). The assumed price elasticity of −1.0 insures that a 0.5 percent increase in net price causes a 0.5 percent decrease in sales. Manufacturers' sales revenues, on the other hand, *increase* by $1.5 billion (Fig. 1); the $7.2 billion in revenue lost due to decreased sales is more than offset by $8.7 billion gained due to the average price increase (before subtracting fuel savings) of $530 per vehicle. Consumers are willing to pay more for cars and light trucks because they perceive at least some value in the fuel savings. In reality, it could well be that when presented with higher fuel economy vehicles consumers would recognize more of the real value of fuel savings. If so, there could be no loss of sales and the increase in revenues would be that much greater. Of course, the increased revenue to car manufacturers will be largely offset by decreased revenues to motor fuel suppliers and oil producers, quantities not directly measured in this analysis.

4.2. Increasing the feebate rate to $1000

Raising the feebate rate to $1000/0.01 GPM (under the 3-year payback assumption) produces a light-duty MPG level of 32, essentially the same as would be obtained if consumers recognized the full value of lifetime fuel savings. Once again, the revenues manufacturers gain as a result of the increase in vehicle prices (about $1000 per vehicle, on average) are greater than the revenues lost due to reduced unit sales. As a result, the net effect is an increase in sales revenues of $0.4 billion.

The apparent consumers' surplus loss is $6.4 billion with the $1000 rate, a substantial increase over the $2 billion loss incurred with the $500 feebate rate. The actual discounted present value of lifetime fuel saving by one model years' vehicles is $29 billion. This compares with consumers' assessment of the value of this fuel (counting only the first 3 years) of $11 billion (about 3/8). Thus, according to these assumptions, consumers have missed $18 billion in fuel savings (Fig. 2).[8] On the other hand, consumers count the fuel tax component of the price of gasoline as a savings, whereas, from a societal perspective it is a transfer payment and not a savings. The national average of state and federal motor fuel taxes in 2001 was 37.5 cents per gallon (US DOT/FHWA, 2002, Table MF-121T). If one assumes $0.40 per gallon in taxes, then the direct cost of motor fuel from a societal perspective is $1.50–0.40 = $1.10, not counting externalities and other non-priced societal costs, such as energy security. This would make the societal value of fuel saved $21 billion, still $10 billion/year greater than the perceived private value using the 3-year rule. Adding the reduction in externalities and other social costs would significantly increase the benefits of fuel savings.

4.3. Effects of class-specific pivot points

Using just a single pivot point for all light-duty vehicles has little impact on overall MPG levels (29.0 vs. 28.9 MPG) or total costs (a $2.1B consumers' surplus loss vs. $2.0B). Because cars receive a net rebate, car sales increase by 2.3 percent. Trucks on average pay a net fee, so truck sales decrease by 2.3 percent. Increasing the number of classes to 11 also has little impact on either fuel economy levels or revenues.

The number of classes and pivot points does affect the way the feebate system impacts manufacturers (Fig. 3). On average, fees are paid by buyers of Ford, GM, Daimler Chrysler and BMW vehicles, although the fees are smaller under the 2- or 11-class systems. Rebates are received by buyers of Honda, Hyundai, Mitsubishi and Toyota vehicles under all systems. Once again, the differences are somewhat reduced under the 2- or 11-class systems. It appears that distinguishing between

[8] An interesting question is whether consumers would ultimately recognize the full value of fuel savings over time as they were received, and what impact that might have on consumers' surplus.

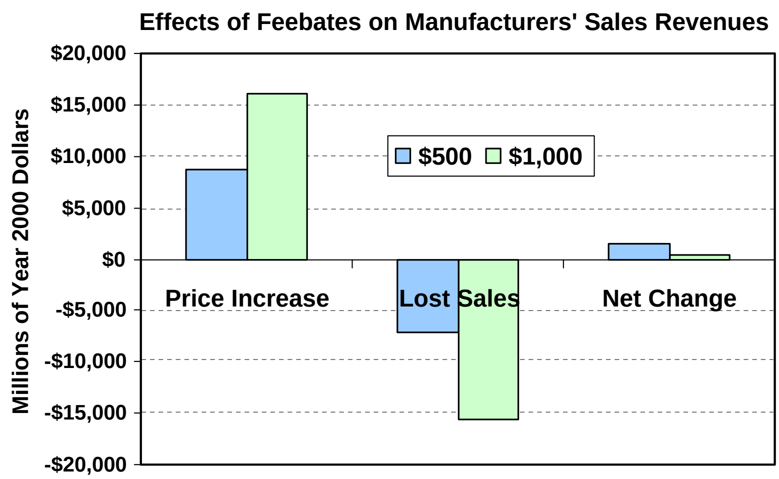

Fig. 1. Effects of feebates on manufacturers' sales revenues.

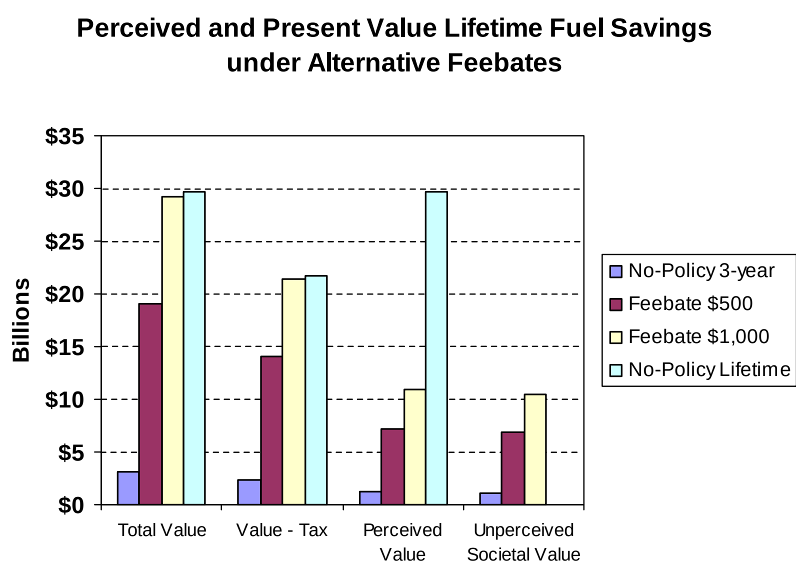

Fig. 2. Perceived and present value lifetime fuel savings under alternative feebates.

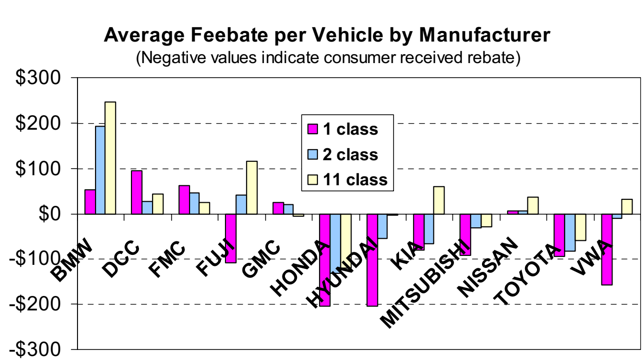

Fig. 3. Average feebate per vehicle by manufacturer.

passenger cars and light trucks reduces the differences among manufacturers about as much as an 11-class system. The 11-class system probably has greater potential for "gaming" at the boundaries of classes by moving vehicles close to the lower boundary of a class into a lower class in order to obtain a rebate instead of a fee. The possibilities for and consequences of gaming at class boundaries have not been analyzed in this study.

4.4. Uncertainties in the cost of increasing fuel economy

The costs of a feebate system do not appear to be sensitive to the cost of increasing fuel economy, but the benefits are. The $500 feebate, car–truck pivot point, 3-year payback case was rerun using the NRC high-cost/low-technology and low-cost/high-technology cost curves. With high costs and low technological potential, average fuel economy is only 26 MPG compared with 28.9 for the NRC average cost curve. Assuming low costs and high fuel economy potential, the result is 31 MPG. Consumers' surplus losses are lower in both cases than for the average fuel economy cost curve, but for different reasons. When the cost of increasing fuel economy is high, little is done which holds down the impact on consumers' surplus (because pivot points are set at the car and truck class averages *after* the feebate has been imposed, gains to car buyers approximately equal losses and so feebates have little impact on consumers' surplus). When the cost of increasing fuel economy is low, much more is done, but at a much lower cost, which also tends to mitigate the impact on consumers' surplus. From a societal perspective, feebates are a low-risk strategy with respect to uncertainty about the costs of increasing fuel economy but are high-risk with respect to the savings achieved.

If the feebate rate is increased to $1000 using the high-cost/low-technology curves, MPG is raised to 29.7 and the loss of consumers' surplus expands to $6.7 billion per year. Still, because consumers' are undervaluing fuel savings, $13.4 billion in fuel savings are not counted by consumers ($7.7 billion excluding fuel taxes).

4.5. Higher price elasticities

The overwhelming long-run response to feebates is the adoption of fuel economy technologies. Given the data and assumptions of this analysis, nearly all of the increase in fuel economy produced by feebates comes about through manufacturers making technological changes to vehicles and very little is caused by consumers choosing different makes, models and classes of vehicles. In the $500 rebate, average cost curve, 3-year payback case, 96 percent of the increase in MPG is the result of technological changes, only 4 percent is due to changes in the mix of vehicles sold. When the feebate rate is increased to $1000, still 95 percent is due to technology. Even in the high-cost/low-technology case, 87 percent of the MPG increase is due to the use of fuel economy technology. These results are consistent with Davis et al. (1995), who reported a typical result of 90 percent due to technology, 10 percent due to sales mix shifts, and DRI/McGraw-Hill (1991) who reported a minimum of 80 percent due to technology.

The market share price elasticities used in this analysis are at or above the upper end of values reported in the literature, as discussed above: −10 for make and model choices within a class, −5 for the choice among classes. However, even doubling these values to −20 and −10 does not fundamentally change the result that the technological response is dominant. Even using the least favorable assumptions for the adoption of fuel economy technologies (the high-cost/low-technology curve, a 3-year payback and a feebate rate of $1000), and doubling elasticities technology still accounts for 84 percent of the increase in MPG (91 percent for light trucks, 78 percent for cars). This result is also consistent with the Greene (1991) finding that mix shifting is a very expensive way to increase fuel economy relative to adopting fuel economy technology or changing vehicle design.

4.6. Rebates

Rebates and gas-guzzler taxes are complementary halves of a rebate system. Because they affect only some of the vehicles affected by a feebate system, their impact on fuel economy may be expected to be correspondingly smaller. In addition, whereas the pivot points of a feebate system do not affect the resulting MPG levels, the pivot points of rebate and gas-guzzler systems do. If the pivot point of a rebate system is set so high that only a few vehicles qualify, it will have little impact. If it is set so low that all vehicles qualify, it becomes effectively a feebate system (this, in fact, is what was done in the DRI/McGraw-Hill study for the gas-guzzler tax). For any base year vehicle set, some vehicles that do not qualify for a rebate in the base year would find it advantageous to increase their fuel economy enough to qualify, while others would not. The same reasoning applies to avoiding a gas-guzzler tax. The need to divide vehicles into affected and unaffected sets makes solving a rebate or gas-guzzler system somewhat more complicated than solving a comparable rebate problem (see Appendix A for details).

Two alternative pivot point assumptions were made in estimating the impacts of $500/0.01 GPM rebate systems: (1) the class average MPG produced by the corresponding $500 feebate system, and (2) 10 percent greater than the base year class average MPG.

Because about half the vehicles are unaffected by the rebate systems analyzed here, they produce smaller MPG increases than the corresponding feebate systems. The $500, car–truck pivot point, average NRC cost curve, 3-year payback rebate case produces 25.5 MPG, only 0.5 MPG higher than the no policy case and 3.4 MPG lower than the corresponding feebate case. There is a $0.6 billion consumers' surplus gain, paid for by $0.8 billion in government expenditures on rebates. Using a single pivot point for all light-duty vehicles produces a greater increase in MPG, mainly because nearly all passenger cars qualify for a rebate. Passenger car MPG increases to 31.1 (nearly the same as the feebate case) but light truck MPG increases to only 22.2 (about 0.4 MPG better than the no policy case). The consumer surplus gain increases to $2 billion, but government rebate outlays increase to $3 billion.

Rebate cases using 10 percent above the base year class MPG levels as pivot points produce somewhat larger MPG increases because more vehicles are affected by the rebates. With two pivot points, 31.1 MPG for passenger cars and 22.8 for light trucks (10 percent above base year average MPG levels), rebates produce a fleet average MPG of 26.7, vs. 25.5 when the pivot points were set at 31.8 and 26. As was the case for feebates, increasing the number of pivot points to 11 has relatively little impact on the resulting average MPG levels, the change in consumers' surplus, government expenditures or sales.

4.7. Gas-guzzler taxes

The mirror image of rebates, gas-guzzler taxes discourage low fuel economy vehicles but do not encourage high MPG vehicles. The two guzzler tax rates tested were designed to approximate the gas-guzzler tax rates in effect from 1986–1990 (~$1000/0.01 GPM), and that in effect from 1991 to the present (~$2000/0.01 GPM) in the United States (Davis and Diegel, 2002, Table 7.21). As noted above, the gas-guzzler tax in effect today applies to passenger cars but not to light trucks. The two pivot points were set at 10 percent above the base year average MPG for cars (31.1 MPG) and 20 percent above the base year average for light trucks (24.9). Vehicles with MPGs below these levels incur a tax penalty. These pivot points are set above base year average MPG levels and so it might seem that about half of all vehicles would be subject to the tax. This would be true if manufacturers did not have the opportunity to raise each vehicle's fuel economy by adopting technologies. This analysis assumes that they do have time to make such changes.

The two gas-guzzler tax rates produce essentially the same result. Given time to adopt enough fuel economy technologies to avoid the tax, all but the most expensive and highest performance vehicles do so. As a consequence, vehicles cluster just above the pivot point MPG, because there is no incentive for vehicles above the pivot point to further increase their MPG. The $1000 rate causes average light-duty vehicle fuel economy to increase to 28.3, while the $2000 rate induces only 0.1 MPG additional fuel economy (28.4 MPG). Apparently the $1000 rate is sufficient to cause almost all vehicles to increase MPG enough to avoid the tax. With few vehicles subject to the gas-guzzler tax, further increasing the tax rate has little impact.

The gas-guzzler tax has a powerful effect on the distribution of passenger cars and light trucks by fuel economy level. As Fig. 4 shows, the frequency distribution of light-duty vehicles before imposition of the $2000/0.01 GPM tax was roughly bell-shaped with a single peak at about 22.5–25 MPG, but skewed toward higher MPG levels. After the imposition of the $2000 gas-guzzler tax with two pivot points, the distribution becomes bimodal. The two peaks correspond to the bin ranges containing the passenger car pivot point (31.1 MPG) and the light truck pivot point (24.9 MPG). The incentive to avoid the tax is strong enough to encourage raising the fuel economy of nearly all vehicles above the pivot point level. Since $2000/0.01 GPM is approximately the current gas-guzzler tax rate, it would be reasonable to infer that the gas-guzzler tax, which applies to passenger cars only, has probably had a similarly profound effect on the distribution of passenger cars by fuel economy level, nearly eliminating vehicles with MPG below 22.5 MPG.

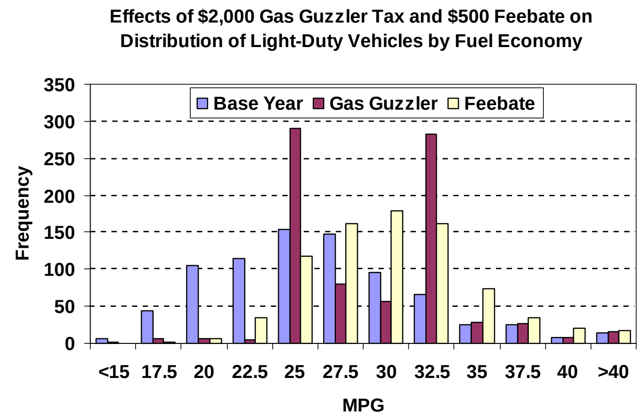

Fig. 4. Effects of $2000 gas-guzzler tax and $500 feebate on distribution of light-duty vehicles by fuel economy.

A comparable feebate system has quite a different impact on the fuel economy distribution. The $2000 gas-guzzler tax increases average light-duty vehicle MPG to 28.4. The $500 feebate with car and light truck pivot points boosts average fuel economy to a slightly higher level, 28.9 MPG. The effect of the feebate on the distribution of light-duty vehicles by MPG is to shift the MPG distribution to the right and compresses it somewhat while still retaining its unimodal, skewed shape.

4.8. Impacts on oil use and carbon emissions

The impacts of the feebate systems examined in this study on US petroleum use and carbon dioxide emissions through 2030 were estimated using the VISION model of vehicle stock evolution and use (Singh et al., 2003). The model uses vehicle survival and age-dependent usage rates to estimate the total vehicle stock and total vehicle travel. Fuel economy by model year is an exogenous input used to compute fuel use and carbon emissions. The VISION model's Base Case is calibrated to the US Department of Energy, Energy Information Administration's (EIA) Annual Energy Outlook 2002 Reference Case projections for vehicle sales, vehicle use and fuel prices over time. However, it differs from EIA's Reference Case in that it assumes that fuel economy is frozen at today's levels. Table 2

Table 2
VISION Base case

	Fuel economy (MPG)	Oil use (mmbpd)				Carbon emissions (MMTCe)			
		2000	2010	2020	2030	2000	2010	2020	2030
Cars	28.5	4.4	4.8	6.0	7.4	211	231	285	354
Light trucks	21.2	3.2	4.8	6.1	7.6	151	231	293	364
Total LDVs	24.3	7.6	9.7	12.1	15.0	362	462	577	718

Table 3
Improvement in average new car and light truck fuel economy as a percentage of final MPG levels

Year	%
2005	4.6
2006	13.6
2007	22.7
2008	31.8
2009	40.9
2010	50.0
2011	60.0
2012	70.0
2013	80.0
2014	90.0
2015	100.0

presents the fuel economy assumptions and oil use and carbon emission estimates of the VISION Base Case currently and in 2020.[9]

In order to calculate the fuel savings due to the feebate, rebate and gas-guzzler analyses reported in Tables 1A and 1B, it is necessary to assume a path that fuel economy will follow from the current level to the level achieved by a feebate policy. It was assumed that the full impact of the programs would not occur until 2015 and that they would start in 2005. The percent of the ultimate increase in fuel economy achieved in years 2006 through 2015 is shown in Table 3. Also input to VISION were changes in the distribution of sales between passenger cars and light trucks predicted by the feebate model. Total sales in the VISION base case, however, were not adjusted.

Feebate rates of $500/0.01 GPM, assuming a 3-year simple payback rule and NRC's average fuel economy cost curves, achieve fuel savings of 0.22 million barrels per day (mmbd) in 2010, rising to 1.4 mmbd in 2020 and 2.1 mmbd in 2030 (Tables 4 and 5). The corresponding reductions in million metric tons of carbon (mmtc) are 11 mmtc in 2010, 66 in 2020 and 98 in 2030. Cumulative reductions in carbon emissions are almost 1300 mmtc by 2030. Raising the feebate rate to $1000 increases fuel savings to 0.38 mmbd in 2010, 2.22 mmbd in 2020 and 3.24 mmbd in 2030. Cumulative carbon emissions reductions increase to over 2000 mmtc through 2030.

Much greater reductions over the base case are achieved if consumers value full lifetime fuel savings.

The rebates and gas-guzzler taxes are less effective at reducing petroleum use and GHG emissions because they affect only about half the vehicles. Gas-guzzler tax rates of $1000 and 2000 do not achieve as much reduction as a comparable $500 feebate system.

5. Conclusions

The findings of this analysis are especially dependent on two critical assumptions. The most important is that the characteristics of vehicles other than fuel economy and price remain constant. This implies that fuel economy technology will not be used to increase horsepower or weight, as has been done in the United States over the past 15 years (Hellman and Heavenrich, 2002). This study does not attempt to estimate the trade-offs between price, fuel economy and performance or weight, but instead focuses only on the price vs. fuel economy trade-off. Including trade-offs with other attributes would change both the "no policy" and feebate/rebate/guzzler results. Second, the analysis applies to a future year by which time manufacturers have had time to fully implement engineering and design changes to vehicles under a normal schedule of redesign and retooling. No attempt has been made to estimate the effects of fiscal incentives during a transition period as was done in Davis et al. (1995) and HLB (1999).

If consumers do not fully value fuel economy improvements, then there appears to be little incentive for manufacturers to increase fuel economy using available, conventional technologies. The effect of this possible market failure on new car fuel economy levels could be partly offset by a $500/0.01 GPM feebate system and fully offset by a $1000/0.01 GPM system. A $1000/0.01 GPM system would raise light-duty vehicle MPG to 32, the same level that would be obtained if

[9] The base year fuel economy of new light-duty vehicles is slightly higher in the EIA Reference Case than in the NHTSA data set used in this analysis (24.4 vs. 24.3 MPG). The MPG levels of the feebate analysis were adjusted upwards slightly to match the VISION model. This will very slightly reduce the estimated fuel savings and carbon emissions reductions.

Table 4
Fuel economy gains and oil savings (mmbpd) of feebates, rebates and gas-guzzler taxes[a]

Case	Case names	Car MPG % gain vs. base	LT MPG % gain vs. base	New vehicle MPG 2015 (VISION)	2010	2020	2030
1	Base (totals)	NA	NA	24.3	9.7	12.1	15.0
2	No policy	0.1	5.1	25.0	0.03	0.22	0.33
Feebate case							
3	Feebate/$500	12.6	25.3	29.1	0.22	1.40	2.07
4	Feebate/$500	12.6	25.3	29.2	0.22	1.39	2.05
5	Feebate/$500	12.5	25.1	29.0	0.22	1.39	2.05
6	Feebate/$1000	24.6	40.7	32.5	0.38	2.22	3.24
7	Feebate/$500	22.7	32.3	31.1	0.32	1.94	2.84
8	Feebate/$500	2.4	14.1	26.5	0.10	0.64	0.95
9	Feebate/$1000	13.4	30.5	29.9	0.26	1.57	2.31
10	No policy	24.4	40.6	32.2	0.38	2.24	3.27
11	Feebate/$500	34.0	52.7	34.8	0.50	2.81	4.06
12	Feebate/$1000	42.3	63.2	37.1	0.60	3.26	4.67
Rebate case							
13	Rebate/$500	2.5	11.4	26.1	0.08	0.55	0.82
14	Rebate/$500	12.1	10.2	27.1	0.13	0.87	1.30
15	Rebate/$500	4.0	22.9	27.7	0.16	1.01	1.50
16	Rebate/$500	6.2	23.9	28.1	0.18	1.12	1.67
Gas-guzzler tax							
17	Guzzler/$1000	12.0	20.8	28.4	0.19	1.23	1.83
18	Guzzler/$2000	12.5	20.9	28.5	0.20	1.25	1.86
Double elasticities							
19	Feebate/$1000	15.2	31.9	30.4	0.28	1.66	2.44

[a] A 15 rebound effect is assumed in calculating oil savings and carbon reductions.

consumers valued full lifetime fuel savings. A $500/0.01 GPM feebate system should produce approximately a 5 MPG (20 percent) increase in light-duty vehicle fuel economy. While consumers' surplus is estimated to fall by about $2 billion per year as a result of the feebate system, this apparent loss would be more than offset by the real economic value of fuel savings. Assuming consumers would not recognize the full lifetime value of fuel savings, vehicle sales would decline by about 0.5 percent, but this would be offset by the increased price of vehicles, so that sales revenues to manufacturers would probably increase.

On the other hand, if consumers fully value the lifetime fuel savings that will result from an improvement in new vehicle fuel economy, then market forces would produce a light-duty MPG level of 32 in the absence of any fiscal incentives.[10] Adding a $500/0.01 GPM feebate would boost light-duty MPG to 34.6, and raising the feebate to $1000/0.01 GPM would produce nearly 37 MPG. Without policy intervention, the *gain* in consumers' surplus would be $12 billion per year. With the $500 feebate system this would slip to $11 billion and raising the feebate rate to $1000 would shrink consumers' surplus gains to $9 billion per year (a net loss of $3 billion).

An important technical feature of feebates is that the fuel economy level attained and the total economic cost of a feebate system depend entirely on the rate of the feebate and not the pivot points chosen. This is because the rate defines the marginal cost or benefit of fuel economy while the pivot point determines who pays and who receives. In terms of economic incentive, it matters not whether a dollar of rebate is gained or a dollar of fee is avoided; a dollar saved is a dollar earned. The pivot points, however, strongly affect whether car buyers, as a group, lose and government revenues increase, or vice versa.

This study confirms that the economics of fuel economy improvement strongly favor technological solutions over changing the mix of vehicles sold. Davis et al. (1995) found that approximately 90 percent of the increase in fuel economy due to a feebate system would be due to the adoption of fuel economy technology rather than changes in the mix of vehicles sold. In this study, typically 95 percent, or more, of the increase in fuel economy is the result of use of technology; only about 5 percent is due to changes in the mix of vehicles. Doubling the price elasticities of vehicle choice (well beyond what can be supported based on the economic

[10] This result is directly dependent on the assumption that other vehicle attributes, particularly power and weight, remain constant. In reality, some fraction of the potential to increase fuel economy would be traded off for increased horsepower and weight.

Table 5
Carbon emission reductions (MMTCe) with feebates, rebates and gas-guzzler taxes

		Annual carbon emissions reduction (million metric tons C)			Cumulative through 2030
Case	Case names	2010	2020	2030	
1	Base (total)	462	577	718	NA
2	No policy	2	10	16	201
Feebate case					
3	Feebate/$500	11	67	99	1296
4	Feebate/$500	11	66	98	1286
5	Feebate/$500	11	66	98	1286
6	Feebate/$1000	18	106	155	2062
7	Feebate/$500	15	93	136	1799
8	Feebate/$500	5	30	45	592
9	Feebate/$1000	12	75	110	1455
10	No policy	18	107	156	2077
11	Feebate/$500	24	134	194	2068
12	Feebate/$1000	28	156	223	3025
Rebate case					
13	Rebate/$500	4	26	39	509
14	Rebate/$500	6	42	62	809
15	Rebate/$500	8	48	71	936
16	Rebate/$500	9	54	80	1043
Gas-guzzler tax					
17	Guzzler/$1000	9	59	87	1144
18	Guzzler/$2000	9	60	89	1164
Double elasticities					
19	Feebate/$1000	13	79	117	1542

literature) increases the sales mix effect to only 16 percent.

5.1. Overall fuel savings and costs

Because feebates apply to all light-duty vehicles, they are far more effective at increasing MPG than rebates or gas-guzzler taxes. Comparable feebate systems achieve more than twice the fuel economy increase accomplished by rebates or gas-guzzler taxes. Rebates increase consumers' surplus, but at a greater cost in expenditure of government revenues. Gas-guzzler taxes cause losses of consumers' surplus, and only very small increases in government revenue.

How consumers value fuel savings is critically important. If consumers count only the first 3 years of fuel savings when evaluating the benefits of fuel economy, then without policy intervention there would be very little increase in fuel economy from the use of currently available, proven technologies. If consumers value the discounted present value of fuel savings over the full life of new vehicles, an increase in MPG of almost 30 percent could be expected from the use of these same technologies even without a feebate policy.[11]

The levels of fuel economy achieved by feebate systems are sensitive to the cost of technology but the cost of feebate systems is not. Exchanging the NRC study's low-cost/high-MPG cost curve for its average curve raises the average fuel economy achieved by a $500, two pivot point feebate system from 28.9 to 31.0. Using the high-cost/low-MPG cost curve decreases the average fuel economy achieved to 26.3. The loss of consumers' surplus, however, is smaller in either case than for the average cost curve.

5.2. Government revenues and rebates/guzzler taxes

Gas-guzzler taxes of the levels set in the United States over the past two decades can have a profound effect on the distribution of vehicles by MPG level. The taxes create a strong disincentive to fall below the minimum MPG level and can cause a concentration of vehicles just above the minimum. It seems likely, therefore, that the gas-guzzler tax on passenger cars has nearly eliminated cars designed to get less than 22.5 MPG.[12]

In all cases but one (double elasticities) feebates increased automobile manufacturers' revenues. Approximately revenue-neutral feebates cause vehicle sales

[11] Again, this is dependent on the key assumption that performance and weight remain constant.

[12] Today, the only cars with MPG numbers below 22.5 are high-priced luxury and performance cars.

to decline by about 0.5 percent, but sales *revenues* increase by a greater amount due to the added value in vehicles making greater use of fuel economy technology. From the consumers' perspective, most of the price increase is offset by increased fuel savings. Sales respond to the change in net value. Manufacturers' revenues, on the other hand, benefit from the full price increase. It is the fuel sector that loses revenue, not vehicle manufacturers.

Appendix A

A.1. Technology: fuel economy technology cost curves

Manufacturers' ability to increase fuel economy is described by price/fuel economy functions relating a fractional change in fuel economy to an increase in the vehicle's retail price:

$$\Delta p = a_1(\Delta E/E_0) + a_2(\Delta E/E_0)^2. \tag{A.1}$$

The functions used here are quadratic equations obtained from the NRC (2002) study of the CAFE standards. The NRC study produced an equation for each of four classes of passenger cars and seven classes of light trucks. In addition, three equations were provided for each class, describing a range of uncertainty from high-cost/low-MPG, to Average, to low-cost/high-MPG. The coefficients for each vehicle class are shown in Table 6.

A.2. Policies: feebate/rebate/gas-guzzler tax structures

While feebate systems can be structured in any number of ways (Davis and Gordon, 1992 provide a thorough review), the most interesting from a theoretical standpoint is also the simplest. The simplest form of a feebate system consists of a *pivot point* and a *rate*. The pivot point, E_0, is the fuel economy level (in MPG) below which fees are paid and above which rebates are received. The rate, R, is a constant specified in units of dollars per GPM (here, per 100 miles), which determines how large the fee or rebate for any particular fuel economy level will be. The feebate, F, for a vehicle getting E miles per gallon would be the following:

$$F = R\left(\frac{1}{E_0} - \frac{1}{E}\right). \tag{A.2}$$

By this convention, rebates are positive and fees are negative. Thus, if the pivot point is 25 MPG and the vehicle in question gets only 20 MPG, the GPM difference will be $0.04–0.05 = -0.01$. If $R = \$50,000$ per 1 GPM (or \$500 per 0.01 GPM), the fee is $F = -\$500$. Likewise, if the vehicle in question got 40 MPG, it would receive a rebate of $F = +\$750$.

The feebate system of Eq. (A.2) gives a constant value to all gallons per mile and thereby to every gallon of fuel saved. Thus, with respect to vehicle purchase decisions (but not vehicle use decisions) a feebate system such as Eq. (A.2) is equivalent to a tax on gasoline (assuming that markets were operating efficiently). A vehicle driven 120,000 miles over its lifetime would save 1800 gallons of gasoline at 40 MPG vs. 25 MPG.[13] Dividing the \$750 dollar rebate by 1850 gallons yields an implied tax rate of \$0.42 per gallon.

An important theoretical property of the feebate system described by Eq. (A.2) is that the increase in a particular vehicle's fuel economy stimulated by the feebate system depends only on R, and not on E_0. In theory, each manufacturer would attempt to increase each vehicle's fuel economy up to the point at which the marginal cost of a gallon saved equals the price of fuel plus the incremental value implied by R. Intuitively, the pivot point does not affect this decision because it does not matter to the manufacturer whether a dollar is saved by gaining a rebate or by avoiding a fee. A dollar is a dollar. It follows that under the feebate system of Eq. (A.2) different pivot points can be established for different classes of vehicles without affecting the fuel economy of any particular vehicle.[14] The choice of pivot point does affect the mix of vehicles sold, however.

If the pivot point(s) of Eq. (A.2) is carefully chosen so that total fees collected equal total rebates paid out, the feebate system is revenue neutral. A revenue-neutral feebate system may be more politically attractive because it represents no net change in the government's tax burden. If revenue neutral, the system of Eq. (A.2) is also equivalent to a fuel economy standard with tradable credits (assuming the credits market is competitive), as was shown by Johnson (1991).

Changing pivot points will affect consumers' purchase decisions and vehicles' market shares, and thereby indirectly affect fuel economy. It is likely that this effect will be small, however, since manufacturers' design and technology responses to feebates appear to be far more significant in determining average new vehicle fuel economy levels than consumers' choices of vehicles. Davis et al. (1995) found that the consumer response accounted for about 10 percent of the fuel economy improvement and the manufacturer-technology response about 90 percent.

Because of the relative unimportance of sales mix changes to the long-run impact of feebates on fuel economy, it may be possible to replace the single pivot

[13] We neglect for simplicity the need to discount future fuel savings to present value. This would, in effect, reduce the "present value" lifetime miles and increase the implied tax per gallon.

[14] Note that this is true even if a manufacturer moves vehicles from one class to another to achieve a lower pivot point, *provided that* the classes themselves are not defined based on fuel economy or that moving to another class does not necessitate a loss of fuel economy.

Table 6
NRC (2002) fuel economy technology/price functions

Fuel economy/price curves		Average cost and MPG		Low-cost/high-MPG		High-cost/low-MPG	
	Base year MPG	(MPG) b	(MPG^2) c	(MPG) b	(MPG^2) c	(MPG) b	(MPG^2) c
Cars	28.25	*Quadratic curves of retail price increase vs. relative increase in MPG*					
Subcompact (1)	30.0	2599.3	3897.0	1471.7	3603.3	4370.1	3288.5
Compact (2)	30.5	2619.7	3553.3	1507.8	3335.9	4339.8	2930.4
Midsize (3)	27.1	2799.3	2152.1	1762.3	2189.4	4298.3	1555.1
Large (4)	25.7	2761.6	1690.3	1815.7	1735.7	4099.3	1226.4
Light trucks	20.75						
Small SUV (5)	24.9	2799.3	2152.1	1762.3	2189.4	4298.3	1555.1
Medium SUV (6)	20.4	2761.6	1690.3	2761.6	1690.3	4099.3	1226.4
Large SUV (7)	17.2	2806.9	1656.4	2062.4	1766.6	3717.1	1380.4
Minivan (8)	23.4	2723.9	1859.2	1835.6	1821.5	3961.8	1559.7
Large van (9)[a]	18.2	2725.6	1857.4	1837.1	1820.1	3963.7	1557.4
Small pick-up (10)	22.5	2684.8	1870.9	1758.1	1844.4	4017.6	1469.5
Large pick-up (11)	19.1	2725.6	1857.4	1837.1	1820.1	3963.7	1557.4
Total	24.30						

[a] Large pick-up parameters.

point system with a set of pivot points for different vehicle classes without significantly reducing the fuel economy benefit. A class pivot point system might reduce the disparities in the impacts of feebates on different manufacturers. Class-specific pivot points can encourage undesirable behavior at class boundaries. Boundary problems are not addressed in this study.[15] The advantage of class-specific pivot points is that manufacturers specializing in larger vehicles are not penalized by the feebate system relative to manufacturers specializing in smaller vehicles.

A.3. Consumer behavior I: the value

The representation of consumers' decision-making is comprised of two parts: (1) determination of the value of future fuel savings due to fuel economy improvements, and (2) a model of vehicle choice that depends on changes in vehicle prices and fuel costs. The value of fuel savings is calculated as a discounted present value over some portion of the vehicle's expected lifetime.

$$V = \int_{t=0}^{L} P_t M e^{-\delta t} \left(\frac{1}{E_0} - \frac{1}{E_0(1+x)} \right) e^{-rt}\, dt, \tag{A.3}$$

where V is the present value of fuel savings, L the effective vehicle lifespan in years, P the price of gasoline in dollars per gallon, M the annual miles traveled by a typical vehicle, δ the annual rate of decline in vehicle miles with vehicle age, r the consumer's required rate of return on an investment in fuel economy, t the time (in years) and x the fuel economy increase as a fraction of base year MPG (E_0).

Eq. (A.3) can represent a range of consumer behavior, depending on the values chosen for key parameters. For example, the simple 3-year payback rule can be represented by assuming $r = 0$, and $L = 3$. Since gasoline prices are notoriously difficult to predict, it is convenient to assume that $P_t = P_0$, i.e., future gasoline prices will equal the current price, though any forecast could be used.

A.4. Consumer behavior II: vehicle

The vehicle choice model is an NMNL function. This is the same functional form used by Davis et al. (1995), but the model used here is calibrated to national vehicle sales data rather than to individual household survey data. This simplification sacrifices the ability of a household-based model to represent differences in consumer preferences that vary with household demographics and income. On the other hand, it allows the model to be quickly and inexpensively calibrated to the most recent sales data, and it also permits a consistent evaluation of the benefits of increased fuel economy by consumers and manufacturers.

The NMNL model represents the probability that a consumer will choose vehicle make and model i of class j

[15] Establishing class pivot points creates an incentive for vehicles on the lower boundaries of classes to jump down to a class with a lower pivot point in order to reduce their fees or gain rebates. Similarly, vehicles at the upper boundary of a class would avoid jumping up to the next class to avoid a higher pivot point. However, in either case the feebate's monetary incentive still provides the same encouragement to increase fuel economy. This implies that it may be possible to define class boundaries using functional attributes (not fuel economy) that manufacturers will be reluctant to change.

as a function of the utility of that vehicle and of all other vehicles (Train, 1986). In this study, light-duty vehicles are divided into the eleven vehicle classes used in the NRC (2002) study and shown in Tables 1A and 1B. The utility of a vehicle is assumed to be a function of its attributes, the average values a typical consumer attaches to one unit of each attribute and an unobserved component that varies from one individual to another. The two key attributes for this analysis are the price of the vehicle, P_{ij}, and the discounted present value of its expected fuel costs, V_{ij}. Since both of these variables are measured in present value dollars, let the average value a consumer attaches to a dollar be B. Clearly, there are many attributes of vehicles other than price and fuel costs that matter greatly to car buyers. Since these are held constant (by assumption) in this analysis, the sum of these attributes' values is represented by a different constant term for each make and model. As will be seen below, the constant terms perform a useful function in calibrating the model to base year 2000 sales data.

Let the utility, u, of vehicle i in class j to the kth consumer be the sum of three components. Two are common to all consumers: (1) a constant term, A, and (2) the typical net value of fuel savings. A third component, ε, is specific to each individual and reflects personal variations in perceptions and preferences: $u_{ijk} = A_{ij} + B(P_{ij} - V_{ij} - F_{ij}) + \varepsilon_{ijk}$. The constant terms A_{ij} were calculated so that the base market shares at zero fuel economy improvement and zero price changes exactly equal the actual market shares for each vehicle. The A_{ij} represent the average value of all attributes other than fuel savings, fuel economy-related price changes and rebates. If ε can be represented by a random variable that has a type I extreme value distribution across consumers for the vehicles in class j, then the probability, s_i, that a consumer will pick vehicle i, given that the consumer will pick a vehicle in class j, is the following:[16]

$$s_{i|j} = \frac{e^{u_i}}{\sum_{l=1}^{n_j} e^{u_l}}. \tag{A.4}$$

In Eq. (A.4), n_j is the number of makes and models in vehicle class j, and l is the index of the makes and models. The probability that a consumer will select a vehicle from class j depends on the expected utility of the choices in class j. Again, assuming that ε has the type I extreme value distribution, the expected utility of class j is given by the following log sum:

$$\bar{u}_j = \frac{1}{B}\ln\left(\sum_{i=1}^{n_i} e^{u_{ij}}\right). \tag{A.5}$$

The probability that the consumer will choose a vehicle from class j is then given by the following logit equation:

$$s_j = \frac{e^{a_j + b\overline{u_j}}}{\sum_{l=1}^{N} e^{a_l + b\overline{u_l}}}. \tag{A.6}$$

In Eq. (A.6), $b < B$, determines the sensitivity of vehicle class market shares to the changes in values of vehicles within the class. The constant terms, a, allow the model to be calibrated to base year vehicle class shares, as well as make and model shares. The probability that vehicle ij will be chosen, which is equivalent to its market share, is the product of the two probabilities, i.e., $s_{ij} = s_{i|j}s_j$.

A.5. Objective function: maximize consumers' surplus

Manufacturers are assumed to choose changes in fuel economy that maximize the gain in consumers' surplus over the initial conditions, given the cost of those improvements and the feebates they induce. In the NMNL model, the change in consumers' surplus is given by the following formula in which u^* indicates the utility of vehicles after fuel economy changes and rebates and u indicates utility of the base vehicles without fuel economy changes or rebates:

$$\Delta U = \frac{1}{b}\ln\left(\frac{\sum_{j=1}^{N} e^{a_j + b\overline{u_j}^*}}{\sum_{j=1}^{N} e^{a_j + b\overline{u_j}}}\right). \tag{A.7}$$

A.6. Calibration

Calibration of the NMNL model requires specifying price slopes (B_j and b) and estimating constant terms for all but one vehicle make and model, such that given no changes in fuel economy or price and no feebates, the NMNL model exactly predicts the base year market shares for every make and model. Price slopes are calibrated from assumed elasticities of market share, s, based on published studies. Let η_j be the price elasticity of market share for cars of class j. The relationship between the price slope for class j and the price elasticity is given by the following:

$$B_j = \frac{\eta_j}{P_i(1 - s_i)}. \tag{A.8}$$

The average price of cars in class j is substituted for P_i and a market share of 1.5 percent is substituted for s_i (corresponding to a class containing about 67 makes and models). For make and model choices within a vehicle class, a price elasticity of -10 is assumed for all classes. This compares with estimates of make and model price elasticities of -2.4 to -4.7 by Bordley (1993) and -3.1 to -6.7 by Berry et al. (1995). Greene (1994) reports that a survey of a dozen econometric studies of make and model choice produced a central estimate of -2.8 at 50 percent market share, which is -5.5 at a 1.5 percent market share. Thus, the literature suggests that an elasticity of -10 is on the high side, and

[16] Derivations of this result and others stated below can be found in Train (1986).

will thus tend to overestimate the amount of mix shifting as a result of feebate systems. As it turns out, the effect of mix shifting on MPG is very small, so we are deliberately choosing to err on the side of overestimating it.

The price elasticity of vehicle class choice is assumed to be -5, which is (in absolute value) less than -10 as required by the NMNL theory. The price slope is calculated at the overall average price of a light-duty vehicle ($23,804) and at a market share of 10 percent (approximately 1/11 classes). For purposes of estimating the impact of feebate systems on overall light-duty vehicle sales, an elasticity of -1.0 is assumed (Kleit, 1990; McCarthy, 1996).

Constant terms that calibrate the NMNL to base year market shares (s_{ij}) for makes and models were calibrated using in Eq. (A.9):

$$A_{ij} = \ln(s_{ij}) - \frac{1}{\sum_{j=1}^{N} n_j} \sum_{j=1}^{N} \sum_{i=1}^{n_j} \ln(s_{ij}). \qquad \text{(A.9)}$$

To calculate class-specific intercepts that calibrate the model to base year shares additional constraint must be imposed. Since there is one fewer equation than there are unknown constants, we assume without loss of generality that the sum of the class intercepts is zero. Let a_1 be the intercept for vehicle class 1.

$$a_1 = b\frac{1}{B_j} \ln \sum_{i=1}^{n_1} e^{A_{ij}} + \frac{1}{N}\left(\sum_{j=1}^{N} \ln\left[\frac{s_1}{s_j}\right] - \sum_{j=1}^{N} b\frac{1}{B_j} \ln\left[\sum_{i=1}^{n_j} e^{A_{ij}}\right] \right). \qquad \text{(A.10)}$$

Then the other class intercepts, a_j, are given by the following equation:

$$a_j = a_1 - \ln\left[\frac{s_1}{s_j}\right] + b\frac{1}{B_1} \ln\left[\sum_{i=1}^{n_1} e^{A_{ij}}\right] - b\frac{1}{B_j} \ln\left[\sum_{i=1}^{n_j} e^{A_{ij}}\right]. \qquad \text{(A.11)}$$

Eqs. (A.9)–(A.11) insure that before any changes in fuel economy and before any feebate policies are imposed, the NMNL model will exactly predict the base year shares for every make and model, and for every vehicle class, as well.

A.7. Solving rebates and gas-guzzler taxes

The feebate problem is well behaved and can be solved by the "solver" function of an Excel™ spreadsheet. Because rebate and gas-guzzler functions have a discontinuity, these optimization problems generally have local optima and require additional steps to find a globally optimal solution.

Solving a rebate problem is more complicated than solving a comparable feebate problem because rebates cause a discontinuity in the consumers' surplus function that can lead to local optima. Consumers' surplus is a function of the change in net value (value of fuel savings minus retail price increase) plus the rebate, if any. At the point where the rebate kicks in (the pivot point), there is a discontinuity, since the "feebate function" is zero up to that point. If at the pivot point the slope of the net value function is negative but smaller in absolute value than the slope of the rebate function (less than the rebate rate), then consumers' surplus will be increasing as fuel economy is increased. But the second derivative of the net value function is negative, so that its slope will become increasingly negative (larger in absolute value) as fuel economy increases. Ultimately, then, the slope of the sum of net value and rebate will become negative, implying that a maximum exists between the pivot point and some higher level of fuel economy. This will not necessarily be the global maximum for consumers' surplus, which could well lie between the rebate pivot point and zero fuel economy improvement.

The following algorithm solves the rebate local optimum problem. First, solve a feebate problem with the same rate as will be used for rebates (e.g., $500/0.01 GPM). Using the fuel economy levels from the solved feebate problem as starting points, solve the rebate problem. For each vehicle, compute the sum of, (i) the retail price change, (ii) the present value of fuel savings, and (iii) the rebate. If this sum is greater than zero for any vehicle, a local optimum that is not a global optimum has been found for that vehicle. Costs can be reduced by setting the fuel economy increase to zero (since this will involve a zero retail price increase, zero fuel savings and possibly some rebate). However, some small level of fuel economy increase might also be preferable to zero. Therefore, set the fuel economy increases to zero for all vehicles with a greater than zero net price change, then resolve the rebate problem.

The above algorithm will find a globally optimal solution to the rebate problem because there can be at most two local optima. Given that the rebate problem was solved starting from the feebate solution, all vehicles for which the sum of (i)+(ii)+(iii)<0, must have a global optimum above the feebate level. If their true optimum had been below the zero level, it would have been discovered in the feebate problem, which does not have multiple optima.

Solving a gas-guzzler tax is different from either a feebate or a rebate problem. If the pivot point of the gas-guzzler tax is less than the MPG level at which the net value of increasing fuel economy (price increase minus value of fuel savings) equals zero, there will be a discontinuity in the curve formed by subtracting the gas-guzzler tax function from the net value curve, but there will be only one optimum value. Unless very high pivot points are chosen, this will be the most common situation. The optimum can be found by the Excel Solver, but will generally require more iterations than a feebate or rebate case to achieve a sufficiently accurate solution.

If the pivot point of the gas-guzzler tax is greater than the zero point of the net value curve, then the optimal value will always lie between the pivot point and zero MPG increase. Moreover, the sum of the gas-guzzler tax and the net value function will be a continuous function between these two point and will have a single optimum.

Given the above, a solution to the guzzler problem can always be found by first solving a comparable feebate problem and using the solution as the starting point for the gas-guzzler problem. The gas-guzzler problem will generally take longer to converge due to the kinks in many net value plus guzzler tax functions.

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