BACKGROUNDER

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Energy Policies for Automobile Transportation

A Comparison Using the National Energy Modeling System

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RESOURCES FOR THE FUTURE

NEPI National Energy Policy Institute

Energy Policies for Automobile Transportation: A Comparison Using the National Energy Modeling System

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Abstract

This paper assesses the costs and effectiveness of several energy policies for light-duty motor vehicles, using NEMS-RFF. The National Energy Modeling System (NEMS) is a computer-based, energy-economy market equilibrium modeling system for the United States developed by the U.S. Department of Energy. NEMS-RFF is a version of NEMS developed by Resources for the Future (RFF) in cooperation with OnLocation, Inc. The policies addressed are higher fuel taxes, tighter vehicle efficiency standards, and financial subsidies and penalties for the purchase of high- and low-efficiency vehicles (feebates). Each policy is analyzed at one or more levels of stringency designed to illustrate the effects of concrete proposals that are administratively feasible. The baseline for comparison is a simulation of the scenario in the Energy Information Administration's *Annual Energy Outlook 2009*, as updated to include the 2009 federal stimulus package and further modified by this project to incorporate the National Energy Program, in which passenger vehicle fuel efficiency standards are to be integrated with greenhouse gas standards.

The fuel efficiency policy analyzed is an extension and further tightening of that National Energy Program through 2030, analyzed here as tighter regulations on corporate average fuel economy (CAFE). The parameters for the feebate policy are designed to produce similar improvements in new-vehicle fuel efficiency. These policies have significant but modest effects, achieving by 2030 reductions in energy use by light-duty vehicles (LDVs) of 7.1 to 8.4 percent. A stronger feebate policy has somewhat greater effects, but at a significantly higher unit cost because even the less draconian policies modeled here nearly exhaust the list of technologies available at reasonable cost.

High fuel taxes, on the order of $2.00 per gallon in real 2007 dollars, have somewhat greater effects and arguably more favorable cost-effectiveness ratios. They also produce their effects much more quickly because they affect the usage rate of both new and used vehicles. Both fuel taxes and the tighter CAFE regulation rely partly on increasing the share of hybrid-electric vehicles, even beyond the already high share of 23–27 percent projected for 2030 in the baseline scenario.

Because a high fuel tax strongly targets the amount of driving, it is complementary to either a CAFE or feebate policy, both of which particularly target fuel efficiency. A combined policy of CAFE and a very high fuel tax is quite effective, achieving a 21 percent reduction in energy use by LDVs by 2030 at a unit cost that is not too much higher than either policy alone.

Shifts among size classes of vehicles play a small role in these simulations, in part because the CAFE and feebate policies are designed specifically to discourage them. In addition, NEMS-RFF portrays consumer choice of size class as rather insensitive to incentives. Some other research supports this view,

but the question is unsettled and deserves more exploration. In addition, newer research questions the validity of the predominant view of federal regulators that shifts to smaller vehicles would pose safety problems.

Policy costs vary greatly with assumptions about the reason for the apparent myopia commonly observed in consumer demand for fuel efficiency. The costs also depend strongly on which categories are included. Under central assumptions, and excluding side effects of the policies on traffic, the policy costs for CAFE and the more modest of the two feebate policies are on the order of $12 per barrel of oil saved or $31–35 per metric ton of carbon dioxide (CO_2) emissions reduced; for the fuel tax policy, these figures are $10 per barrel of oil or $22 per metric ton of CO_2. However, counting the external costs of driving (congestion, accidents, and local air pollution) can greatly change the cost estimates, causing CAFE and feebates to be somewhat more expensive and the fuel tax to have a negative cost to society (that is, its ancillary benefits outweigh its costs), as a result of its depressing effect on the amount of driving and the resulting decrease in traffic congestion and accidents.

This background paper is one in a series developed as part of the Resources for the Future and National Energy Policy Institute project entitled "Toward a New National Energy Policy: Assessing the Options." This project was made possible through the support of the George Kaiser Family Foundation.

Contents

Energy Policies for Automobile Transportation: A Comparison Using the National Energy Modeling System

Kenneth A. Small*

Introduction

The significant role of passenger land transportation in greenhouse gas (GHG) emissions and petroleum consumption is well known. Consequently, most analysts believe that serious strategies to address climate change will require significant reductions from the transportation sector. For example, Stern (2008, 7) asserts that, to stabilize ambient concentrations of GHGs at 550 parts per million carbon dioxide (CO_2) equivalent, which he considers a minimally acceptable target, "richer countries will need to have close-to-zero emissions in power (electricity) and transport by 2050." Of course the actual emissions reduction appropriate for the transportation sector, and the best means of achieving it, depend on (a) an economic assessment comparing the costs and effectiveness of various transportation policies with each other and with policies affecting other sectors of the economy and (b) the benefits of lower emissions.

This paper undertakes such an assessment. It does so by defining specific measures as input parameters to the National Energy Modeling System (NEMS), the comprehensive model of energy sectors used by the Energy Information Administration (EIA) for its regular projections and analyses of energy trends and policies. This paper is part of a larger suite of studies, commissioned by Resources for the Future (RFF) in conjunction with the National Energy Policy Institute, all using NEMS-RFF to analyze a wide variety of energy and GHG policies. These policies are designed with quite an aggressive overall goal in mind as a benchmark, namely, reducing U.S. petroleum consumption from 20 million barrels per day in 2007 to 16 million in 2030.

The specific policies addressed here are higher fuel taxes, tighter vehicle efficiency standards, and financial subsidies and penalties for the purchase of high- and low-efficiency vehicles (*feebates*). Each policy is analyzed at one or more levels of stringency designed to illustrate both the potential and the limitations of the policy, including whether it seems feasible to achieve the benchmark just noted. In determining the policy's effect, the baseline for

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comparison is a simulation of the *Annual Energy Outlook 2009* scenario, as updated to include the 2009 federal stimulus package and with additional modifications reflecting the National Energy Program announced by the president later in May 2009. In the latter initiative, passenger vehicle fuel efficiency standards are to be integrated with GHG standards.

Comparative results of this study include changes in a number of indicators, including fuel prices, fuel consumption, efficiencies of new and used vehicles, the use of alternative fuels and technologies, oil imports, and CO_2 emissions. Equally importantly, the modeling exercise reveals the workings of key market mechanisms, identifies factors with special importance (and some with surprising unimportance), and identifies synergies and conflicts with other trends and policies. Furthermore, by quantifying the effects of specific mechanisms, the study highlights key parameters whose values are especially important for policy analysis.

In addition, I go to great lengths to estimate the costs (or offsetting benefits) to relevant parties—including car manufacturers, consumers, and governments—of enacting energy policies. This enables me to compute overall societal costs and various cost-effectiveness measures, as well as to see some of the politically important patterns of the incidence of these costs. This cost estimation is more difficult than it might appear. A model that is fully derived from a single formulation of well-defined utility and profit functions, such as that by Bento et al. (2009), contains all of the information needed for rigorous welfare analysis; the cost of doing so is that the form of the model's specific behavioral relationships, such as demand functions and market interactions, is quite constrained by this overall framework and the need to make it mathematically tractable. In contrast, a model such as NEMS-RFF, containing many empirically based components, each aimed at realism, does not permit a direct calculation of consumer utility, so welfare measures must be inferred from demand and cost curves. Doing so is quite complex because of the many dimensions of behavior involved. Furthermore, certain well-established behavioral regularities represented in the model, such as consumers' use of short time horizons for their purchase decisions, are inconsistent with standard assumptions in economic theory, and therefore require some auxiliary assumptions to determine changes in well-being. One of the major contributions of this research is a quite elaborate framework to measure welfare changes under both baseline and alternative assumptions about such behavior, all within an empirically based model. To the best of my knowledge, other studies using large-scale simulation models of energy markets, such as NEMS-RFF, have not attempted such an analysis of societal costs.

One strength of NEMS-RFF is that it incorporates explicitly the way in which energy markets may strengthen or counter policies in the transportation sector. For example, what

portion of a change in fuel taxes is passed on to consumers? How do transportation policies affect oil imports and the prices of other energy sources? These and other questions can be addressed consistently within the well-used and publicly documented NEMS-RFF, making it possible to quantify how market interactions alter the first-round expected effects of a given policy. NEMS-RFF also has certain weaknesses for our purposes, discussed in Section 2.

1. Passenger Highway Transportation in the United States

The relative contribution of transportation to energy problems is quite different depending on which problem indicator one considers. In 2008, transportation accounted for 28 percent of energy consumption and 33 percent of CO_2 emissions, but a much larger 71 percent of consumption of liquid fuels. Motor gasoline, mostly related to passenger transportation on highways, accounts for about 60 percent of transportation energy consumption; most of the rest is diesel fuel, used mainly by heavy trucks (23 percent), and jet fuel, used by aircraft (12 percent). Thus, passenger motor vehicles account for approximately 17 percent of all energy consumption, 18 percent of all CO_2 emissions, and 44 percent of liquid fuels consumption (Table 1.1).

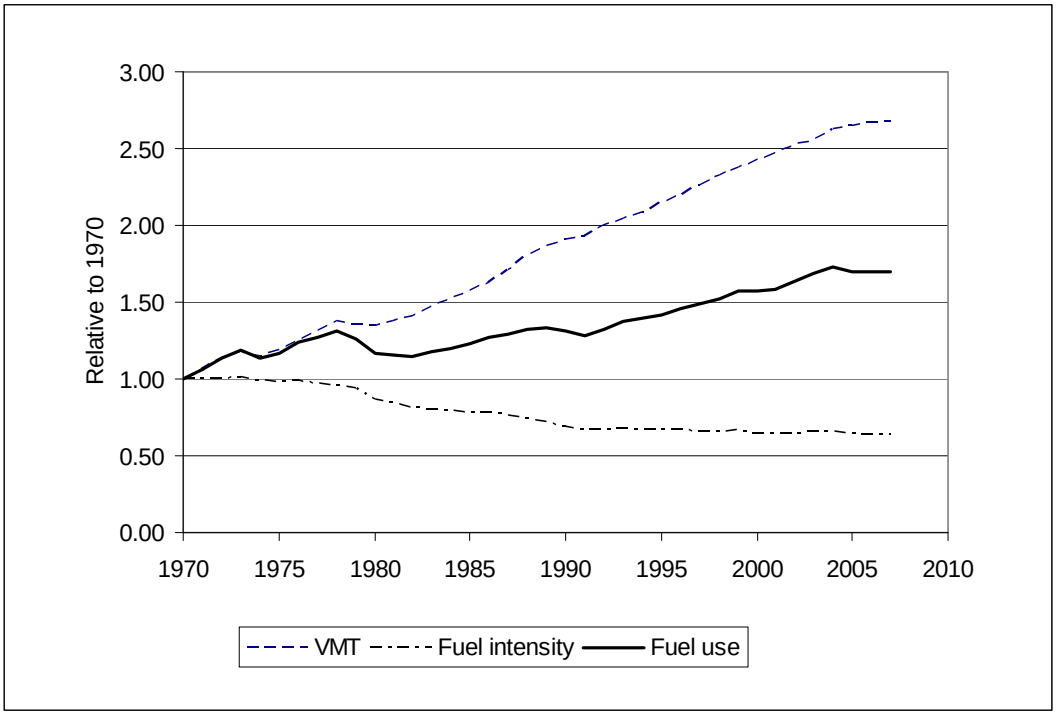
Energy consumption by the passenger highway transportation sector has grown substantially, though not steadily. From 1970 to 2007, it grew by 70 percent, but the growth path was punctuated by declines in 1974, 1979–1982, 1990–1991, and 2005–2006 (Figure 1.1). The overall growth was a net result of two countering trends, also shown in the figure: vehicle-miles traveled (VMT) rose dramatically, by 168 percent (annual average growth rate of 2.70 percent per year); whereas the fuel intensity of vehicles (i.e., the reciprocal of fuel efficiency), *declined* by 36 percent (annual average growth rate –1.22 percent per year).

Table 1.1. Major Components of Energy Consumption, Liquid Fuels, and CO_2 Consumption, 2008

Sector	Energy consumption (quadrillion Btus)	Liquid fuels consumption (quadrillion Btus)[d]	CO_2 emissions (million metric tons)
Residential	21.8	1.4	1,234
Commercial	18.6	0.6	1,072
Industrial	32.2	9.2	1,622
Transportation	28.0	27.2	1,921
Light-duty vehicles[a]	16.8	16.8	1,081
Freight trucks[b]	6.2	6.2	352
Aircraft[c]	3.1	3.1	183
Total	100.5	38.4	5,849
As percentage of total:			
Residential	21.7	3.5	21.1
Commercial	18.5	1.5	18.3
Industrial	32.0	24.1	27.7
Transportation	27.8	70.9	32.8
Light-duty vehicles[a]	16.7	43,6	18.5
Freight trucks[b]	6.2	16.2	6.0
Aircraft[c]	3.1	8.2	3.1
Total	100.0	100.0	100.0

Note: Btu, British thermal unit.
[a, b, c] For energy and liquid fuels, these three sectors are approximated by motor gasoline, distillate fuel oil, and jet fuel, respectively. [d] The net heat content of crude petroleum is 5.54 million Btus per barrel; hence 1 quadrillion Btus is equivalent to 180.5 million barrels of crude.
Source: EIA (2009a, Tables 2, 19).

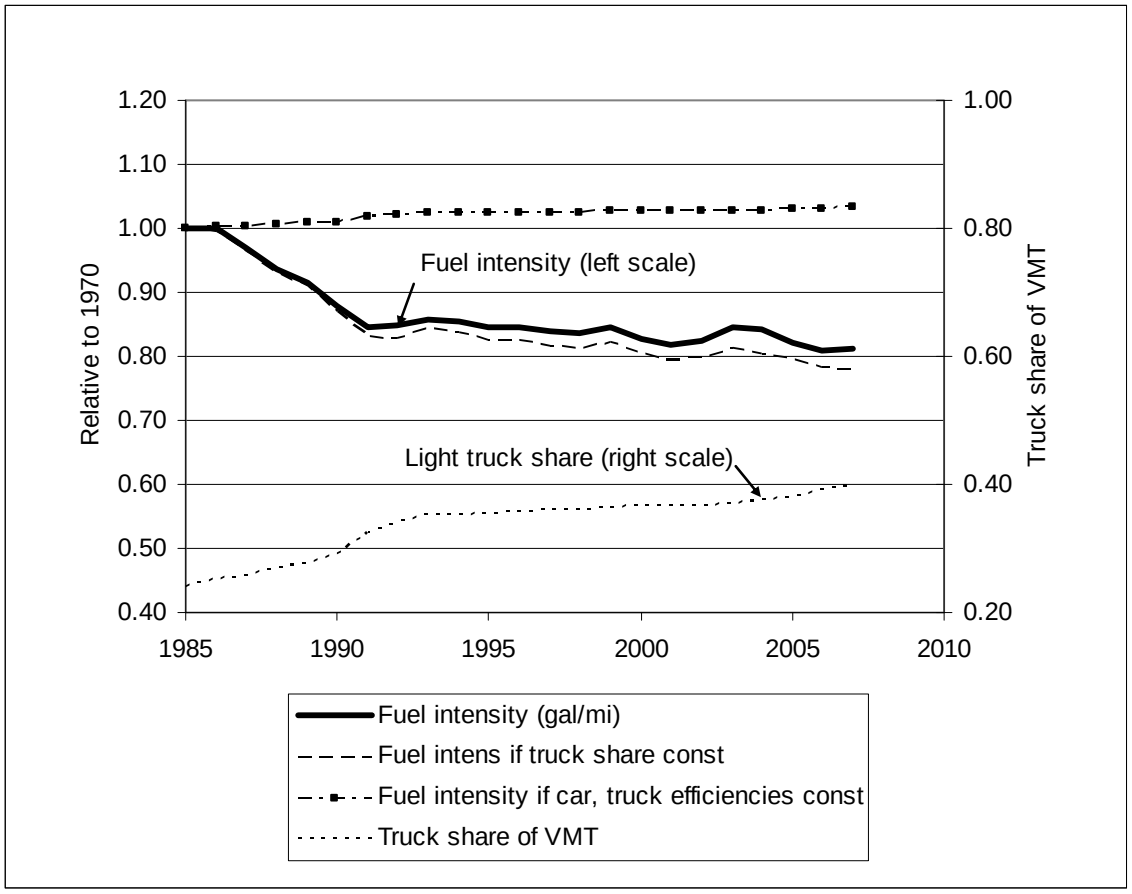
Figure 1.1. Changes in Fuel Use and Its Components



Note: VMT, vehicle-miles traveled.
Source: Computed from data in Davis et al. (2009).

Looking more deeply into the decline in fuel intensity, it appears that it was caused mainly by changes in the fuel efficiencies of individual vehicles, somewhat counteracted in more recent years by changes in the size mix of vehicles. Figure 1.2 portrays the effects of one kind of vehicle mix shift, starting in 1985, when the Federal Highway Administration began keeping consistent data separately on cars and light trucks. During the ensuing 22 years, the share of light-duty VMT accounted for by light trucks (pickups, vans, and sport utility vehicles [SUVs]) rose from 24 percent to 40 percent. Because light trucks consistently had around 19 percent higher fuel intensity, this 16 percentage point shift alone kept fuel intensity 3 percent higher than otherwise, as seen in the top line in the figure and also by comparing the solid line (actual fuel intensity) with the dashed line (fuel intensity that would have occurred if the truck share were constant).

Figure 1.2. Changes in Fuel Intensity and Truck Share of VMT



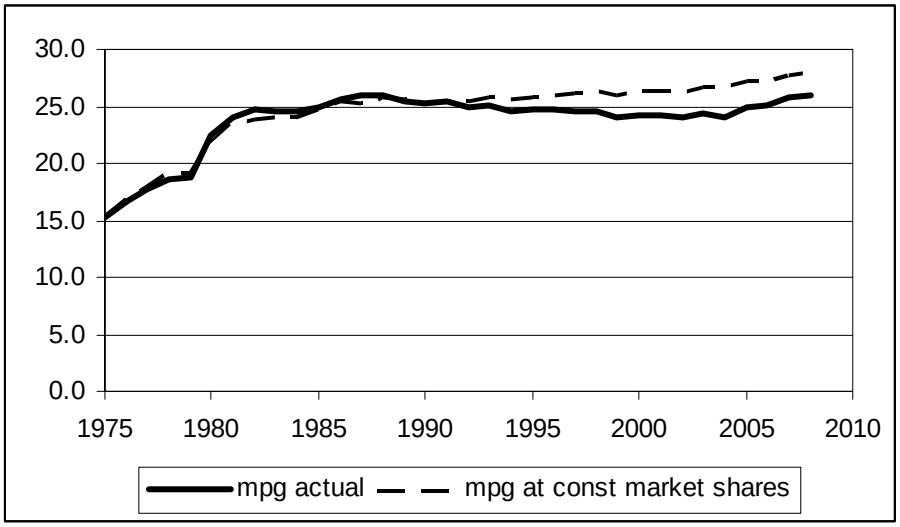
Source: Computed from data in Davis et al. (2009).

We can better see the effects of changes in vehicle sizes by analyzing data on new vehicles, which can be obtained separately for six types of cars and nine types of trucks. One can then calculate what would have happened to the fuel economy of new vehicles (weighted by sales, not by mileage) if the fuel economy of each size class had developed as it did but keeping the total market shares of each car and truck size class frozen at its 1975 value. Figure 1.3 shows the result: fuel efficiency would have been 7.3 percent higher in 2008 than it actually was.[1]

[1] This is a smaller shift than that resulting only from shifts between cars and trucks because some of the latter shift was from large cars to light trucks; as a result, the size mix within cars became more weighted with smaller cars, partly countering the adverse effect of growth in truck market share.

Market shares of new vehicles have fluctuated strongly during the 33 years shown; the years 1980 and 2004 are especially notable, as can be seen in the figure—the effects of vehicle mix changes (since 1975) were most favorable in 1980, when small cars made substantial gains following the oil crises of the 1970s, and were most unfavorable in 2004, a sort of peak in consumer demand for power and size. Indeed, if the figure were redrawn using 1980 market shares as a starting point, the average light-duty vehicle (LDV) fuel efficiency in 2004 would have been 14 percent higher than it was: 27.3 miles per gallon (mpg) instead of 24.0 mpg. Thus, a substantial, though not enormous, gain in fuel efficiency is possible just through market share shifts of magnitudes actually encountered during the last three decades.

Figure 1.3. Effect of Market Shares by Size and Type on Fuel Efficiency

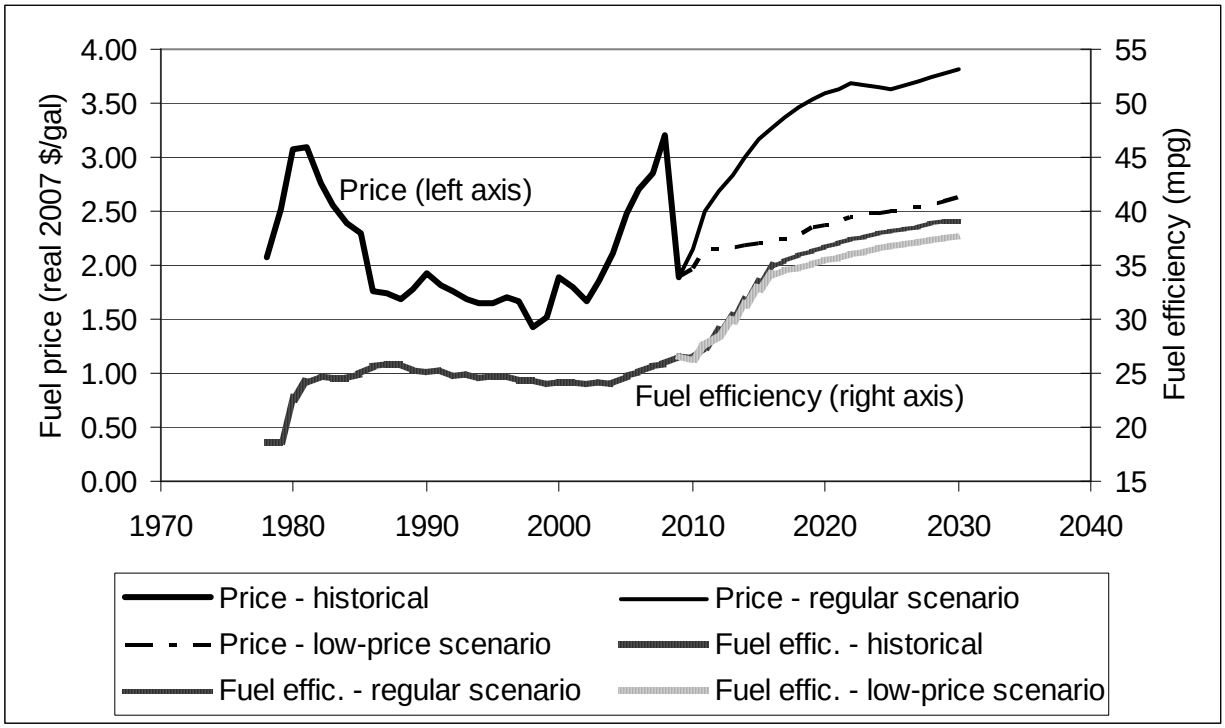


Source: Computed from data in Davis et al. (2009).

Fuel prices have played a significant role in driving vehicle fuel efficiency, and they promise to continue to do so in the future. Figure 1.4 shows the annual average real price of gasoline from 1978 through 2008 and two alternative projections through 2030. Shown on the same graph are the average sales-weighted fuel efficiencies of cars and light trucks, as lab tested (and thus about 20 percent higher than on-road). The projections of both prices and fuel efficiencies are from the Core cases of the RFF project, including the updates reflecting the 2009 stimulus package and the computed effects of the Obama administration's announced intention to implement new integrated corporate average fuel economy (CAFE) and GHG standards through 2020. The price projections assume that the federal fuel tax will remain unchanged in nominal terms, but that state fuel taxes will rise with inflation. EIA has stated that these

assumptions are consistent with recent experience and that they conform to EIA's practice of assuming no changes in federal law other than those being analyzed (EIA 2009c, 137).

Figure 1.4. Fuel Prices and Efficiencies of New Vehicles, Historical and Projected



Source: Computed from data in Davis et al. (2009).

The broad price changes, especially the trough from 1986 through 2002 and the subsequent rise, seem likely to be causally related to the broad trends in fuel efficiency—although CAFE standards also played a role. Studies that attempt to disentangle fuel price and CAFE standards as causes have generally found a consistent, though moderate, response of fuel efficiency to price. Small and Van Dender (2007, Table 5) measure this as an elasticity of –0.04 in the short run and –0.20 in the long run, averaged over the last third of the 20th century. Their estimates incorporate any responses going beyond those embodied in new vehicles, arising from changes in average speed, from VMT mix among the vehicles owned by a given household, and perhaps from changes in driving aggressiveness. A few studies have verified some of these responses. For example, a Congressional Budget Office study by Austin (2008) finds that speed changes alone produce a substantial responsiveness of fuel efficiency to price for weekend freeway driving in California. Busse et al. (2009) find responses in used vehicle markets, but

mostly in the prices of vehicles rather than in vehicle mix because the latter can be changed only by retiring vehicles.[2]

Data on market shares of new-vehicle sales further illuminate the effect of the sharp run-up in prices in 2003–2008. Assuming that sales would lag by a year as a result of production constraints, Table 1.2 shows changes in aggregated market shares in 2004 and 2008, spanning a period of rapid increases in gasoline price. During this time, the market share of light trucks declined by 4.0 percentage points. The biggest shifts were from pickup trucks toward large and midsize cars, resulting in a modest increase in average fuel efficiency. Austin (2008) makes a similar point for the 2004–2006 period. Austin also models the response statistically, using monthly data by vehicle category, and finds that a 20 percent increase in gasoline price raises the market share of cars among all new LDVs by 2.6 percentage points.

Table 1.2. Market-Share Shifts among Selected Sizes and Types of LDVs, 2004–2008

Vehicles	2004	2008	Change
Cars			
Small	22.8%	22.7%	0.0%
Medium	17.1%	18.8%	1.7%
Large	8.2%	10.5%	2.3%
Subtotal cars	48.0%	52.0%	4.0%
Light Trucks			
Pickups	16.0%	12.9%	–3.1%
Vans	6.1%	5.4%	–0.6%
SUVs	30.0%	29.6%	–0.4%
Subtotal trucks	52.0%	48.0%	–4.0%
Total	100.0%	100.0%	0.0%

Source: Computed from data in Davis et al. (2009, Tables 4.7, 4.9).

The other major driver of fuel efficiency in U.S. passenger vehicles has been the CAFE standards that first went into effect in 1978, following passage of the Energy Policy and Conservation Act in 1975. The standards, applied separately to cars and most light trucks

[2] By contrast, Jacobsen (2010) finds quite large quantity shifts in the vehicle mix in the used-car market, including selective retirements of low-efficiency vehicles; these shifts, in turn, play a significant role in his estimates of results of higher fuel efficiency standards.

(specifically, those with gross weight under 8,500 pounds), rose gradually through 1984 and then were nearly flat for 20 years. During this time, the market share of light trucks rose dramatically, and many observers have attributed this, in part, to the more lax CAFE standard to which they were subjected, compared to that for cars (Godek 1997).

The standard for cars remained constant through 2009, but that for light trucks began to rise again starting in 2005 through regulatory rulings by the National Highway Traffic Safety Administration (NHTSA), still under the original 1975 legislation. Starting in 2008, the standard for light trucks was also modified (with a three-year optional phase-in period) to a *footprint-based* structure, whereby the required numerical value for average efficiency of a given manufacturer's vehicles was based on its proportions of various sizes, as measured (roughly) by the physical area covered under its wheels. NHTSA provided a carefully researched justification for this procedure, largely based on research suggesting that downsizing vehicles below some value (known only with uncertainty) would increase injuries and fatalities (NHTSA 2006). Furthermore, it had become apparent that vehicles with gross weights of 8,500–10,000 pounds, known as *medium duty passenger vehicles* and previously omitted from CAFE regulations, were largely used as passenger rather than commercial vehicles—for example, the famous Hummer model fell into this category—and so they were also brought into CAFE regulation starting in 2011 (NHTSA 2006, 16–17).[3]

The resulting standards for the years 1978 through 2009, excluding the optional footprint-based calculation for medium-duty trucks, are shown in Table 1.3.

Two subsequent changes in CAFE will bring significant new increases in fuel efficiency starting in 2011. The first is the Energy Independence and Security Act (EISA) of 2007, which mandates regulations intended to achieve average fuel efficiency of LDVs of 35 mpg in model year 2020 (Congressional Research Service 2007). The second is the National Energy Program announced by President Obama in May 2009, to be carried out jointly by the U.S. Environmental Protection Agency (EPA) and NHTSA. Under this program, regulations for GHG emissions under the Clean Air Act are coordinated with CAFE regulations to create a single set of national regulations affecting motor vehicle energy efficiency (U.S. EPA and NHTSA 2010)). The announced target is a reduction in GHGs equivalent (if it were achieved solely through reductions in CO_2) to an average new-vehicle fuel efficiency of 35.5 mpg by model year 2016.

[3] For a fuller definition see NHTSA (2006, note 31).

Table 1.3. CAFE Standards, 1978–2009 (mpg)

Model year	Cars	Light trucks		
		2-wheel drive	4-wheel drive	Combined
1978	18.0			
1979	19.0	17.2	15.8	
1980	20.0	16.0	14.0	
1981	22.0	16.7	15.0	
1982	24.0	18.0	16.0	17.5
1983	26.0	19.5	17.5	19.0
1984	27.0	20.3	18.5	20.0
1985	27.5	19.7	18.9	19.5
1986	26.0	20.5	19.5	20.0
1987	26.0	21.0	19.5	20.5
1988	26.0	21.0	19.5	20.5
1989	26.5	21.5	19.0	20.5
1990	27.5	20.5	19.0	20.0
1991	27.5	20.7	19.1	20.2
1992	27.5			20.2
1993	27.5			20.4
1994	27.5			20.5
1995	27.5			20.6
1996	27.5			20.7
1997	27.5			20.7
1998	27.5			20.7
1999	27.5			20.7
2000	27.5			20.7
2001	27.5			20.7
2002	27.5			20.7
2003	27.5			20.7
2004	27.5			20.7
2005	27.5			21.0
2006	27.5			21.6
2007	27.5			22.2
2008	27.5			22.5
2009	27.5			23.1

Source: NHTSA (2009, 3).

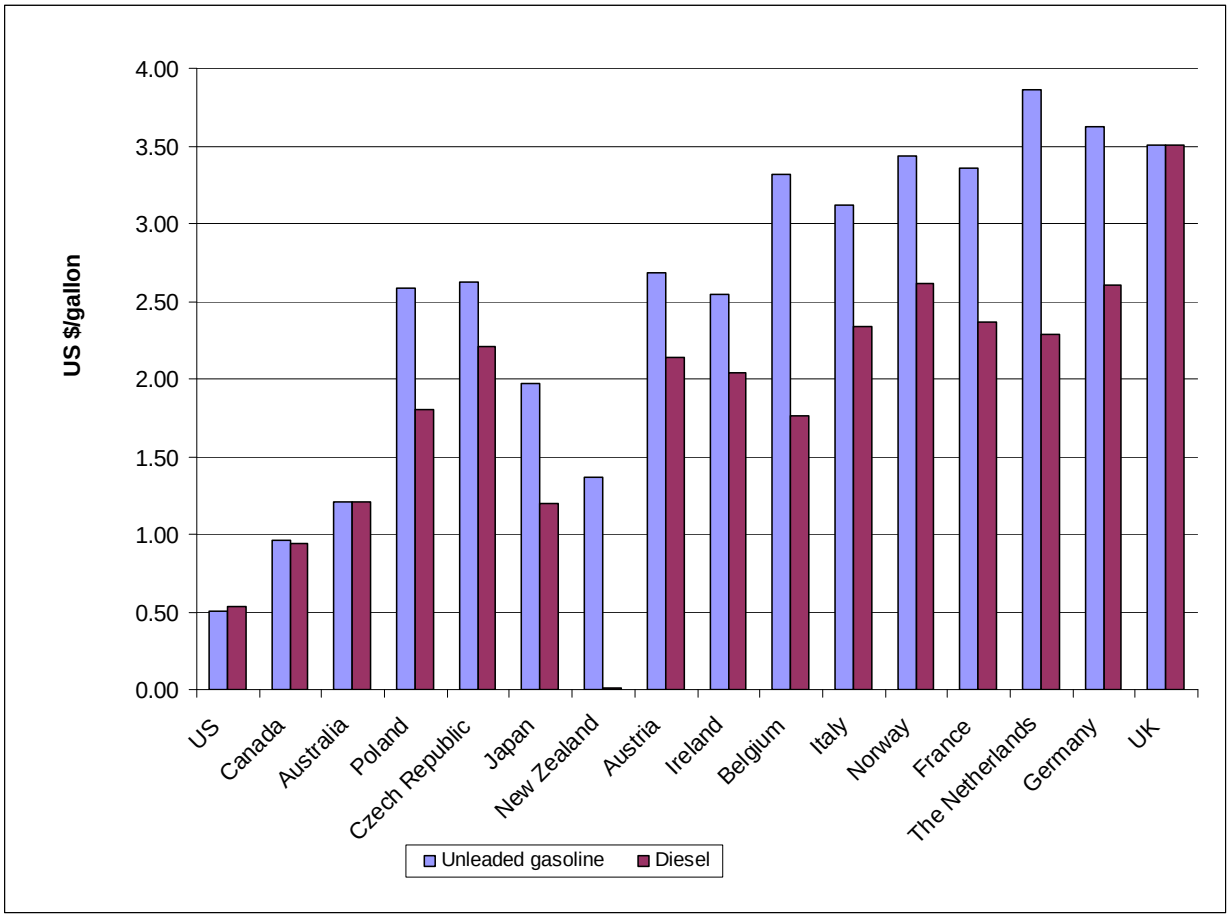
Thus, current legislation and administrative procedures in progress provide for sharp increases in fuel efficiency through 2016 but little or no tightening after that. For subsequent policy design, several key factors should be considered. First is how to treat vehicle weight and size mix. As described later, the research on safety is, in fact, ambiguous concerning the full effects of smaller vehicles on safety, and NHTSA's use of it ignores a strong external cost element—namely, that a given driver may benefit in terms of safety by choosing a larger and/or heavier vehicle but, in so doing, imposes higher accident costs on other vehicles with which it may collide. Second is the role of hybrid-electric technology in meeting future efficiency goals. Third is the role of electric vehicles, along with the associated environmental impacts of large-scale battery production.

Finally, it is worth remembering that the United States has extremely low fuel taxes by international standards. Figure 1.5 compares 2008 tax rates for 16 nations, converted to U.S. dollars using current exchange rates. (These are excise taxes only and do not include general sales tax, value-added tax, or consumption tax, which are quite high in many nations and usually apply to fuel, in contrast to most locations within the United States.) We see that the U.S. tax rate is about half that of the next-lowest nation, Canada, and about one-fourth to one-seventh those of Japan and most nations in Europe.[4]

Fuel prices and taxes have also influenced the market shares of diesel-powered passenger vehicles. Diesels have taken a substantial market share in Europe, where diesel taxes are often considerably lower than gasoline taxes. In the United States, diesel cars enjoyed a surge following the gasoline price rises of the 1970s, but lost nearly all their market share subsequently because of a combination of performance problems, high particulate pollution, and declining real fuel prices. Only in 2009 has the automotive press begun to report interest on the part of manufacturers in reintroducing new diesel passenger vehicles to the U.S. market.

[4] Canada is missing from International Energy Agency (2009); instead I have substituted the average over 52 weeks' data for 2008 as listed in Natural Resources Canada (2009).

Figure 1.5. International Comparison of Excise Tax Rates on Fuel: Second Quarter 2009



Source: International Energy Agency (2009, Part II: Energy End-Use Prices in OECD Countries, 74–301) and Natural Resources Canada (2009).

2. Light-Duty Vehicles in NEMS-RFF

NEMS-RFF models all forms of surface passenger motor transportation, but provides much more detail for motor vehicles (LDVs) than others, presumably because of the complexity of federal regulations affecting their energy use. The description here is mainly from EIA (2008, 2009d). An overview of NEMS is given in EIA (2009b).

LDVs are divided in NEMS-RFF into two types, cars and light trucks. Each of these is divided into six size classes, each intended to represent a homogeneous product in terms of measurable characteristics valued by consumers. The classes for cars are mini-compact, subcompact, compact, midsize, large, and two-seaters (sports cars); those for light trucks are small and large pickups, small and large vans, and small and large SUVs.

LDVs also encompass 16 fuel types, the most important of which are conventional gasoline, conventional diesel, E85 (a blend of 85 percent ethanol and 15 percent gasoline), gasoline electric hybrid, and diesel electric hybrid. (Many of these fuel types have zero market shares in most years.) LDVs are also considered to be manufactured by seven manufacturer groups: domestic car manufacturers, imported car manufacturers, three domestic light truck manufacturers, and two imported light truck manufacturers (EIA 2008, 8, 11). Each of these manufacturer groups has a distinctive pattern of market shares of fuels types and size classes that gives it a unique calculation for CAFE compliance.

Response to energy markets occurs in the model mainly at four different points. First, each manufacturer group chooses which of a large set of possible technologies are cost-effective for it to adopt in a given year for a given fuel type, taking into account consumers' valuation of attributes (EIA 2008, 10–45). These attributes include fuel savings over an assumed payback period of just three years and discounting at a rather high interest rate of 15 percent—probably overly conservative assumptions, as discussed later.[5] The technologies available are assumed to improve exogenously over time, and their costs are responsive to cumulative production volume to represent learning by doing (EIA 2008, 20). However, no explicit process of research and development is modeled, and the technologies are basically those known today. These limitations probably give the model a somewhat conservative bias in modeling very strong policies, especially in the later years of the simulations.

Manufacturers' decisions about technologies produce a set of market shares for those technologies, and thus a description of the range of vehicle characteristics that are offered within each fuel type and size class. These characteristics include vehicle price, which is simply assumed to equal production cost plus any fine (or minus any rebate) applied. In the case of CAFE standards, I have increased the model's default fine ($50 per vehicle per unit mpg deficit) to $200 for these runs, reflecting anticipated tougher enforcement and experimentation showing that otherwise more aggressive standards would have little effect other than forcing

[5] The NEMS default payback period and discount rate are stated in EIA (2009d, 59). Countering this conservatism, NEMS assumes that manufacturers, in making this calculation, project gasoline prices over the payback period based on trends observed over the past eight years (EIA 2008, 17), which at most times in the simulation would result in projected prices higher than the current price. However, evidence suggests that consumer expectations of future fuel prices are based either on just the current price, thereby implicitly assuming that prices are a random walk, or on an expectation that they will revert to past values, known as *mean reversion* (see Li et al. 2009, 121, and Allcott and Wozny 2010, Section 5.1.3, for discussion and references).

manufacturers to pay fines. This may be viewed as an approximation to a shadow cost of meeting the constraint for those firms that do so and find it just binding.[6]

Next, consumers as a group make several choices, modeled as aggregate demand functions (EIA 2008, 51–77). First, they choose the shares of cars and light trucks according to a logit-like formula that predicts the *change* in market share from the previous year as a function of variables including *changes* in income, fuel price, and new-vehicle fuel efficiency.[7] Second, they choose among the six size classes available for each of the cars and light trucks according to an aggregate model, again predicting *change* in market share from the previous year as a function of *changes* in several variables such as fuel price, vehicle price, and income (EIA 2008, 10, 41). Third, consumers choose market shares of various fuel types through a three-level aggregate nested logit model whose variables describe vehicle price, fuel cost, range, battery replacement cost (if applicable), acceleration, luggage space, and several variables representing the availability of fueling stations and the existence of multiple makes and models for a given fuel type and size class (EIA 2008, 51–61). Coefficients of these aggregate choice models have been calibrated to match known market shares in recent years; some of them also vary with time, representing EIA's judgments about the likely evolution of tastes and future marketing efforts.

Finally, the stock of LDVs on the road is determined by combining new-vehicle sales, as described above, with exogenous vehicle survival rates (EIA 2008, 78–84). Total VMT are modeled as a consumer choice determined by a lagged adjustment process following a log-linear regression with two variables: income and fuel cost per mile (EIA 2008, 84–85). This VMT is apportioned by vintage, which is a key part of determining total energy consumption. It is important to remember that most energy consumption by LDVs is by older vehicles, mainly because they constitute more than 90 percent of the stock; so past years' new-vehicle characteristics and the assumed survival rates are quite important in determining final energy consumption.

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[6] A more sophisticated approach is taken by Jacobsen (2010), who includes the CAFE standard as a constraint that can be violated at some fixed cost (representing public relations and political considerations) plus the cost of fines. He finds that the constraint is binding on the largest U.S. manufacturers and estimates a model of their response to current standards to compute the shadow cost of the constraint, which varies by manufacturer. For the U.S. "big three," the estimated shadow cost for passenger cars varies from $52 per vehicle for Ford (approximately equal to the actual fine) to $438 for GM; for light trucks, it varies from $157 per vehicle (Chrysler) to $264 (GM).

[7] This formula seems not well documented in the various NEMS model descriptions, but was provided to me by OnLocation, Inc./Energy Systems Consulting, the private firm that adapted and ran NEMS for this project.

An additional, simpler, model determines these same choices for fleet vehicles, such as those of government agencies or rental companies (EIA 2008, 61–62). Fleets generally account for 10–20 percent of vehicle sales so are neither crucially important nor negligible.

As noted earlier, medium duty passenger vehicles (roughly, those between 8,501 and 10,000 pounds gross vehicle weight) were only recently brought into CAFE regulations. They are treated in NEMS-RFF as primarily commercial, although many—for example, Hummers—are used primarily for passengers.[8] These vehicles play a relatively minor role in the responses to policies analyzed here. For this reason, I do not discuss them in detail, although the response of this and other sectors of the economy to fuel prices and fuel taxes are included in the NEMS-RFF results for the overall economic and policy impacts.

The results of modeling the transportation sector depend, of course, on overall assumptions about future population, income, and energy prices. These are all as used by EIA (2009a) in its *Annual Energy Outlook* 2009. Briefly, the U.S. population is projected to grow between 2010 and 2030 at 0.9 percent annually, real per capita disposable income at 1.9 percent annually, and real petroleum price at 4.7 percent annually.

2.1 Consumer Myopia

Researchers have long debated whether consumers fully account for future operating-cost savings in their purchases of durable goods, especially automobiles (Hassett and Metcalf 1993, Dreyfus and Viscusi 1995, Allcott and Wozny 2010. The predominant view is that they do not; explanations include credit constraints, imperfect information, information overload in decisionmaking, and consumers' uncertainty about future fuel prices and about the duration of their vehicle holdings.[9] Whatever the reason, the phenomenon is often called *consumer myopia*, that is, apparent short-sightedness compared to a fully rational and informed consumer.

NEMS-RFF assumes considerable myopia in its default parameters, used here. When choosing technologies, manufacturers calculate value to consumers assuming that they consider only three years of fuel savings, and even those savings are discounted at a 15 percent interest rate. This strong assumption may bias the results toward a smaller response to incentives, or greater noncompliance with regulations, than could actually be achieved.

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[8] In NEMS they are called *light commercial trucks* or *Class 2b vehicles* (EIA 2008, 76–77).

[9] For the last argument, see especially Greene et al. (2009).

Nevertheless, the evidence for some myopia is quite strong. Allcott and Wozny (2010), using an extremely detailed data set to examine whether the market prices for new and used automobiles respond one for one to changes in expected discounted lifetime fuel costs, find that only 61 percent of those fuel costs are accounted for, even though they go out of their way to make assumptions that would favor a finding of 100 percent. (This compares with my estimate in appendix A that the NEMS-RFF assumptions imply that only 26 percent are accounted for.) Among the advantages of the study by Allcott and Wozny is that the large size of their data set (based, among other things, on five million annual used-car auction sales) enables them to eliminate many of the potential confounding effects, such as quality differences among different makes and models of automobile, which plague most empirical work on this topic. In large part, their estimate relies on how changes in gasoline prices over the course of a vehicle's life affects its used-car value, thereby holding vehicle quality constant in the comparison.

To cover a large range of possibilities, I compute in Section 5 the costs of energy policies by alternately assuming that the apparent myopia in NEMS-RFF is or is not actually the result of unobserved amenity losses that occur as part of fuel efficiency improvements.

2.2 Discussion

NEMS-RFF contains some limitations for the purposes of understanding transportation policies. First, because the parameters affecting choice among vehicle types are taken to be constant, those choices cannot respond to long-term events that might be indirectly influenced by policy, such as marketing campaigns, changes in consumer preferences, or changes in the perceived reliability of new technologies. I account for this in a very limited way by adjusting the negative constant preferences for gasoline–electric hybrids so that they gradually become zero (neutral) over time. This slightly altered baseline policy, Core 1 Neutral, is used as the backdrop for the CAFE and feebate policies described below.

A second limitation is that manufacturers are modeled with a very simple pricing strategy; namely, they pass through all of their average costs to consumers. This does not permit us to track the kinds of price shifts that occur as manufacturers try to influence their sales mix to meet profit and regulatory objectives. In particular, it causes the model to predict that most of the response to fuel efficiency regulations or incentives occurs through adding technology to each vehicle type and size, rather than through changes in the mix of vehicle types and sizes. Some evidence suggests that this is, in fact, the real outcome of markets, but it is not definitive, and the model is unable to explore such possibilities. By contrast, such pricing strategies are included in the model developed by the Congressional Budget Office (Austin and Dinan 2003, 21). The

resulting price shifts influence the distribution of impacts, but the authors do not say whether they result in any significant shifts in vehicle mix.

A third limitation is that used-vehicle markets are not modeled as markets; rather, scrappage of old cars is exogenous and purchases of new cars are unrelated to used-car prices. This lack of an explicit used-vehicle market prevents me from modeling incentives to scrap old vehicles, such as the popular "cash for clunkers" program of 2009. More generally, it prevents me from tracking carefully the possible offsets to fuel efficiency policies that might occur if higher vehicle prices cause consumers to keep their vehicles for longer durations.

NEMS-RFF also has important advantages. The extensive delineation of potential technologies is far more complete and sophisticated than most models of manufacturer response to fuel prices and related policies. The way technologies change over time and with scale are helpful in providing realistic future scenarios, even though they are not fully endogenous, as would be desirable. Vehicle disaggregation is sufficient to permit an in-depth understanding of the patterns of fuel economy changes, levels of fines, and technology changes.

3. Policy Options

3.1 Fuel Tax

One very direct way to reduce fuel consumption is by taxing fuel. This sets an economic level on the environmental benefits of fuel consumption reductions (formally, a shadow price on fuel use) and leaves all decisions on how to achieve them to private parties. To the extent that markets are competitive, information is complete, and social costs are internalized, the private parties will achieve an efficient solution. Even if those conditions are not met, private parties may do a better job than government regulators of finding low-cost solutions.

In the case of motor vehicle fuels, some well-known discrepancies between social and private costs (*externalities*)—especially congestion, motor vehicle accidents, and local air pollution—have been shown to be quantitatively important. These discrepancies further increase the value of a fuel tax because they imply incidental benefits from fuel reduction beyond those motivating energy policy. I use this rationale for one of the two fuel tax scenarios formulated in the next section. Furthermore, as already noted, fuel tax rates in most of the rest of the world are much higher than those in the United States, so ample evidence suggests that such high rates can be collected and administered effectively.

In NEMS-RFF, fuel tax revenues simply go into the national budget and do not affect tax rates. In fact, the efficiency of a fuel tax can be considerably influenced by how revenues are used. If the revenues are used for ordinary expenditures yielding conventional benefits or rates of return, this results in a considerable *deadweight loss* to the economy from the higher prices that is not reflected in the cost estimates presented in Section 5. This is caused by the existence of high taxes that already reduce the return to labor income (primarily payroll taxes, income taxes, and state sales taxes) and therefore tend to reduce labor supply inefficiently. Any policy that raises prices without compensating in some way is likely to exacerbate this effect and cause a further contraction in labor supply, possibly causing significant economic costs. On the other hand, if revenues are used to reduce taxes with high deadweight loss, this can mitigate such economic costs, enhancing the overall efficiency of the policy. These issues are discussed in Bovenberg and de Mooij (1994) and Goulder et al. (1997).

3.2 Fuel Efficiency Standards

Fuel efficiency standards (herein called *CAFE standards*) aim at one component of energy use by passenger transportation, namely, the efficiency of the vehicles in which it is carried out. In the version currently being implemented by NHTSA, the goal is narrower still: it aims to foster technology improvements to vehicles, and it does so by mandating a standard that varies by the vehicle *footprint*—roughly the area of roadway covered by the four points of contact of its tires. NHTSA has provided a thorough and elaborately researched rationale for this approach, which is on schedule to begin in model year 2011. The rationale is basically one of safety: NHTSA interprets two decades of research as showing that larger vehicles are safer than smaller ones, at least up to some size whose value is known only approximately.

The safety issue is complex because a vehicle of larger size and weight is safer for its occupants but more dangerous for anyone colliding with it. This is accounted for in the research reviewed by NHTSA, but some behavioral reactions that may occur are not accounted for. Specifically, if individuals choose larger vehicles than they need as a defensive measure, wishing to improve their *relative* size or weight as protection against damage from collisions, then the average size and weight chosen may well be higher than socially desirable, even accounting for its safety advantage for its own occupants. Accounting for these behavioral reactions, White (2004), Brozovíc and Ando (2009), and Li (2010) find considerable social safety benefits in

shifting a driver from a large to a small passenger vehicle, or from a light truck to a car—despite the fact that some of the greater damage to occupants of small vehicles is borne by third parties.[10]

The point is perhaps most intuitively depicted by Wenzel and Ross (2005), who calculate the fatality experience of 92 popular models of LDVs covering model years 1997–2001. Using data from the Fatality Analysis Reporting System, they distinguish between fatalities to the vehicle's own driver and fatalities to drivers of other vehicles via collisions. (Passengers are not considered to avoid introducing extraneous variation due to different vehicle occupancies of different vehicle models.) The results are summarized here in Figure 3.2.1, which closely approximates Wenzel and Ross's Figure 1. The figure shows the results of calculating the annual number of fatalities (per million registered vehicles per year) associated with each vehicle type, obtained by aggregating over the models within that vehicle type and adjusting for different annual mileages.[11] The lower portion of each bar is the risk to the vehicle's own driver. It is clear from the figure that, except for a few categories, total fatalities tend to rise as one goes from cars to SUVs to compact trucks to large trucks. (The exceptions are the American and Korean subcompacts, sports cars, unibody SUVs, and minivans.) This overall tendency is due mainly to the risk to other drivers—the externality—which varies strongly by vehicle type. The own-driver risk has a much less clear relationship: it tends to be especially large in pickups but also in American- and Korean-made subcompacts and in sports cars.

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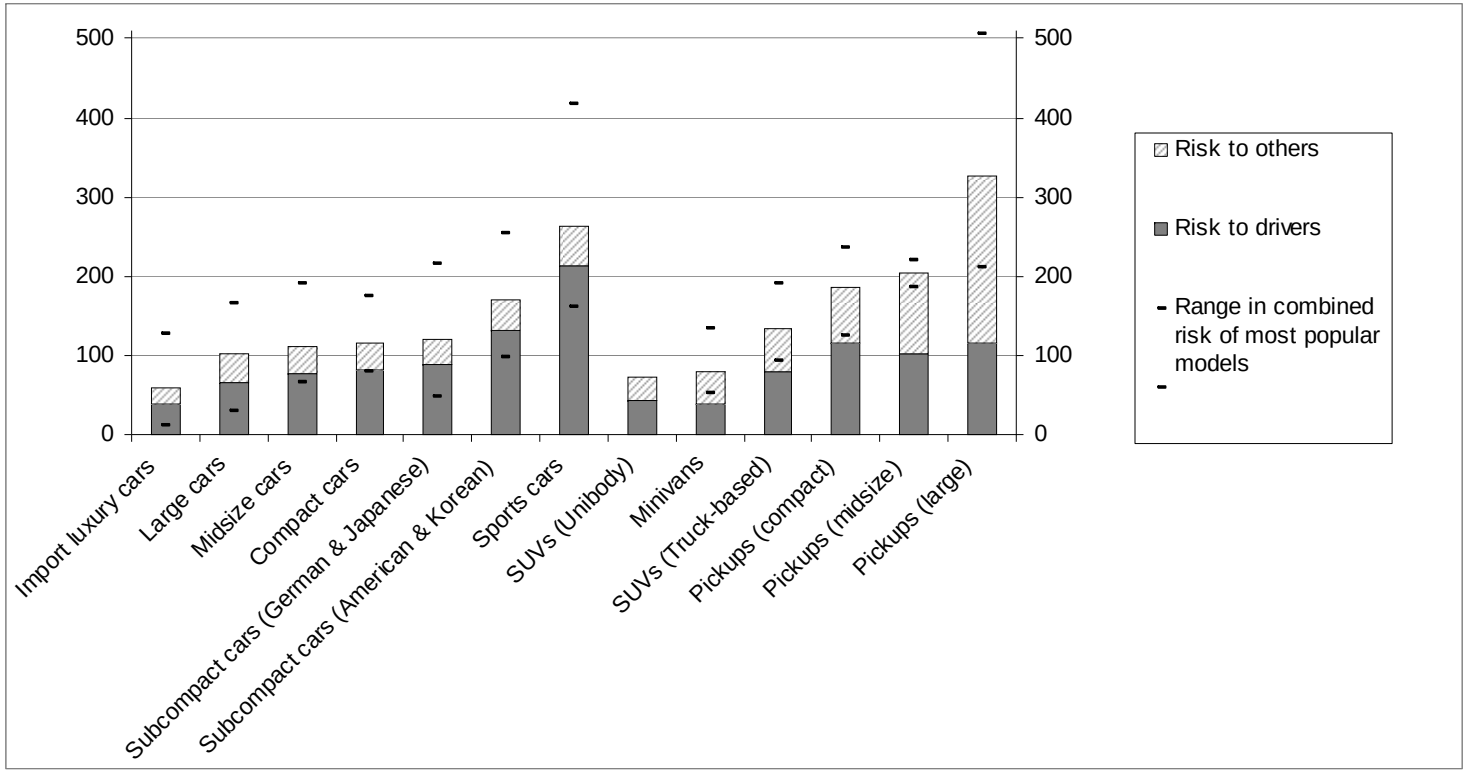
[10] Such third-party costs include medical costs borne by government agencies and insurance companies and the loss of income tax or labor tax revenues resulting from lost work time. These results are driven mainly by fatalities, which account for about half of all accident damage (Small and Verhoef 2007, section 3.4.6); it is unknown whether property damage would have similar characteristics—if it does, this would further increase the external costs of large vehicles.

[11] The raw data are from Wenzel and Ross (2005, Table 2-5). Here, subcompact cars are divided by American and Korean versus Japanese and German, based on Wenzel and Ross's observation that these two groupings have quite different accident experience conditional on vehicle characteristics (their Section 4.2, especially Figures 4–5). In addition, SUVs are here divided into a *body-on-frame* (truck-based) design versus a *unibody* (car-based or crossover) design, based on the discussion in their Section 4.3. (The two unibody models are Honda CR-V and Toyota RAV4.) Finally, to simplify the figure, full-size pickup trucks are shown in just two, instead of three, categories: midsize (half ton) and large (three-quarter and one ton), based on the model numbers in their Table 4, along with the identifiers in their Figure 9. (Specifically, the first three "full-size pickups" in their Table 4 are here classified as midsize, the other six as large). The adjustment for mileage is determined by miles per vehicle relative to subcompact cars, using the last column of their Table 5.

Figure 3.2.1. Fatality Rates for Vehicle Classes



Source: Calculated from data in Wenzel and Ross (2005, Tables 2–5); format adapted from their Figure 1.

Some of the differences depicted by Wenzel and Ross are due to the characteristics of the owners of various types of vehicles, rather than the vehicles themselves. For example, American and Korean subcompacts are owned disproportionately by young males. But after an extensive consideration of this factor, Wenzel and Ross conclude that substantial differences remain. Furthermore, there is very large variation among specific models of the same vehicle class (not shown in Figure 3.2.1 except for subcompact cars). Many of these differences can be traced to specific technological differences, suggesting that safety technology and driver behavior are the main determinants of vehicle safety, with fuel efficiency secondary.

To summarize, the effect of smaller vehicles on public safety remains uncertain and controversial, as noted by Greene (2009). In my judgement, the predominant evidence is that widespread reductions in size and weight are beneficial to safety. But even if they are not, the safety *externality* is unambiguously in a direction that would favor policies to explicitly encourage downsizing of vehicles, especially from midsize and full-size pickups to passenger cars. This is because drivers already consider much of the safety advantage, if any, of their vehicle's weight to its own occupants, whereas they presumably do not consider (at least not very much) the strong safety disadvantage of their vehicle's weight to occupants of other vehicles with which it may collide. Therefore, at the very least, there seems no good reason to constrain energy policy by insisting that it not result in downsizing. On the contrary, any reduction of vehicle sizes and weights that may result from energy policy can be counted as a side benefit of that policy.

Because of the limitations on consumer behavior noted in Section 2, NEMS-RFF is not the ideal model for investigating this type of complex behavior. For this reason, the scenarios specified here use an approximation to NHTSA's footprint-based approach, and do not explore the possibilities that manufacturers could be induced to intentionally alter their vehicle mix to help meet CAFE standards. (The vehicle mix does change in NEMS-RFF simulations, but only as a result of consumer choice, not of manufacturer pricing strategies.) Therefore, the standards modeled here may appear to be less effective and more costly than would be possible to achieve in practice. Probably the discrepancy is not very large because shifts in vehicle mix seem to play only a small role in several other simulation analyses of the CAFE and feebate policies that allow for them (Kleit 2004; Greene et al. 2005a,b).

One advantage of CAFE standards over fuel taxes is that the standards provide a quantitative target whose effects on energy consumption can be reasonably well predicted. A political advantage is that they do so without any explicit tax on a consumer good—although of

course they do raise the price of vehicles and so are not really free to consumers. Countering these advantages are two main disadvantages. First, by specifying a specific measure of fuel efficiency (a test cycle, with results averaged over vehicles in a specified manner), they give no incentive to adopt other ways of reducing fuel consumption, such as reducing speed, driving less aggressively, or reducing VMT. Second, they actually provide an incentive to *increase* VMT because, by reducing the fuel cost of traveling a given distance, they lower the effective price of driving. This well-known response has historically been called the *rebound effect* because it represents a take-back of some portion of the energy gains that would occur in the absence of any changes in behavior. It has historically accounted for nearly half of the total price elasticity of LDV fuel consumption (Parry and Small 2005).

The rebound effect has been the subject of considerable research, most of which has found a long-run rebound effect of 10 to 30 percent: that is, a 1 percent improvement in fuel efficiency will, after enough time has passed for all behavioral adjustments to take place, result in a 0.1 to 0.3 percent increase in VMT. (In more technical terms, the long-run elasticity of VMT with respect to the fuel cost of driving is between –0.1 and –0.3.) One recent study, however, suggests that the rebound effect falls with real income and that, in the United States, it has fallen considerably below the values just mentioned (Small and Van Dender 2007). The authors suggest that the reasons are a decline in money cost and an increase in time cost (due to rising incomes) as important factors in decisionmaking about travel. The same argument suggests that the rebound effect should rise with fuel price; indeed, Small and Van Dender (2007) find support for this argument, but the effect is considerably smaller empirically. In its rulemaking on CAFE standards, NHTSA (2008, 24409) highlights this study as crucial to its modeling decisions about the rebound effect but does not assert that corroborating evidence is sufficient to use the value found by Small and Van Dender for more recent years. Rather, NHTSA opts to use a long-term value of 15 percent, within but toward the lower end of the range of most estimates. NEMS-RFF portrays VMT as being sensitive to fuel cost in a manner that yields a similar rebound effect, around 17 percent.[12]

[12] The rebound effect is numerically identical to the elasticity of VMT with respect to fuel price (holding size and the mix of vehicle stock constant). Thus, the same behavioral response that tends to undermine CAFE standards also is an important part of the desired response to a fuel tax. If the values used in NEMS overstate the rebound effect—as seems likely, though not certain—then NEMS will be unduly pessimistic about a CAFE standard and unduly optimistic about a fuel tax in terms of effectiveness.

One might also consider whether CAFE standards should apply only to particular types of vehicles, such as those fueled by petroleum. This would depend, in part, on whether the main goal is to reduce GHGs or oil dependence; furthermore, one might distinguish vehicles that use biofuels, but this is hard to accomplish given the flexibility of fuels that some vehicles can use. In practice, these distinctions have not been made by CAFE policies, so for purposes of comparability and modeling consistency, I consider policies that treat all vehicles equally. Of course, such a policy might be combined with others that target biofuels or unconventional engines—as in fact is the case in the EISA of 2007.

Another issue is the trading of credits across manufacturers—that is, a system allowing one company that exceeds its CAFE standard to sell credits to another that falls short. EISA provides for some such trading and, theoretically, it has efficiency advantages. These advantages probably are not very great because the footprint-based standards already allow for differences among manufacturers, most of which have a diverse portfolio of models with varying performance, so the averaging process used in calculating compliance can work. A nice feature of NEMS-RFF is that, because the manufacturer is modeled as a rather broad category (two for cars, five for trucks) rather than as a real-life firm, some credit trading among firms is implicitly allowed within the model. This should further reduce any inaccuracy resulting from not explicitly representing credit trading across firms.

3.3 Feebates

It is possible to combine some of the features of fuel efficiency regulations with those of tax incentives. One way to do this is through a feebate policy—a combination of fees and rebates related to fuel efficiency. Specifically, the policy imposes on the manufacturer a fee for each vehicle that falls short of some specified level of fuel efficiency (the *pivot point*) and a rebate on each vehicle that exceeds the level. This can be viewed as an extension of the "gas guzzler tax" currently in place, which incorporates the fee but not the rebate, and which currently applies only to cars, not trucks. (The gas guzzler tax is included in NEMS-RFF.) Often, the proposed pivot point is set so that the program is overall revenue-neutral to the government.

This policy has one political advantage over fuel taxes: it does not add directly to the average price level of anything purchased by consumers, assuming that it is revenue-neutral, although it will in fact add to vehicle price because manufacturers will be motivated to adopt more expensive technologies to save fuel. It also has several advantages over CAFE standards. First, it provides incentives to improve every vehicle, whether or not CAFE standards are met.

Second, it allows manufacturers more leeway to choose where and when to make efficiency improvements because there is no legal requirement to meet a particular standard.[13] However, it is more difficult with a feebate policy to set parameters so as to achieve any particular target of average fuel efficiency.

The pivot point can be set differently for different classes of vehicles, just as CAFE standards can be. Johnson (2006) stresses the political and administrative advantage of this approach in producing much smaller magnitudes of fines and rebates than if a single pivot point is used for all vehicles. However, differentiation of pivot points reduces or eliminates one type of response that would otherwise occur, namely, shifts in vehicle mix across those different classes. Policy simulations by Greene et al. (2005a,b) suggest that these vehicle mix shifts are not very important, accounting for only about 4 percent of the change in average fuel efficiency when the simulation uses a single pivot point.[14] Greene et al. (2005a, 765) acknowledge that a system of multiple pivot points "probably has greater potential for 'gaming' at the boundaries of classes" by slightly altering the characteristics of vehicles near those boundaries, a phenomenon that neither they nor I can analyze with the available models.

To see whether NEMS-RFF shows similarly small size class shifts, I carried out two types of runs, one with a single pivot point for all LDVs (which should encourage such shifts) and the other with a separate pivot point for each of NEMS-RFF's 12 vehicle size classes (which should not). The results are very similar, so I conclude that whatever the actual merits of a single pivot point, for the purposes of modeling, it makes little difference. I report here only the results using multiple pivot points.

Greene et al. (2005a,b) examine feebate policies using base assumptions in which consumers consider the fuel savings for just three years with no discounting. Thus, consumers are slightly less myopic than the current NEMS-RFF default assumptions. The authors analyze,

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[13] One might think that the schedule of CAFE fines would play the same role as a feebate for manufacturers falling short of the CAFE standard. But in fact only a few specialty manufacturers regularly pay fines; others apparently believe that it is more important to remain in legal compliance than to trade off marginal efficiency improvements against changes in fines. See Jacobsen (2010, Section 4b[ii]), for an illuminating analysis.

[14] Cuenot (2009, 3840), on the other hand, claims that a feebate program introduced in France in 2008, known as "Bonus/Malus," led quickly to large shifts in market shares of vehicles of various sizes. No numerical evidence is provided, except the claim that the average CO_2 emissions from new vehicles fell as a result by 9 grams CO_2 per kilometer, which appears to be roughly 6 percent based on the typical 2005 emissions rates given in Cuenot's Table 4. The one substantial response in vehicle mix that Greene et al. (2005a,b) find is between trucks and cars.

among other policies, a feebate whose fee and rebate schedule is set to $1,000 per 0.01 gallon per mile (gpm) fuel intensity, a level that implies a difference of $108 between two vehicles getting 30 and 31 mpg fuel efficiency.[15] This policy achieves quite substantial gains in fuel efficiency: about 25 percent for cars and 41 percent for trucks (Greene et al. 2005b, Table 4, policy 6). The response is more than 50 percent greater if consumers are assumed instead to consider savings over the median lifetime of a vehicle (14 years), using a 6 percent discount rate (their policy 12).

Greene et al. (2005a,b) also compare the feebate policy with two policies that implement just one part of the feebate: a fee-only policy (gas-guzzler tax), and a rebate-only policy. As expected, the partial policies have considerably smaller effects. A gas-guzzler tax at the same rate achieves about half the efficiency improvements, whereas a rebate of $500 per 0.01 gpm achieves efficiency gains of only 1.6 percent for cars and 8 percent for trucks (their policies 13, 17). Interestingly, the gas-guzzler tax does not become more effective when its rate is doubled; even at the lower rate of $1,000 per 0.01 gpm, nearly every vehicle is improved to the point where no tax must be paid, and the policy provides no incentive to improve them beyond that rate.[16]

The rationale for making the tax proportional to fuel intensity (gpm) rather than efficiency (mpg) is the same as the rationale used by Congress in calculating fleet-average fuel efficiency using a harmonic average. It provides a constant incentive rate for each gallon of fuel consumed, assuming that all vehicles are driven the same amount per year. A fee or rebate proportional to fuel efficiency (mpg), by contrast, would provide the same incentive to increase fuel efficiency from 20 to 21 mpg as from 50 to 51 mpg, even though the annual fuel saving for the former is six times greater (36 vs. 6 gallons per year for a car driven 15,000 miles). It is very important for any policy aimed at fuel consumption to target the most fuel-inefficient vehicles simply because they are the ones using the most fuel, presuming that they are in regular use.

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[15] Thus it would be become worthwhile for a manufacturer to adopt technology raising fuel efficiency from 30 to 31 mpg if the cost were less than $1,000 x (0.0333 – 0.0323)/0.01 = $108 per vehicle. In our Core1 case in 2010, the average fuel efficiencies of compact and midsize cars are 33.8 and 30.0 mpg, respectively, for a difference in fuel intensity of (0.0333 – 0.0296) = 0.0037 gpm. Thus, a feebate at $1,000 per 0.01 gpm applied to a group including both of these vehicle size classes would add a price wedge of $370 between them.

[16] By way of comparison, the U.S. gas guzzler tax has a pivot point set at the inverse of 22.5 mpg, with a tax rate of roughly $1,500/0.01 gpm. See U.S. EPA (2006) for the precise schedule.

4. Policy Specification and Results

As already noted, I chose three relatively well-known policies for analysis: an increased fuel tax, stricter fuel efficiency standards (CAFE), and a tax and rebate schedule on new vehicles related to their energy efficiency (feebate). In the case of the fuel tax and feebate, I specify two scenarios, one stronger than the other; but because I want to study nonmarginal policies that have significant effects, even the weaker of the two policies is quite strong and indeed would be difficult to achieve politically. In the case of the fuel efficiency standard, the baseline scenario already includes a strong policy, so only one further policy is modeled. That policy and the High Feebate policy (which is the weaker of the two modeled here) are chosen to be roughly comparable in their effects. I also consider a combination of a stringent CAFE standard and a fuel tax.

4.1 Fuel Tax

As noted in Section 3.1, one argument for higher fuel taxes is that driving imposes a number of external costs on others, even aside from those that are the object of energy policies. These externalities are mostly proportional to vehicle travel rather than fuel consumption; for example, local air pollution, which is regulated in such a way that emissions are relatively constant per mile across a wide range of vehicles, is one such externality. For this reason, the most direct way to address most such externalities would be to tax vehicle miles; taxing fuel is less efficient precisely because it induces ancillary responses, such as more fuel-efficient cars, that tend to blunt the desired effect on the externality itself.

Nevertheless, taxing fuel can still help control these other externalities. Parry and Small (2005) calculate the second-best fuel tax rate for addressing the main road-use externalities in the United States and the United Kingdom. This tax rate is about 60 percent smaller than the actual discrepancy between social and private marginal costs because it is only an indirect approach to addressing them. Even so, they estimate that the optimal tax in the United States for this purpose would be $1.01 per gallon in 2000 prices.17 This is about 2.5 times the actual U.S. tax rate

[17] This figure includes about $0.06 for an estimate of the costs of global climate change, which is smaller than the shadow price that would result from currently contemplated policies. It also includes a *Ramsey component* reflecting the revenue-raising advantages of the gasoline tax over other excise taxes on goods that have greater price elasticities. I ignore the overlap between these parts of the externality charge and the goals of energy policy in the discussion of this subsection. West and Williams (2007) find that the revenue-raising function of the gasoline tax alone justifies the level currently found in the United States, even in the absence of any external costs.

(combined state and federal) at that time, and three to four times the values projected by EIA between 2010 and 2030, which assume no nominal price adjustments at the federal level and state adjustments to just keep up with inflation.18

I therefore specify a High Fuel Tax scenario in which this externality charge is simply added to the tax rates already projected in NEMS-RFF. Although economic logic would suggest replacing the existing tax with the one calculated to be most efficient, there is a public-relations logic for adding them, given that existing taxes are traditionally viewed as a mechanism for paying for roads, whereas the new charges are specifically to account for externalities. I update the added tax over time, accounting for rising real values of some of the externality costs.19 The result is a tax increment over the baseline which, in constant 2007 dollars, begins at $1.27 per gallon in 2010 and grows at an annual rate of 1.54 percent to reach $1.73 per gallon in 2030. (The overall tax rate, including average state taxes, is $1.65 and $2.04 per gallon in those same two years, respectively.)

I also specify a Very High Fuel Tax scenario, which is simpler but more draconian; namely, I add to the baseline tax an increment of $3.00 per gallon (nominal) in 2010, adjusted for inflation so as to remain constant in real terms. (The value is $2.90 per gallon in constant 2007 dollars.) The purpose here is to describe a very aggressive but easily understandable energy policy, one that can achieve significant savings yet is not out of line with the rest of the world—it brings U.S. fuel tax rates to only a little higher than the rates observed today in Japan and most European nations, as described in Section 1.

In both cases, the tax rates on diesel fuel, ethanol, and ethanol blends are set to equal that on gasoline when adjusted for energy density: that is, the tax increment on each of these fuels is the same rate per British thermal unit.

The results of these scenarios are shown in Tables 4.1.1 and 4.1.2. Consider first the more realistic case of the High Fuel Tax. Its greatest impact is on vehicle travel, reducing VMT by 5

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[18] The combined federal and weighted-average state tax on gasoline assumed in NEMS is $0.381 per gallon in 2010, $0.346 in 2020, and $0.317 in 2030, all in real 2007 dollars.

[19] Specifically, half of the externality charge is assumed to remain constant in real terms, and the other half to rise at the rate of real wage rates (as projected by EIA (2009a) in its *Annual Energy Outlook* 2009.). The reason for the latter assumption is that a large part of the externalities represents time costs and an aversion to the risk of injury or death. Both of these costs are known empirically to rise as a function of wage rates, although somewhat less than proportionally: see Small and Verhoef (2007, 52–54, 100–103).

percent in 2020 and 6 percent in 2030. This is not enough to eliminate the increase in VMT over time, which is 7 percent over the decade 2010–2020 and a frightening 30 percent over the two decades 2010–2030. (In these figures, the 2010 value is the starting point without the fuel tax.) Without the fuel tax, however, VMT is projected to grow even faster: 13 percent over 10 years, and 39 percent over 20 years (not shown in the table). Thus, the High Fuel Tax cuts the 10-year growth in VMT by nearly half, and the 20-year growth in VMT by nearly one-fourth. By contrast, the CAFE requirements in our Core 1 plan are actually exacerbating the increase in VMT, although by only 1.4 percentage points over the full 20-year period.

Table 4.1.1. Results: High Fuel Tax

	Value in Core 1	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	5.00	5.43	1.40	1.65	39.0%	43.5%
Tax component	0.38	1.84	2.04	1.49	1.73	432.2%	544.1%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	66%	68%	6%	4%	9.6%	6.8%
Hybrids - market share	2%	17%	27%	2%	4%	15.6%	15.3%
Diesels - market share	2%	7%	11%	1%	1%	20.3%	5.9%
Fuel efficiency (mpg):							
Cars	30.4	41.3	43.8	0.2	0.8	0.5%	1.8%
Trucks	23.6	32.2	35.0	0.7	1.2	2.2%	3.7%
All LDVs	26.5	37.7	40.5	1.0	1.4	2.8%	3.6%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	25.5	30.6	0.4	0.9	1.5%	2.9%
VMT (trillions)	2.79	2.99	3.64	-0.15	-0.24	-4.9%	-6.1%
Energy use (quad Btus)	16.41	14.50	14.84	-1.01	-1.40	-6.5%	-8.6%
Economy-wide outcomes							
GHGs (mill. metric tons CO_2 equiv):							
Energy-related CO_2	5,746	5,751	6,058	-130	-135	-2.2%	-2.2%
All GHGs	7,058	7,251	7,811	-132	-135	-1.8%	-1.7%
Liquid fuels (million barrels/day):							
Net petroleum imports	10.1	8.6	7.5	-0.7	-0.6	-7.4%	-7.7%
Total petroleum consumption	18.5	17.1	17.2	-0.8	-0.8	-4.3%	-4.4%
Total liquid fuel consumption	19.6	18.9	19.7	-0.8	-1.0	-4.2%	-4.7%

The High Fuel Tax scenario also increases fuel efficiency compared to Core 1, especially after 2016 when the CAFE requirements in Core 1 stop rising.[20] This is because manufacturers consider fuel prices when deciding what fuel-saving technologies consumers are willing to pay for. In 2030, the fuel efficiency of new cars would be 43.0 mpg without the fuel tax and 43.8 mpg with it, a very modest 1.8 percent difference. For new light trucks in 2030, the fuel efficiency is affected more: 33.8 mpg without the tax and 35.0 with it, a 3.6 percent difference. Fuel efficiency for all new LDVs combined gets an extra boost because the tax induces a small shift away from light trucks and toward cars. Overall, however, these responses in new-car fuel efficiency are small, and result in less fuel savings that does the reduction in VMT.

This policy reduces overall energy use by LDVs by 6.5 percent in 2020 and 8.6 percent in 2030 relative to that in the Core 1 scenario. Net petroleum imports are reduced by 7.4 and 7.7 percent in 2020 and 2030, respectively. Overall energy-related CO_2 emissions, which include those from electricity generation, are reduced by just 2.2 percent in 2030.

By way of comparison, Morrow et al. (2010) use NEMS to model a fuel tax of $0.50/gallon in 2010, rising in real terms by 10 percent per year to a value of approximately $3.36/gallon—thus starting at less than half but ending at nearly double the rate analyzed in our "high fuel tax" scenario. Their tax scenario for year 2022 is about the same rate as ours for year 2020 ($1.52/gal above baseline for gasoline). Comparing results for those years, their fuel tax raises new-vehicle fuel efficiency by 2.6 percent and reduces VMT by 4.8 percent, very similar to our estimates in Table 4.1.1.[21]

The fuel tax policy, unlike others considered in this paper, affects other sectors of transportation besides LDVs; namely, surface freight and air transportation, both of which use gasoline, diesel, or closely related fuels. However, it appears that these sectors are assumed—

[20] Fuel efficiency, stated in mpg, is a consumption-weighted average over the various fuels used, mainly gasoline, diesel, and E85. The efficiency of vehicles using each fuel is first converted from physical gallons to gallon-equivalents using the energy density of the fuel. These conversion factors vary slightly by year, reflecting measured and projected changes in fuel sources. The conversion factors are constant over the period 2011–2030: one physical gallon of diesel fuel equals 1.133 gallon-equivalents because diesel has a higher energy density than gasoline; whereas one physical gallon of E85 equals 0.784 gallon-equivalents. In our results, prices are reported per physical gallon, but efficiencies are per gallon-equivalent.

[21] Their results are depicted graphically in their Figures 9 and 13; I thank the authors for sending me the numerical results reported here.

perhaps unrealistically—to be very unresponsive to energy prices.[22] Therefore, we would get essentially the same results if we could isolate just the policy impacts that are due to the LDV sector alone.

The Very High Fuel Tax scenario is qualitatively similar, but has substantially larger effects (Table 4.1.2). The average fuel efficiency of new vehicles in 2030 is now 42.2 mpg, nearly 8 percent higher than the baseline; the average efficiency of the fleet, always lagging behind that of new vehicles, is still 6.0 percent higher than the baseline. The amount of travel (VMT) is 10 percent lower, and light-duty energy use is nearly 15 percent lower. These savings result in a nearly 13 percent reduction in petroleum imports, compared to the baseline, and an absolute fall in annual petroleum consumption over the 20-year period of 1.8 million barrels per day. Roughly two-thirds of the reduction comes from reduced VMT, the rest from increased fuel efficiency.

[22] NEMS predicts that, in 2030, this fuel tax would lead to 0.9 percent higher efficiency for the fleet of heavy-duty trucks, and 0.2 percent higher efficiency for aircraft.

Table 4.1.2. Results: Very High Fuel Tax

	Value in Core 1	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	6.40	6.88	2.80	3.09	78%	82%
Tax component	0.38	3.42	3.49	3.07	3.17	889%	999%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	70%	71%	9%	7%	15.3%	10.9%
Hybrids - market share	2%	19%	30%	4%	7%	31.2%	28.3%
Diesels - market share	2%	9%	12%	3%	2%	42.6%	23.6%
Fuel efficiency (mpg):							
Cars	30.4	41.9	45.1	0.7	2.1	1.8%	4.9%
Trucks	23.6	32.9	36.5	1.4	2.7	4.4%	8.1%
All LDVs	26.5	38.7	42.2	2.0	3.1	5.4%	7.8%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	25.9	31.5	0.8	1.8	3.0%	6.0%
VMT (trillions)	2.79	2.88	3.49	-0.27	-0.39	-8.6%	-10.0%
Energy use (quad Btus)	16.41	13.73	13.83	-1.78	-2.41	-11.5%	-14.8%
Economy-wide outcomes							
GHGs (mill. metric tons CO_2 equiv):							
Energy-related CO_2	5,746	5,636	5,979	-245	-213	-4.2%	-3.4%
All GHGs	7,058	7,134	7,734	-249	-212	-3.4%	-2.7%
Liquid fuels (million barrels/day):							
Net petroleum imports	10.1	8.1	7.1	-1.2	-1.0	-13.2%	-12.7%
Total petroleum consumption	18.5	16.4	16.7	-1.4	-1.3	-7.8%	-7.0%
Total liquid fuel consumption	19.6	18.2	18.9	-1.5	-1.7	-7.5%	-8.3%

The model results for 2030 can be used to roughly assess the responsiveness to fuel price built into NEMS-RFF, relative to other literature, because with the higher fuel tax constant in real terms for 20 years, we can expect 2030 to represent equilibrium long-term responses. In 2030, fuel price is 82 percent higher than in the baseline scenario, resulting in VMT 10 percent lower and fleet fuel efficiency 6 percent higher. The implied long-run elasticities of VMT and of fuel efficiency with respect to fuel price are thus 0.16 and 0.10 in magnitude, respectively.[23] By comparison, a literature review by Parry and Small (2005, 1283) found central values for these

[23] That is, the elasticities are –ln(1.10)/ln(1.82) = –0.16 and –ln(1.06)/ln(1.82) = –0.10. The total price elasticity of fuel use by light-duty vehicles is the sum of the two: -0.26. The first elasticity can be restated by noting that fuel cost per mile changed by a fraction (1.82/1.06) = 1.717; therefore, the VMT elasticity with respect to fuel cost per mile is –ln(1.10)/ln(1.717) = –0.18. This elasticity, restated as a positive percentage (18%), is also called the rebound effect.

elasticities of 0.22 and 0.33, respectively.[24] Thus, the responsiveness of VMT in NEMS-RFF is slightly higher than what was found in that earlier literature, whereas the responsiveness of fuel efficiency in NEMS-RFF is considerably lower. Probably the main reason is that the CAFE standards, already included in the baseline scenario, are very strict, so adding the incentive of a fuel tax makes less additional difference. It is also possible that NEMS-RFF does not portray all the ways in which people change fuel efficiency. For example, NEMS-RFF portrays rather limited effects of fuel price on consumers' choices among size groups, as noted earlier.

Much of the improved fuel efficiency in this scenario comes about through a significantly higher market share of hybrids: 30 percent in 2030, compared to 23 percent in the Core 1 scenario.[25] This is largely because in NEMS-RFF, consumers respond to fuel prices in their choice of vehicle type. As a result, in each of our fuel tax scenarios, CAFE is no longer binding overall as of 2016 (although it might be for some vehicle configurations): that is, the average fuel efficiency in 2016 exceeds the assumed legislative CAFE target of 34.9 mpg.

Thus the fuel tax by itself, even when it is raised to 10 times its current values (combined federal and state), has only a moderate impact on target variables for energy policy. The main reason is that both manufacturers and consumers are relatively price-insensitive, suggesting that they have strong preferences for energy-consuming services. These same characteristics also suggest that targeting the motor vehicle sector for GHG reductions may exact significant costs from manufacturers and consumers unless consumers are subject to significant market failures in their energy choices—a question discussed earlier and quantified in Section 5. Nevertheless, the

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[24] In work subsequent to Parry and Small's review, Bento et al. (2009) estimate the first elasticity (VMT) at 0.34, and the second as being very low (no value calculated); but as they acknowledge, their estimates of consumer shifts among vehicles may be small because of limitations from using a single cross-sectional data set. By contrast, the value of 0.33 for the elasticity of vehicle fuel efficiency from the Parry–Small review is roughly consistent with two other recent studies. Li et al. (2009, 132) estimate it at 0.20 through demand-side responses using panel data, which generate much more price variation than a single cross-section; they caution that it would be further increased by supply-side responses by manufacturers. In a more recent study of the second elasticity, Clerides and Zachariadis (2008) use an international cross-sectional time series and find a long-run elasticity of vehicle efficiency equal to 0.25 for a sample including all 18 nations and 0.29 for just a single time series of the United States. (I have calculated these two numbers from their Table 4, p. 2667, by dividing the short-run elasticities of 0.10 and 0.08, respectively, by $1-\lambda$, where λ is the coefficient of the lagged dependent variable.)

[25] This shift occurs even though, unlike the CAFE and Feebate scenarios discussed next, the alternative-specific parameter in the function depicting consumer demand for hybrids is here kept at its default value in NEMS, which implies some bias against hybrids over equally well-performing conventional vehicles. (See Section 4.2 for explanation.)

gasoline tax is a very efficient way to target this sector because its side effects are mostly beneficial rather than exacerbating.

The revenue raising potential of a fuel tax, not shown in the tables, is nothing short of phenomenal. Tax increases of the magnitudes considered here could easily eliminate the much-discussed inadequacies of the Highway Trust Fund in funding highway infrastructure needs in the US, with money left over for other purposes such as deficit reduction or lowering of other taxes. For example, one of the federal commissions that recently examined infrastructure financing cited a "gap" between needs and resources under current law of $47-166 billion annually, averaged over the period 2008-2035, depending on assumptions.[26] The NEMS-RFF simulations over a similar period, 2010-2030, show an average annual revenue increase of $148 billion and $320 billion for the "high" and "very high" fuel tax scenarios.

4.2 Fuel Efficiency Standards

For fuel efficiency standards, the Core 1 scenario already has very ambitious standards in place through 2016, raising the efficiency of the average LDV by 31.7 percent compared to its 2010 value—*viz.* from 26.5 to 34.9 mpg.[27] In this case, NEMS-RFF has been specified to achieve the official goal announced by President Obama in May 2009—namely, that an average LDV would have GHG emissions reductions equivalent to those that would occur if fuel efficiency were raised to 35.5 mpg. As is explicitly acknowledged by NHTSA in its description of the program, this implies that the actual fuel efficiency will be somewhat lower because some GHG reductions will in fact be achieved by other means, such as improved air conditioners (U.S. EPA and U.S. DOT 2009).

The Core 1 federal policy up to 2016 was driven in large part by the desire to satisfy California's stringent policy targets at the federal level; thus, it seems reasonable that another aggressive policy would do the same for another four years (the limit of California's written targets). For a fairly draconian extension, then, I model the Pavley CAFE policy, which follows

[26] National Surface Transportation Infrastructure Financing Commission (2009), Exhibit 2-22.

[27] Specifically, in modeling this scenario, the standards applying to all vehicle types and their footprints are raised proportionally to achieve the target values. Note that the issue of compliance is moot because it is assumed that the standards are made high enough so that the target is achieved despite any noncompliance. This seems consistent with the fact that most of the increase in standards will be promulgated under the authority of EPA to regulate CO_2 emissions, giving EPA wide latitude to design compliance mechanisms free of the specific requirements of CAFE regulations.

the targets already tentatively adopted by California from 2016 through 2020—namely, an increase of 3.7 percent per year—and continues progress after that at a rate of 2.5 percent per year.[28] Doing so implies a 16 percent improvement between 2016 and 2020, followed by another 28 percent by 2030, for a total 2010–2030 increase in fuel efficiency of new vehicles of 95 percent, to an average across cars and trucks of about 52 mpg.

In the case of the Pavley CAFE and feebate policies (Sections 4.2 and 4.4), the baseline policy used for comparison is slightly different from the Core 1 policy. The coefficients used in the standard version of NEMS-RFF imply a utility penalty on the choice of gas–electric hybrids. This is sensible when the hybrid is a new niche vehicle; but the policies considered here (and in related work specifically modeling hybrid subsidies) are likely to make these vehicles "mainstream," so I thought it likely that any consumer-perceived penalty on hybrids would disappear over time. Therefore, both the baseline (Core 1) and the policy scenarios (Pavley CAFE and Feebate) were modified so that this disadvantage does in fact disappear over time. This change has little effect except that the CAFE mandates in all of these policies (including Core 1) are achieved with a much sharper increase in gas–electric hybrid penetration. In each case, the policy changes shown are calculated against the baseline that corresponds to how that policy was modeled (called Core 1 Neutral in the Pavley CAFE and Feebate cases).

Results are shown in Table 4.2.1. The Pavley CAFE is moderately successful, achieving an 18.8 percent increase in new-vehicle fuel efficiency by 2030 and an 11.2 percent increase in

[28] The policy through 2020 is known in California as "Pavley 2," named for the author of the legislation underlying the California standards. For 2016–2020, I have specified the increase in standards such that, with no further change in vehicle mix beyond 2016, the standard for an average LDV would rise to 40.4 mpg in 2020; this is the figure calculated by the California Air Resources Board (2008, Table 7) as representing the effects of applying its standards to the federal vehicle mix (which differs considerably from California's vehicle mix).

the efficiency of the entire fleet by that date. Petroleum consumption in 2030 is reduced by 4.0 percent, oil imports by 7.2 percent, and energy use from LDVs by 8.4 percent.[29, 30]

But the policy suffers from some defects. First, the Core 1 policy is already very aggressive, so it is more difficult to make further improvements using the same policy tool. Second, CAFE affects only new vehicles, so it takes several years for its effects to be felt: even though the new-vehicle fleet is improving markedly, the efficiency of the overall fleet improves (compared to Core 1) by only 0.4 mpg in 2020 and by just 3.3 mpg (an 11 percent improvement) in 2030. Third, as noted before, the policy does nothing to discourage driving and, in fact, encourages it slightly: the 39 percent VMT increase already projected in Core 1 over the two decades 2010–2030 (not shown in the table) becomes even larger, 41.4 percent, with this policy.[31] Fourth, the policy does nothing to encourage a shift to smaller vehicles and, in fact, results in a small shift *away* from cars and toward trucks (a shift of 3 percentage points in 2030).

The Pavley CAFE policy as modeled does not, in fact, achieve the legally set CAFE targets in the later years. One reason is that manufacturers are unable to find enough technologies to meet the standard during the last few years, at least not at a rapid enough pace and/or at reasonable cost (defined in our current NEMS-RFF as $200 per unit improvement in mpg). This is mainly due to assumed technical limitations on the rate of adoption of new technologies, which are built into NEMS-RFF. Thus, the achieved new-vehicle fuel economy in 2020 (40.2

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[29] Jacobsen (2010), using an extension of the model of Bento et al. (2009), estimates that increasing the CAFE standard prevailing in 2009 by 1.0 mpg would decrease fuel use by 3.4 percent after 10 years. Although difficult to compare, this appears to suggest a greater response to the policy than shown in our model. The reason is that two-thirds of the fuel reductions in Jacobsen's simulations come from reduced driving, whereas our analysis predicts (as is conventional) that driving would *increase* as a result of lower vehicle operating costs per mile. The reason for Jacobsen's counterintuitive finding seems to be that his model simulates large changes in the mix of small and large vehicles, which eventually work their way through the used-car market and into the entire fleet (Jacobsen 2010, 26). These cars do not meet people's preferences as well as the original fleet, so (apparently) the model predicts that they drive them less. By contrast, NEMS assumes that people's driving responds modestly to fuel cost, as discussed in Section 3.2, and not at all to vehicle quality.

[30] Morrow et al. (2010) apparently find very small effects on energy use from the CAFE policy that they simulate, which rises only to a 43.7 mpg standard in 2030. (I infer this statement from their Figure 4 for GHG emissions and their discussion of it.) These small findings could be expected because the difference between their policy and the baseline (34.9 mpg) is about half the difference in the Pavley CAFE policy analyzed here.

[31] This is the increase from the first to the third column of numbers for VMT in Table 4.2.1. The difference in VMT of 1.9 percent in 2030, caused by the Pavley CAFE policy, results from the average fleet fuel efficiency increase of 11.2 percent. Their ratio is 0.17, which is, thus, a rough estimate of the implied rebound effect, or elasticity of VMT, with respect to fuel efficiency. However, this is a measure of the rebound effect over an uncertain time period because the fleet fuel efficiency is continually changing in this scenario.

mpg) nearly meets the targeted standard (40.4 mpg); but between 2020 and 2025 the achieved fuel economy rises by slightly less than 2 percent annually, not the 2.5 percent mandated, and it rises even more slowly thereafter. To appreciate this point, it is worth noting that even under the baseline policy, manufacturers must pay a fine on 36 percent of vehicles sold in 2015 because they do not meet CAFE. Under the baseline, this problem cures itself over the next five years because of the continued adoption of new technology, for which NEMS-RFF models maximum take-up rates. But under Pavley CAFE, the percentage of vehicles on which fines must be paid continues to rise: to 69 percent in 2020, 77 percent in 2025, and 100 percent in 2030. This despite the fact that some of the increased CAFE requirements are met by offering more gas–electric hybrids such that the hybrid market share rises to 28 percent in 2030, slightly higher than under the baseline. Such a high level of fines may represent our stretching the limits of technologies in the set considered by NEMS-RFF; in reality, either new technologies would be developed or the program would probably need to be modified to avoid such a politically unsustainable level of noncompliance.

Table 4.2.1. Results: Pavley CAFE

	Value in Core 11	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	3.62	3.69	0.02	-0.10	0.4%	-2.6%
Tax component	0.38	0.35	0.32	0.00	0.00	0.0%	0.0%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	59%	59%	-1%	-3%	-1.8%	-5.6%
Hybrids - market share	2%	25%	28%	1%	2%	3.1%	6.0%
Diesels - market share	2%	5%	9%	0%	-1%	-4.0%	-7.1%
Fuel efficiency (mpg):							
Cars	30.4	45.1	50.9	3.6	8.1	8.8%	18.9%
Trucks	23.6	34.7	40.7	2.6	7.0	8.0%	20.9%
All LDVs	26.5	40.2	46.2	3.0	7.3	8.1%	18.8%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	25.6	33.1	0.4	3.3	1.5%	11.2%
VMT (trillions)	2.79	3.15	3.95	0.00	0.07	0.1%	1.9%
Energy use (quad Btus)	16.41	15.31	14.86	-0.21	-1.36	-1.4%	-8.4%
Economy-wide outcomes							
GHGs (mill. metric tons CO_2 equiv):							
Energy-related CO_2	5,747	5,869	6,088	-19	-101	-0.3%	-1.6%
All GHGs	7,059	7,372	7,842	-20	-101	-0.3%	-1.3%
Liquid fuels (million barrels/day):							
Net petroleum imports	10.1	9.2	7.6	-0.1	-0.6	-1.3%	-7.2%
Total petroleum consumption	18.5	17.7	17.3	-0.1	-0.7	-0.7%	-4.0%
Total liquid fuel consumption	19.6	19.6	19.8	-0.1	-0.8	-0.7%	-4.1%

I also examine the same Pavley CAFE policy under the more optimistic assumptions about automotive technology embedded in EIA's "high-tech" assumptions, consisting of a more

optimistic set of parameters across the board describing the costs and possible rates of adoption of various fuel-saving technologies. Applying these high-tech assumptions to both the base and the policy scenarios gives the results in Table 4.2.2. (Only the transportation-related impacts were recomputed for these scenarios, so economywide impacts are not shown here.) The average fuel efficiency of new vehicles under these assumptions is moderately higher even in the base policy (not shown in the table): 39.8 mpg in 2030 compared to 39.1 mpg under the normal assumptions about technology. This is because the industry is more successful under these assumptions at achieving the Core 1 CAFE mandates.[32] Furthermore, the incremental improvement of the Pavley CAFE policy is also greater under optimistic assumptions about technology: in 2030, it raises new-vehicle fuel efficiency by 9.1 mpg instead of 7.3 mpg. These results also suggest that a policy aimed specifically at encouraging these technology improvements would have a payoff, although at what cost I cannot say.

Table 4.2.2. Results: Pavley CAFE with High-Tech Assumptions

	Value in Core 1	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	na	na	na	na	na	na
Tax component	0.38	1.84	2.04	1.49	1.73	432.2%	544.1%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	57%	58%	-2%	-3%	-2.7%	-5.5%
Hybrids - market share	2%	24%	28%	10%	5%	72.3%	21.9%
Diesels - market share	2%	5%	9%	-1%	-1%	-16.7%	-7.7%
Fuel efficiency (mpg):							
Cars	30.4	46.5	54.4	4.6	10.4	11.1%	23.6%
Trucks	23.6	34.8	42.7	3.0	8.3	9.4%	24.1%
All LDVs	26.5	40.7	48.8	3.6	9.1	9.8%	22.8%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	25.8	34.0	0.4	3.9	1.7%	12.8%
VMT (trillions)	2.79	3.15	3.94	0.00	0.06	0.1%	1.6%
Energy use (quad Btus)	16.41	15.24	14.49	-0.20	-1.57	-1.3%	-9.8%

4.3 Combined Fuel Tax and Fuel Efficiency Standards

We have seen that the fuel tax and CAFE policies achieve reductions in fuel use in different ways. The fuel tax primarily affects travel, with some favorable effect on fuel efficiency. CAFE policies primarily affect fuel efficiency, with a small but troublesome effect on

[32] An indication of this is a lower fraction of the fleet failing to meet the standards. For example, the fractions of vehicles not meeting the standards in 2025 (with Pavley CAFE) is 77 percent with default assumptions but only 0.3 percent with high-tech assumptions.

travel in the wrong direction. This suggests that the policies do not really substitute for each other. What if we implement them together?

Table 4.3.1 shows the result, using the most aggressive fuel tax. Although the effects are somewhat less than additive, the combined policy does indeed achieve much of the advantages of each component, resulting in a policy that is stronger than either considered individually. Consider the policy impact in 2030. Pavley CAFE alone increased the fuel efficiency of the average new LDV by 18.8 percent, and the Very High Fuel Tax improved it by only 7.8 percent; together they improve it by 24.3 percent, less than their sum but considerably more than either alone. The VMT changes resulting from the separate policies were +1.9 percent and –10.0 percent, respectively (again in year 2030); and the combination produces –8.6 percent, which is very close to the sum of the two separate policies. This pattern is quite understandable: VMT changes are produced by the changes in fuel cost per mile of driving, which is close to additive; whereas, for some kinds of vehicles, the CAFE standard will become nonbinding with the Very High Fuel Tax and so doesn't add any additional impetus for changing fuel efficiencies. The net result of this combined policy (in 2030) is a reduction of 20.7 percent in energy use by LDVs, 17.5 percent in petroleum imports, and 9.6 percent in total petroleum consumption. In fact, petroleum consumption declines to 16.3 million barrels per day by 2030, almost to the target level of 16 mentioned in the introduction.

As already discussed, one advantage of combining CAFE with a fuel tax is that the fuel tax can overcome the tendency of CAFE to cause an increase in the amount of driving. An even more direct way to accomplish this would be to combine CAFE with a tax on VMT.[33] Such a combination would probably be quite similar to the combination analyzed here, because the CAFE standard blunts the impacts of the fuel tax on vehicle fuel efficiency anyway. However, the VMT tax would not have the same beneficial impact on the ease of implementation of CAFE standards because it would not give consumers any incentive to support manufacturers' attempts to introduce technologies or design changes that increase fuel efficiency.

[33] A VMT tax has been studied extensively in Oregon: see Whitty (2007). A variant of the VMT tax is "pay-as-you-drive" or "pay-at-the-pump" automobile insurance, a proposed policy in which insurance premiums are charged proportionally to VMT. See Parry (2005) and Bordoff and Noel (2008).

Table 4.3.1. Results: Combined Pavley CAFE and Very High Fuel Tax

	Value in Core 1	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	6.38	6.84	2.78	3.05	77.2%	80.6%
Tax component	0.38	3.42	3.49	3.07	3.17	888.9%	999.0%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	69%	70%	9%	7%	14.8%	11.4%
Hybrids - market share	2%	30%	33%	6%	6%	23.2%	24.0%
Diesels - market share	2%	7%	10%	1%	1%	27.6%	8.6%
Fuel efficiency (mpg):							
Cars	30.4	45.8	51.8	4.3	9.0	10.5%	21.0%
Trucks	23.6	34.8	41.8	2.7	8.1	8.4%	24.2%
All LDVs	26.5	41.8	48.3	4.6	9.4	12.4%	24.3%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	26.3	34.4	1.0	4.6	4.1%	15.4%
VMT (trillions)	2.79	2.88	3.54	-0.27	-0.33	-8.5%	-8.6%
Energy use (quad Btus)	16.41	13.62	12.87	-1.91	-3.36	-12.3%	-20.7%
Economy-wide outcomes							
GHGs (mill. metric tons CO_2 equiv):							
Energy-related CO_2	5,747	5,626	5,897	-263	-292	-4.5%	-4.7%
All GHGs	7,059	7,124	7,652	-267	-291	-3.6%	-3.7%
Liquid fuels (million barrels/day):							
Net petroleum imports	10.1	8.0	6.7	-1.3	-1.4	-13.9%	-17.5%
Total petroleum consumption	18.5	16.4	16.3	-1.5	-1.7	-8.2%	-9.6%
Total liquid fuel consumption	19.6	18.2	18.4	-1.5	-2.3	-7.8%	-11.0%

4.4 Feebates

The feebate policy can be viewed as an economic incentive targeted at the same goal as CAFE regulation: new-vehicle fuel efficiency. Therefore, one can expect that there is some value in the strength of the economic incentive that will roughly duplicate the effects of any given CAFE policy. Here I consider two feebate policies, a High Feebate and a Very High Feebate. The High Feebate policy is aimed at achieving results somewhat comparable to those of the Pavley CAFE policy analyzed in Section 4.2; it has a basic rate of $2,000 per 0.01 gpm in 2007 dollars. (That is, each vehicle's fuel intensity—the reciprocal of fuel efficiency—is compared with the pivot point, and a fee or rebate is applied equal to $2,000 for each 0.01 gpm

difference.)[34] To make the policy more comparable to the Pavley CAFE policy, in which standards are phased in gradually, the feebate rate is phased in starting at a rate of $1,000 in 2017 (immediately after the CAFE standards stabilize in Core 1) and rising in $500 increments each year between 2018 and 2021. The rate is then further increased at 2.5 percent per year (still in real terms), so that it rises to $2,969 per 0.01 gpm in 2030.

The pivot points are chosen to approximate a revenue-neutral policy within each vehicle size class. Specifically, for each class, the pivot point in a given year (i.e., the stated level of fuel intensity in gpm for which there is neither a fee nor a rebate) is set to the average achieved fuel intensity of the previous year, less 1.5 percent to reflect typical progress with this policy in place.

The Very High Feebate scenario is even stronger: it sets the feebate rates to be exactly twice as large as in the High Feebate scenario. The purpose here is to model an extremely aggressive policy aimed squarely at changing the fuel efficiency of new cars but using strictly economic incentives. This enables us to explore the maximum reach of the technologies assumed in NEMS-RFF to be available.

Results are shown in Tables 4.4.1 and 4.4.2. The High Feebate scenario performs similarly to the Pavley CAFE, with about 85 percent of the latter's effectiveness (the difference is due solely to the particular parameters we chose). Two differences are notable, however. First, it achieves more of its efficiency gains through the use of hybrids and diesels. The High Feebate policy increases the hybrid and diesel market shares in 2030, relative to the baseline policy, by 9 and 6 percentage points, respectively; in contrast, Pavley CAFE had almost no effect on those shares. Second, the High Feebate policy causes an even larger shift from cars to trucks—about 6 percentage points more than the baseline, twice the impact of Pavley CAFE. Both of these changes are rooted in the two relevant consumer choice models in NEMS-RFF, and it is difficult to discern just why this particular pattern occurs. The main difference between the policies is that the feebates are passed through to customers in vehicle prices; this tends to keep the prices of conventional vehicles higher, and those of hybrid and diesel vehicles lower, than in the case of Pavley CAFE. Evidently, the demand for hybrid and diesel vehicles is sufficiently sensitive that this price differential increases their market shares. Neither feebates nor CAFE provide any

[34] This basic rate of $2,000/(0.01 gpm) is nearly twice that considered by Greene et al. (2005a,b). To get an idea of its magnitude, consider a car driven 12,683 miles per year (the projected 2021–2030 average for all vehicles in our Core1 Neutral policy) over its expected 14-year life. Then the rate implies a fee or rebate of $2,000/0.01gpm/(12,683*14 miles) = $1.13/gallon.

strong direct pressure on the prices of cars versus trucks, and I have been unable to determine why trucks are advantaged by the feebate policy.

Table 4.4.1. Results: High Feebate

	Value in Core 1	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	3.59	3.67	-0.01	-0.12	-0.2%	-3.2%
Tax component	0.38	0.35	0.32	0.00	0.00	0.0%	0.0%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	59%	57%	-2%	-6%	-3.0%	-9.0%
Hybrids - market share	2%	31%	36%	7%	9%	29.1%	35.4%
Diesels - market share	*2%*	*8%*	*16%*	*3%*	*6%*	56.1%	66.3%
Fuel efficiency (mpg):							
Cars	30.4	43.9	49.6	2.5	6.8	6.0%	15.9%
Trucks	23.6	36.4	40.8	4.3	7.2	13.4%	21.3%
All LDVs	26.5	40.5	45.4	3.3	6.6	8.9%	16.9%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	25.8	33.0	0.5	3.2	2.1%	10.9%
VMT (trillions)	2.79	3.16	3.95	0.02	0.08	0.5%	2.2%
Energy use (quad Btus)	16.41	15.33	15.07	-0.20	-1.16	-1.3%	-7.1%
Economy-wide outcomes							
GHGs (mill. metric tons CO_2 equiv):							
Energy-related CO_2	5,747	5,869	6,108	-20	-82	-0.3%	-1.3%
All GHGs	7,059	7,371	7,861	-20	-82	-0.3%	-1.0%
Liquid fuels (million barrels/day):							
Net petroleum imports	10.1	9.2	7.6	-0.1	-0.6	-1.2%	-7.2%
Total petroleum consumption	18.5	17.7	17.3	-0.1	-0.7	-0.7%	-3.7%
Total liquid fuel consumption	19.6	19.6	19.9	-0.1	-0.8	-0.6%	-3.8%

The Very High Feebate policy is notably more effective on all measures. Average fuel efficiency for new vehicles in 2030 rises to 48.3 mpg, 24 percent higher than the baseline and 82 percent higher than its 2010 value. Energy use in 2030 is reduced by 10 percent (relative to the baseline), GHGs by 1.5 percent, petroleum consumption by 5 percent, and petroleum imports by nearly 10 percent. Market shares of gas–electric hybrids and diesel engines rise strikingly, to a total of 62 percent, relegating conventional gasoline cars to a minority status.

Table 4.4.2. Results: Very High Feebate

	Value in Core 1	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Fuel price (retail)							
Gasoline (2007$/gal)	2.14	3.59	3.62	-0.01	-0.17	-0.3%	-4.5%
Tax component	0.38	0.35	0.32	0.00	0.00	0.0%	0.0%
Transportation outcomes							
New LDVs:							
Cars - market share	49%	57%	57%	-3%	-6%	-5.1%	-9.4%
Hybrids - market share	2%	36%	42%	12%	16%	51.9%	59.2%
Diesels - market share	*2%*	*12%*	*20%*	*6%*	*10%*	114.2%	103.6%
Fuel efficiency (mpg):							
Cars	30.4	46.1	53.0	4.7	10.1	11.3%	23.6%
Trucks	23.6	38.8	43.4	6.7	9.7	21.0%	28.9%
All LDVs	26.5	42.7	48.3	5.5	9.5	14.9%	24.4%
All LDVs (new and used):							
Fuel efficiency (mpg)	20.6	26.1	34.6	0.9	4.9	3.4%	16.3%
VMT (trillions)	2.79	3.18	3.99	0.03	0.12	0.9%	3.1%
Energy use (quad Btus)	16.41	15.24	14.59	-0.29	-1.64	-1.9%	-10.1%
Economy-wide outcomes							
GHGs (mill. metric tons CO_2 equiv):							
Energy-related CO_2	5,747	5,861	6,072	-28	-117	-0.5%	-1.9%
All GHGs	7,059	7,363	7,826	-28	-117	-0.4%	-1.5%
Liquid fuels (million barrels/day):							
Net petroleum imports	10.1	9.2	7.4	-0.2	-0.8	-1.9%	-9.8%
Total petroleum consumption	18.5	17.6	17.1	-0.2	-0.9	-1.1%	-5.2%
Total liquid fuel consumption	19.6	19.5	19.5	-0.2	-1.1	-1.0%	-5.6%

Still, these changes are far less than double those achieved by the High Feebate policy, demonstrating the diminishing ability of these policies to stimulate efficiency improvements. This is true at least within the bounds of available technologies, pricing policies, and consumer choice behavior as portrayed in NEMS-RFF. It is quite possible that with such large incentives, manufacturers would adopt new strategies that go beyond our current ability to predict. One of the attractions of feebate policies over CAFE standards is that they would continue to strongly motivate such innovative strategies even after the original targets of the policies were met.

It is worth noting that the Very High Feebate policy produces a 5 percentage point drop in the share of flex-fueled vehicles (those that can use E85); this is because they are not particularly efficient on an energy basis. If that is viewed as a drawback (which is debatable given how we now produce ethanol), it could be corrected by combining the feebate with an oil tax or by exempting alternative-fueled vehicles from the feebates. However, such an exemption could backfire if consumers in fact use mostly gasoline in their flex-fueled vehicles, which is the case today.

5. Costs of Policies

5.1 Cost Methodology

The social costs of policies are here measured by applying the usual microeconomic tools to the two primary markets affected, that for new vehicles and that for travel. Fuel demand is derived from the demand for travel, so the market for fuel is implicitly incorporated. The full theory of welfare calculations in these interrelated markets, as represented in this paper, is described in Appendix A; here I present an abbreviated and more intuitive version.

My implementation of the theory is simplified in its depiction of time. I adopt what can be viewed as a cash-flow rather than an accrual method of accounting. The accrual method, detailed in Appendix A, would require that future fuel cost savings of each new car sold be estimated, discounted, and added to get a present value that offsets any additional purchase price. To be fully accurate, this would require assigning a risk premium for the uncertainty in future fuel prices. Instead, I simply keep track of the costs and benefits as they occur in each year. Thus, the higher production costs incurred as a result of a CAFE policy for vehicles purchased in 2020 are all allocated to year 2020. The fuel savings that occur in subsequent years are allocated to those years; fuel savings in 2020 (due to prior years' purchases) are allocated to 2020. This procedure probably better represents how social costs are borne by various cohorts of people over time. It reflects the fact that policies like CAFE have up-front costs offset by later cost savings (primarily from fuel savings) spread over future years; such policies will show a time pattern of high social costs in earlier years and low or even negative social costs in later years. (Negative costs would indicate a net cost savings or the existence of some ancillary benefit that outweighs the other policy costs.)

To provide a single summary measure, I also perform an approximate calculation of the total present value of policy costs by interpolating between the years for which costs are calculated carefully, then discounting to 2007 (at a 5 percent real interest rate) and adding across years. I also provide a cumulative but undiscounted total of policy benefits in physical units: in other words, a reduction in total barrels of oil consumed or in total tons of CO_2 emitted.

The summary measures of costs and benefits just described are incomplete because the simulations are cut off in 2030. In all our policy scenarios, manufacturers incur substantial costs in the later years of the simulation to produce more fuel-efficient cars. But there is an "overhang" from having undertaken these costs: consumers and society will continue to reap the benefits of less fuel consumption as long as those cars remain in the fleet. Thus, further cost savings last for about 15 more years, the approximate average lifetime of a vehicle, that need to be counted

because they offset extra vehicle production costs incurred during the simulation period. As vehicles are gradually replaced in the fleet, these cost savings and policy benefits will gradually diminish. Therefore, I approximate this overhang on the assumption that the fuel savings due to fuel efficiency improvements diminish linearly from their measured value in 2030 to zero in 2045. I use the same assumption to approximate the policy benefits (in physical units) that occur between 2030 and 2045 as a result of fuel efficiency improvements during and prior to 2030. These estimates of overhang costs and policy benefits are added to the respective totals, with the costs discounted to 2007 as with other costs. Note that these calculations make no assumption about whether the policy continues after 2030; no costs or benefits are counted from any such continuation. The result is an estimate of the total net present value (NPV) of costs, and the total (undiscounted) savings in oil consumption and CO_2 emissions, due to the policy being in place until 2030.

In the tables, both the net present discounted value of costs and the total undiscounted amount of policy benefits are shown under the row "NPV." The ratio of these two numbers is shown as cost-effectiveness. Because the cost measures are discounted but the effectiveness measures are not when computing these aggregates, this measure of cost-effectiveness can be lower than the cost-effectiveness in any single year.

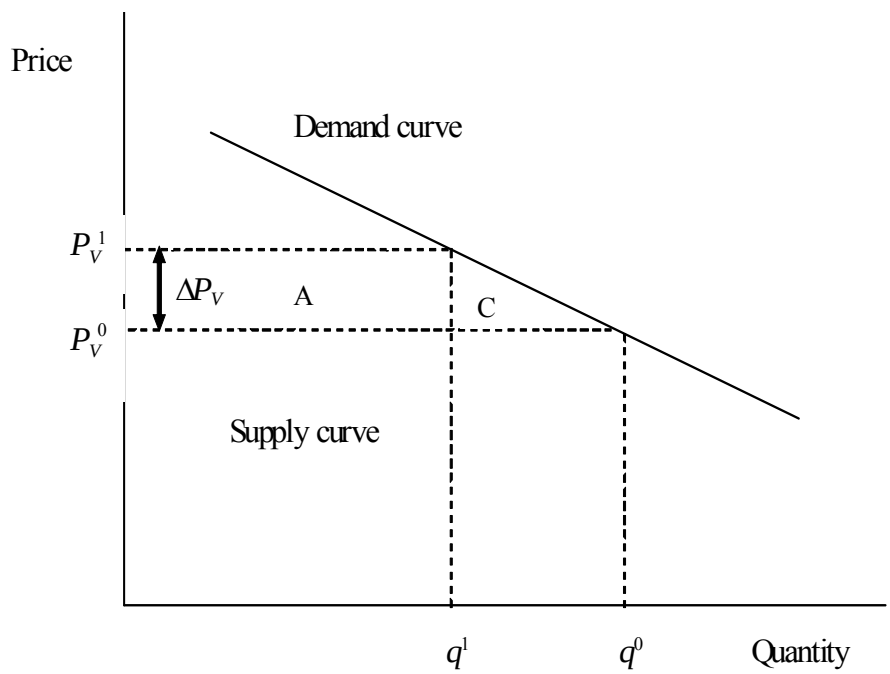
The annual net costs of each policy are categorized in the Appendix and summarized in Appendix equations (A14a–d) for CAFE policies, with slight modifications for other policies as described there. Here, I describe the components of these equations, which are very similar to those in the analysis by NHTSA (2008), in more intuitive terms as seven categories of policy costs. The values in some categories are negative, so the full calculation should be viewed as a series of costs and offsetting benefits. The offsetting benefits do not include a social value for the targets themselves, such as oil consumption, oil imports, or GHG emissions. Thus, the sum of the categories listed here is not a cost–benefit calculation, but rather is just the cost side of either a cost–benefit or a cost-effectiveness calculation; that is, it is the social cost of achieving the changes in target variables by means of this policy.

I denote each category by $-\Delta W_k$ if it is a one-time cost for the vehicle and by $-\Delta w_k$ if it is an ongoing expenditure, where k denotes a particular category of cost or benefit. (One can think of W or w as denoting "welfare;" thus, $-\Delta W_k$ or $-\Delta w_k$ is positive for a cost, negative for a benefit.) The seven categories of policy cost are as follows.

(1) Higher Production Cost of Vehicles and Consumer Surplus Loss on Vehicles Not Purchased

If consumers pay more for vehicles because of efficiency changes, the lost welfare to them is measured by the area of a trapezoid to the left of the demand curve for vehicles and between the lines representing their initial and final prices. This trapezoidal area is shown as areas A + C in Figure 5.1.1, which depicts the demand curve for vehicle purchases as a function of price.[35] Superscripts 0 and 1 represent situations without and with the policy in place. Provided the demand curve is nearly linear or the changes in price and quantities of vehicles sold are small, area C is approximately a triangle and A + C is approximately the average number of vehicles purchased with and without the policy, $\bar{q} \equiv (q^1 + q^2)/2$, multiplied by the price increase caused by the policy, $\Delta P_V \equiv P_V^1 - P_V^0$. This quantity is computed separately for each of our vehicle classes and added, with a small further adjustment for the extra cost of replacing conventional vehicles with hybrids and diesels as described in the appendix.

Figure 5.1.1. Welfare Effects in New-Vehicle Markets



[35] Figure 5.1.1 is a simplified version of Figure A.1 in which the supply curve is assumed to be horizontal, corresponding to the NEMS assumption that manufacturers pass all extra costs through to consumers in the form of higher prices.

This cost category consists mostly of area A, which represents production-cost increases for making vehicles (which are assumed to be passed through to consumers). The smaller area, C, is lost consumer surplus from vehicles no longer purchased, also a social cost of the policy. In the case of a feebate policy that is not strictly revenue-neutral, the increased price of vehicles also reflects the fees paid net of rebates received, which are not social costs because they are a transfer from consumers to government; I therefore subtract the net fees, leading to the summary as given by Appendix equation (A14a′)

$$-\Delta W_V = \bar{q}\Delta P_V - (\text{net fees paid by manufacturers})$$

In practice, ΔP_V represents changes in performance as well as in fuel efficiency, and manufacturers' decisions on these two dimensions are closely intertwined. For example, the same technology might be used to increase either efficiency or engine power. For this reason, the policies analyzed here result in modest changes in performance, the costs of which are impossible within NEMS-RFF to separate from the costs incurred to change fuel efficiency. This tendency seems to be most pronounced in the High Feebate policy, which, in year 2030, results in about 6 percent greater horsepower on average for cars, and 2 percent greater for trucks, than the baseline comparison. Because vehicle weight is also being reduced, there should be a noticeable performance enhancement, to which some of the cost should be allocated. To approximate that cost, I assume that it is absent in the CAFE scenario, for which the corresponding horsepower changes are 1 percent and –4 percent, respectively.[36] I then calculate $-\Delta W_V$ for feebates by assuming that is has the same ratio to fuel efficiency improvements as in the CAFE scenario; this is reasonable because the two scenarios use similar technologies and achieve similar changes in fuel efficiency.

[36] The reason why horsepower increases less in the CAFE than in the Feebate scenario is that NEMS iteratively checks CAFE compliance as it considers potential technologies for adoption. If compliance is not met, the manufacturer is assumed to "take back" some of the horsepower improvements that it would otherwise adopt, according to the model's portrayal of cost and consumer demand for performance. Because this mechanism is absent in the Feebate scenario, manufacturers are there portrayed as more free to comply with their perceptions of consumer demand for performance. The difference in how manufacturers are portrayed in these two scenarios may be an artifact of the model rather than a real behavioral difference.

(2) Fuel Savings Due to Increased Fuel Efficiency (Negative Cost)

This category is an offset to other costs. The price of fuel is measured at its pretax value so that only the social cost of fuel is included in the cost measure. The result is Appendix equation (A14b)

$$-\Delta w_F = \overline{VMT} \cdot \left[(\overline{P_F} - \overline{\tau_F}) \Delta F \right]$$

where $\overline{VMT}$ is the average of before- and after-policy VMT, $(\overline{P_F} - \overline{\tau_F})$ is the average pretax fuel price, and ΔF is the change in fuel intensity of the average vehicle (i.e., the reciprocal of the change in the harmonic average of vehicle fuel efficiencies). As described in Appendix A, this quantity incorporates a small amount representing consumer surplus gained or lost because of increased or decreased VMT resulting from fuel efficiency improvements.

(3) Loss of Tax Revenues

The changes in tax revenue due to changes in fuel efficiency were explicitly excluded in calculating the fuel cost savings of category (2), by use of net-of-tax fuel prices, so they do not need to be added back in as an offset to costs. However, a change in tax revenues also occurs as a result of changes in VMT, even at the original fuel tax rate. This change was implicitly included in category (2), so it is subtracted out here, with the interpretation that any reduction in revenues is a policy cost and any increase is a policy benefit

$$-\Delta w_R^V = -\overline{\tau_F F} \cdot \Delta(VMT)$$

where $\overline{\tau_F F}$ is the average of pre- and postpolicy values of tax revenue per vehicle-mile.

(4) Loss of Consumer Value Due to Shifting from Cars to Trucks (Fuel Tax Scenario Only)

Higher fuel prices cause consumers to shift their purchases away from trucks and toward cars. The resulting fuel savings are counted in category (2) as a benefit, but because consumers did not do this voluntarily, they must have perceived that trucks offer some value justifying the extra fuel expenditures in their eyes. Part of this value may be real driving amenities, another part may represent an “arms race” for safety and so may not be a social value; but those safety costs will be accounted for separately in category (7). Thus the full value needs to be included here. As explained in Appendix A, this is done by imputing the value from the fuel costs incurred to drive trucks. In practice, this category turns out to be small.

(5) Hidden Amenity Losses

The fuel efficiency improvements brought about by CAFE and feebate policies may exact a loss of amenities to drivers—for example, designing for higher fuel efficiency diverts technologies that might otherwise be used to increase power. This is one possible explanation for why drivers fail to consider the full present discounted value of fuel savings when making purchase decisions. I have developed a very approximate measure of the maximum such amenity loss, based on the assumption that they account for the full difference between the present discounted value of fuel savings and those savings accounted for by consumers (see Appendix A). This approximation in effect offsets three-fourths of the fuel cost savings because that is the portion of such savings that consumers seem to ignore in the open market according to NEMS-RFF assumptions.

(6) External Cost of Changed Amount of Driving

This is simply an estimate of the marginal external cost of congestion, local air pollution, and accidents multiplied by the change in VMT

$$-\Delta w_E = c_M \Delta(VMT)$$

This component turns out to be quite important to our results so, for comparability with other studies, I show results both with and without it. The key parameter c_M begins at a value \$0.111/mile in 2010 (stated in real 2007 dollars) and grows at 1.1 percent per year, as described in detail in the Appendix.

(7) Accident Costs from Trucks

As an optional calculation, I also implement an estimate of the additional accident costs incurred by shifts from cars to trucks, discussed in Section 3.2. Here I take the estimates of Li (2010), which imply that each shift of one million vehicles from cars to trucks adds the equivalent of 20.3 fatalities per year to accident costs.[37] Applying a medium estimate of the value of a statistical life of \$5.5 million, as does Li, gives an accident cost of \$112 per year for each car that is replaced by a truck in the overall fleet.

[37] This is Li's calculation at an initial truck share of 45 percent, which is close to the average over the years 2010–2030 in my baseline case.

5.2 Results

The tables that follow show the results of these calculations for annual costs in 2015, 2020, and 2030, as well as the NPV. The latter includes the overhang of costs and benefits after 2030 resulting from policy-induced changes in vehicle characteristics in 2030. Each table also shows the annual and (undiscounted) cumulative reduction in two policy targets: petroleum consumption and CO_2 emissions. It then shows the results of dividing the NPV of costs by the cumulative policy gains, resulting in a summary measure for cost-effectiveness.

Two subtotals of categories are highlighted in the tables. The first ("lower estimate") corresponds to the categories (1)–(4), which are those included in most other cost assessments. The second ("upper estimate") adds category (5), the maximum estimate of hidden amenity losses. The cost effectiveness of a policy is then calculated, both for petroleum consumption and for CO_2 emissions, alternately using these two subtotals. The result is four cost-effectiveness measures: a lower and upper measure for petroleum savings and a lower and upper measure for CO_2 reduction. In addition, the tables show a third total containing all categories except (5); this is useful for seeing the importance of the side effects of policies on external costs, including changes in accident costs resulting from shifts between cars and trucks.

Table 5.2.1 shows the results for the two fuel tax scenarios considered. Consistent with the minimal technological efficiency gains of this policy, the costs to manufacturers are quite modest, reaching $3.9 billion per year in 2030 for the High Fuel Tax scenario. Yet the fuel savings are substantial, largely because of decreased driving. Also because of decreased driving, substantial fuel tax revenue and consumer surplus is lost. The end results are cost-effectiveness measures that are quite low if consumer myopia is real: $3–$17 per barrel of oil or $6–$38 per metric ton of CO_2 in the case of the High Fuel Tax, and considerably more for the Very High Fuel Tax. If external costs of driving are counted, the policy costs are strongly negative for both policies, even using the higher cost estimate.[38]

The fact that the cost-effectiveness measures are much larger for the higher tax demonstrates the law of diminishing returns: as we increase the strength of a policy, the benefits tend to rise modestly whereas the costs may rise dramatically, in part because the policy presses against technological limits or forces consumers to divert further from their preferred choices.

[38] This is seen by noting that row 6 (external cost savings) is negative and larger in magnitude than the row just above it (the upper estimate of costs).

Table 5.2.1. Policy Costs: Fuel Tax Policies

	High Fuel Tax Policy				Very High Fuel Tax Policy			
	2015	**2020**	**2030**	**NPV**	**2015**	**2020**	**2030**	**NPV**
Costs of policy (billions 2007 $)								
1. Extra cost of new, more fuel-efficient vehicles sold	-0.2	1.1	3.9	11.3	-0.8	2.7	9.6	26.5
2. –Fuel cost savings from more fuel-efficient vehicles	-2.3	-5.8	-11.7	-74.5	-4.5	-10.7	-23.4	-143.7
3. Lost tax revenue & consumer value from less driving	4.6	6.6	9.2	75.3	18.1	19.5	23.5	224.7
4. Loss of value from light trucks (fuel tax only)	0.1	0.3	0.6	3.5	0.3	1.0	2.2	13.2
Total (1–4) (lower estimate)	**2.2**	**2.2**	**1.9**	**15.6**	**13.1**	**12.4**	**12.0**	**120.7**
Alternative calculations:								
5. Hidden amenity cost	2.4	5.8	11.8	75.4	5.7	12.9	27.4	171.6
Total with hidden amenity cost (1–5) (upper estimate)	**4.6**	**8.0**	**13.7**	**91.0**	**18.7**	**25.3**	**39.4**	**292.3**
6. –External cost savings from of less driving	-11.4	-19.1	-32.8	-235.8	-25.7	-33.5	-53.7	-418.7
7. –Accident cost savings from shift in car–truck mix	-0.7	-1.3	-1.7	-13.8	-1.3	-2.1	-2.7	-22.9
Total with external & accident costs (1–4,6–7)	-10.0	-18.2	-32.6	-234.0	-13.9	-23.2	-44.5	-320.9
Policy effectiveness (reduction from baseline)								
Petroleum consumption (milllion barrels)	206	280	290	5,228	443	511	460	9,614
Energy-related CO_2 (million metric tons)	111	130	135	2,419	240	245	213	4,590
Cost-effectiveness (based on "lower estimate")								
Policy cost per:								
barrel petroleum consumption ($/bbl)	11	8	7	**3**	29	24	26	**13**
metric ton CO_2 reduced ($/tonne)	20	17	14	**6**	54	51	56	**26**
Cost-effectiveness (based on "upper estimate")								
Policy cost per:								
barrel petroleum consumption ($/bbl)	22	29	47	**17**	42	50	86	**30**
metric ton CO_2 reduced ($/tonne)	41	62	102	**38**	78	103	185	**64**

Notes: Positive numbers denote a cost of the policy, negative numbers an offsetting benefit other than the policies' target benefits of lower energy consumption and lower GHG emissions. bbl stands for barrels. NPV stands for net present value in 2007, computed at a 5 percent interest rate and including estimated continuing benefits through 2045. For effectiveness measures, it is just the undiscounted total for 2010–2045. Because costs are discounted but effectiveness measures are not, overall cost-effectiveness in the "NPV" columns can be lower than the cost-effectiveness in any single year.

Countering the attraction of tax measures on cost-effectiveness grounds, of course, is the political disadvantage of very large tax payments flowing from consumers to the government. Even in the more modest High Fuel Tax policy, those tax payments (not shown in the table) reach $251 billion annually by 2030, roughly six times their value in the baseline scenario. It should be noted, however, that in the baseline, the fuel tax declines precipitously, making it completely inadequate as a way to finance highway expenditures; thus, some other form of financing would have to be found if not a higher fuel tax.

A notable feature of the policy cost calculations in these scenarios is the very large size of row three, "Lost tax revenue & consumer value from less driving." This term, detailed in Appendix equation (A14c′), equals the reduction in VMT multiplied by the average of the pre- and postpolicy tax rates per mile. It includes both (a) half of the tax revenue that would have been raised by the tax hike were it not for its effect on VMT and (b) the loss of travelers'

consumer surplus resulting from their cutting back on VMT in response to the higher fuel cost per mile. In the NPV calculation for the High Fuel Tax policy, these losses offset all of the value of fuel savings, so the resulting total cost ("lower estimate") is dominated by the incremental cost of building more fuel-efficient vehicles.

If amenity losses from more fuel-efficient vehicles are assumed to fully explain consumer myopia, then those losses (category 5) are especially high in the case of fuel tax policies, more than offsetting the fuel savings. This is because amenity losses are based on fuel prices gross of tax, and here the tax is very large. For example, under the Very High Fuel Tax, manufacturers adopt the most aggressive of the five available material-substitution technologies on 23 percent of new vehicles in 2030, compared to just 6 percent under the Core 1 scenario. This choice is driven by consumer demand to reduce their fuel expenditures, including, for example, a $3.49 per gallon tax component for gasoline that is greater than the net-of-tax gasoline price, as can be seen in Table 4.1.2. However, I reiterate that this assumption—that all apparent consumer myopia is due to hidden amenity losses—is extreme; it seems more likely that much of the myopia is due to financial constraints, uncertainty, or other factors that distort their choices relative to socially optimal ones, as strongly argued by Greene et al. (2009).

Table 5.2.2 shows the cost calculations for the Pavley CAFE policy, both by itself and combined with the Very High Fuel Tax. Because it relies so heavily on new-car fuel efficiency, the CAFE policy alone produces high costs but few benefits in the early years when it is in effect (2016–2020). But it produces considerable benefits later on, both in the form of targeted outcomes (petroleum consumption, CO_2 reduction) and in the form of fuel cost savings that offset much of the policy costs. As a result, its cost-effectiveness varies widely over time, even becoming negative in the later years according to the "lower estimate" of policy cost. The NPV of cost is also negative according to the lower estimate. If one believes in hidden amenity costs, however, the costs become fairly large, resulting in overall cost-effectiveness numbers of $33 per barrel of petroleum and $85 per metric ton of CO_2, similar to those of the Very High Fuel Tax policy.

Table 5.2.2. Policy Costs: CAFE Policies

	Pavley CAFE				Combined Pavley, Very High Fuel Tax			
	2015	**2020**	**2030**	**NPV**	**2015**	**2020**	**2030**	**NPV**
Costs of policy (billions 2007 $)								
1. Extra cost of new more fuel-efficient vehicles sold	0.0	16.7	42.5	156.6	-1.0	17.9	45.1	159.3
2. –Fuel cost savings from more fuel-efficient vehicles	0.0	-5.7	-44.0	-185.5	-4.4	-14.2	-55.3	-274.1
3. –New tax revenue or + Lost tax revenue	0.0	0.0	-0.8	-2.8	18.0	19.1	18.5	205.7
4. Loss of value from light trucks (fuel tax only)	0.0	0.0	0.0	0.0	0.1	0.6	2.5	12.1
Total (1–4) (lower estimate)	**0.0**	**11.0**	**-2.3**	**-31.7**	**12.7**	**23.4**	**10.8**	**103.0**
Alternative calculations:								
5. Hidden amenity cost	0.0	4.8	36.1	152.5	5.6	17.1	64.9	325.7
Total with hidden cost (1–5) (upper estimate)	**0.0**	**15.7**	**33.8**	**120.8**	**18.3**	**40.5**	**75.6**	**428.8**
6. External cost from increased driving	0.0	0.3	10.3	35.4	-25.6	-33.2	-45.9	-392.1
7. –Accident cost savings from shift in car–truck mix	0.0	0.1	0.6	2.2	-1.3	-2.1	-2.7	-22.7
Total with external & accident costs (1–4,6–7)	0.0	11.4	8.6	5.9	-14.2	-11.9	-37.8	-311.7
Policy Effectiveness (reduction from baseline)								
Petroleum consumption (milllion barrels)	0	43	263	3,612	0	537	628	10,054
Energy-related CO_2 (million metric tons)	0	19	101	1,429	0	263	292	4,511
Cost-effectiveness (based on "lower estimate")								
Policy cost per:								
barrel petroleum consumption ($/bbl)	na	255	-9	**-9**	29	44	17	**10**
metric ton CO_2 reduced ($/tonne)	na	563	-22	**-22**	53	89	37	**23**
Cost-effectiveness (based on "upper estimate")								
Policy cost per:								
barrel petroleum consumption ($/bbl)	na	366	129	**33**	42	75	120	**43**
metric ton CO_2 reduced ($/tonne)	na	808	334	**85**	77	154	259	**95**

Notes: Positive numbers denote a cost of the policy, negative numbers an offsetting benefit other than the policies' target benefits of lower energy consumption and lower GHG emissions. bbl stands for barrels. NPV stands for net present value in 2007, computed at a 5 percent interest rate and including estimated continuing benefits through 2045. For effectiveness measures it is just the undiscounted total for 2010–2045. Because costs are discounted but effectiveness measures are not, overall cost-effectiveness in the NPV columns can be lower than the cost-effectiveness in any single year.

The policy costs are much more even over time for the combined fuel tax and CAFE policy, shown in the right-hand columns in Table 5.2.2.[39] This policy produces strong results and has fairly moderate costs, resulting in cost-effectiveness measures comparable to, or only slightly higher than, each of its constituent policies taken alone. Thus, high fuel taxes and CAFE standards fit well together as policies, and even more so when one considers implementation and

[39] In 2015, the costs for the combined policy should logically be identical to those for the Very High Fuel Tax because the policies are identical until 2017. The reason they differ slightly in the tables is that the combined policy was run with the adjustment of hybrid-choice constants described in Section 4.2, and compared against the Core 1 Neutral baseline; whereas the Very High Fuel Tax policy was run with NEMS default constants and compared with the standard Core 1 policy.

enforcement because the fuel tax will make customers much more interested in the enhanced fuel efficiency that manufacturers are required by CAFE to offer. Furthermore, the costs of this combined policy—like those of the fuel tax alone—are greatly reduced if one considers the external cost of driving due to the substantial reduction in VMT whenever a high fuel tax is in place.

Table 5.2.3 shows the cost estimates for the feebate policies. As could be expected, the pattern of costs of the High Feebate policy is very similar to that of the Pavley CAFE policy, which it was designed to mimic. As noted in Section 5.1, I have adjusted the extra cost of new vehicles (category 1) to be the same, per unit of change in fuel efficiency, as in Pavley CAFE because the same technologies are available to manufacturers in the two policies. The detailed model results show that with feebates, compared to Pavley CAFE, manufacturers use somewhat fewer technological means to improve efficiency but sell more hybrids; they achieve this by passing through to consumers the considerable rebates available for hybrids in the form of lower hybrid prices.

The Very High Feebate policy shows quite high costs relative to effectiveness. Clearly, it is increasingly costly to push the envelope for new-car fuel efficiency, especially if done without any incentive to reduce driving.

One more difference between the feebate and CAFE policies is surprising and informative. Both policies increase driving slightly as a result of the rebound effect. But feebates reduce driving more than could be accounted for in this way. The reason is that the energy sector part of NEMS-RFF predicts a small decrease in fuel prices due to these policies, presumably because pressure on world and national resources is relieved. For gasoline, this price decrease in 2030 is 10 cents per gallon for the Pavley CAFE policy and 12 cents for the High Feebate policy. These small changes in price are powerful enough to induce more driving, especially under feebates. This makes little difference in the policy costs as calculated at the top of the table, but it affects line six (the external cost from increased driving) enough to noticeably raise the total cost of the High Feebate relative to Pavley CAFE when such external costs are included. It is hard to know how much these economywide differences may be driven by the interactions of these policies with alternative fuel mandates, incentives for diesels and E85, and other factors that affect overall demand for different types of fuels.

Table 5.2.3. Policy Costs: Feebate Policies

	High Feebate				Very High Feebate			
	2015	**2020**	**2030**	**NPV**	**2015**	**2020**	**2030**	**NPV**
Costs of policy (billions 2007 $)								
1. Extra cost of new more fuel-efficient vehicles sold	0.0	17.8	42.3	159.4	0.0	34.7	70.9	288.9
2. –Fuel cost savings from more fuel-efficient vehicles	0.0	-8.3	-42.7	-193.0	0.0	-13.3	-60.8	-282.9
3. –New tax revenue	0.0	-0.2	-0.9	-3.8	0.0	-0.4	-1.2	-5.7
4. Loss of value from light trucks (fuel tax only)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (1–4) (lower estimate)	**0.0**	**9.3**	**-1.3**	**-37.5**	**0.0**	**21.0**	**8.9**	**0.3**
Alternative calculations:								
5. Hidden amenity cost	0.0	6.8	35.1	158.8	0.0	11.0	50.0	233.0
Total with hidden amenity cost (1–5) (upper estimate)	**0.0**	**16.1**	**33.8**	**121.3**	**0.0**	**32.0**	**58.8**	**233.2**
6. External cost from increased driving	0.0	2.0	11.6	47.1	0.0	3.5	16.5	69.9
7. Accident costs from shift in car-truck mix	0.0	0.1	0.8	3.3	0.0	0.1	1.1	4.7
Total with external & accident costs (1–4,6–7)	0.0	11.4	11.1	12.9	0.0	24.7	26.4	74.9
Policy Effectiveness (reduction from baseline)								
Petroleum consumption (milllion barrels)	0	47	242	3,454	0	74	344	4,998
Energy-related CO2 (million metric tons)	0	20	82	1,211	0	28	117	1,739
Cost-effectiveness (based on "lower estimate")								
Policy cost per:								
barrel petroleum consumption ($/bbl)	na	198	-5	**-11**	na	285	26	**0**
metric ton CO_2 reduced ($/tonne)	na	473	-16	**-31**	na	753	76	**0**
Cost-effectiveness (based on "upper estimate")								
Policy cost per:								
barrel petroleum consumption ($/bbl)	na	344	140	**35**	na	435	171	**47**
metric ton CO_2 reduced ($/tonne)	na	820	412	**100**	na	1,149	502	**134**

Notes: Positive numbers denote a cost of the policy, negative numbers an offsetting benefit other than the policies' target benefits of lower energy consumption and lower GHG emissions. bbl stands for barrels. NPV stands for net present value in 2007, computed at a 5 percent interest rate and including estimated continuing benefits through 2045. For effectiveness measures, it is just the undiscounted total for 2010–2045. Because costs are discounted but effectiveness measures are not, overall cost-effectiveness in the NPV column can be lower than the cost-effectiveness in any single year.

5.3 Summary Comparison of Policies

Table 5.3.1 presents summary numbers from the results for the six policies just described: two fuel tax policies, one CAFE extension, a combined CAFE extension and fuel tax, and two feebate policies. The welfare costs shown are the average of the lower and upper policy cost estimates described earlier; in effect, they assume that half of the discrepancy between perceived and objective fuel cost savings represents a real economic distortion (for example, due to consumer uncertainty about future fuel prices) and half is caused by hidden amenity losses associated with those cars. Results are shown for years 2020 and 2030. Certain key variables are also shown for these two years, along with 2007 for comparison.

The table reveals substantial reductions in oil imports over the period 2007–2030, but most of it comes from the policies and trends in our Core 1 baseline. Specifically, under that baseline, imports fall by 2.1 million barrels per day, from 19.9 to 17.8. Each of the policies

produces some further reductions; predicted 2030 imports range from 17.7 million barrels per day, under either the Pavley CAFE or the High Feebate policy, down to 16.4 million barrels per day when CAFE is combined with a $3 per gallon fuel tax. Thus, the maximum 23-year reduction achievable by the policies modeled is about 3.5 million barrels per day. This is not to say that it would be impossible to do more with transportation policies, but it does show the difficulty of making drastic reductions in the transportation sector alone.

I also calculated the cost savings to the LDV sector of the economy from lower pretax fuel prices, which occur from most policies. Such a price reduction would occur mainly because the United States accounts for a large enough part of world demand for petroleum that lowering its demand will have a discernable effect on world prices. However, these cost savings to the United States mostly consist of a transfer of wealth from oil-exporting nations; thus, they are not really an offset to policy cost, but rather one of the policy objectives—to lower the overall costs of energy (mainly petroleum) to the domestic economy.[40] For this reason, these calculations are not shown here, but it is worth keeping in mind that these cost savings can be quite large. In our simulations, the reduction in the average price of automotive fuels in 2030 is small but far from negligible: $0.07, $0.09, and $0.11 per gallon-equivalent for the High Fuel Tax, Pavley CAFE, and High Feebate scenarios, respectively. The associated cost savings in 2030, just to the LDV sector, are $8.8 billion, $12.0 billion, and $14.0 billion, respectively. Of course, other sectors of the economy would realize even larger savings.

[40] This phenomenon is known as the *monopsony component* of the *oil import premium*, the latter defined as "the quantifiable per-barrel economic costs that the U.S. could avoid by a small-to-moderate reduction in oil imports" (Leiby 2007, 2). One could argue that it is inconsistent to consider it as a benefit if one also considers, as is usual, that the benefits from reduced GHGs should be measured on a worldwide, and not just parochial, basis.

Table 5.3.1. Summary of Policies Using Key Annual Metrics, 2020 and 2030

	2007	2020								2030							
		Baseline		Policy run						Baseline		Policy run					
		Core 1	Core 1 Neutral	High Fuel Tax	Very High Fuel Tax	Pavley CAFE	Pavley CAFE & Very High Fuel Tax	High Feebate	Very High Feebate	Core 1	Core 1 Neutral	High Fuel Tax	Very High Fuel Tax	Pavley CAFE	Pavley CAFE & Very High Fuel Tax	High Feebate	Very High Feebate
Key metrics – annual																	
Total petroleum (million bpd)	**19.94**	**17.84**	**17.85**	17.07	16.44	17.73	16.38	17.72	17.65	**17.99**	**17.99**	17.19	16.73	17.27	16.27	17.33	17.05
Total energy-related CO_2 emissions (mmt)	**5,991**	**5,881**	**5,888**	5,751	5,636	5,869	5,626	5,869	5,861	**6,193**	**6,190**	6,058	5,979	6,088	5,897	6,108	6,072
Total GHG emissions (mmt)	**7,282**	**7,383**	**7,391**	7,251	7,134	7,372	7,124	7,371	7,363	**7,946**	**7,943**	7,811	7,734	7,842	7,652	7,861	7,826
Real GDP, $ billion (2000 $)	**11,525**	15,399	15,399	15,373	15,353	15,396	15,352	15,400	15,400	19,871	19,871	20,008	20,169	19,865	20,156	19,873	19,874
Total welfare cost of policy, $ billion (2007$)	–	–	–	5.1	18.9	13.3	32.0	12.7	26.5	–	–	7.8	25.7	15.8	43.2	16.3	33.9
Average welfare cost of reducing petroleum, $/barrel	–	–	–	18.2	36.9	310.3	59.5	271.1	360.3	–	–	27.0	55.7	60.0	68.8	67.1	98.5
Average welfare cost of reducing CO_2, $/ton	–	–	–	39.4	77.1	685.6	121.6	646.5	951.2	–	–	58.0	120.4	155.6	147.8	198.3	288.9

Notes: GDP, gross domestic product; bpd, barrels per day; mmt, million metric tons.
Source: Author's calculations. Welfare costs are the average of the "lower" and "upper" estimates in Tables 5.2.1–5.2.3.

Table 5.3.2 provides a summary of policy costs and cost-effectiveness. The table shows that, for each of the pairs of policies, the average cost-effectiveness rises substantially as policy stringency is increased. Nevertheless, the combined CAFE and fuel tax continues to stand out as a policy that achieves the most reductions in petroleum use and CO_2 emissions, yet at an intermediate level of cost per unit of reduction.

Table 5.3.2. Summary Comparison of Policies' Costs and Cost-Effectiveness

	High Fuel Tax	Very High Fuel Tax	Pavley CAFE	Pavley CAFE & Very High Fuel Tax	High Feebate	Very High Feebate
Effects of policies relative to baseline (total)						
Total effect: petroleum reduction (million barrels)	5,228	9,614	3,612	12,262	3,454	4,998
Total effect: CO_2 reduction (million metric tons)	2,419	4,590	1,429	5,679	1,211	1,739
Policy cost metrics						
Without external costs of driving:						
Welfare cost ($ billion)	53.3	206.5	44.6	265.9	41.9	116.8
Cost effectiveness: petroleum ($/barrel)	10.2	21.5	12.3	21.7	12.1	23.4
Cost effectiveness: CO_2 ($/metric ton)	22.0	45.0	31.2	46.8	34.6	67.1
With external costs of driving:						
Welfare cost ($ billion)	-182.5	-212.2	80.0	-126.2	89.0	186.6
Cost effectiveness: petroleum ($/barrel)	-34.9	-22.1	22.1	-10.3	25.8	37.3
Cost effectiveness: CO_2 ($/metric ton)	-75.4	-46.2	55.9	-22.2	73.5	107.3

Notes: All monetary figures are in 2007 dollars except where noted. Fuel taxes are relative to the Core 1 baseline; other policies are relative to the Core 1 Neutral baseline. Welfare costs are discounted at 5 percent interest (real), and include an estimate of post-2030 costs or cost offsets. Total effects are undiscounted totals, also including estimate of post-2030 effects. (Post-2030 costs and effects are those due to capital in place by 2030, not to any assumed further continuation of policy.)
Source: Author's calculations of NPVs (for costs) and cumulative totals (for policy effects). Cost-effectiveness is their ratio. Welfare costs are the average of the "lower" and "upper" estimates in Tables 5.2.1–5.2.3.

The bottom panel of the table highlights how dramatically different the results are if one accounts for the external costs of driving, estimated as explained earlier (category 6). These costs are so large—approximately 11 to 13 cents per mile over the simulation period—that even the small increases in VMT resulting from CAFE and feebate policies add substantially to their policy costs. Even more dramatically, the large reductions in VMT from the scenarios involving higher fuel taxes bring policy benefits that, in these calculations, more than offset all the policy costs. These results depend, of course, on the validity of the external cost estimates and the responsiveness of VMT to the fuel cost of driving that is assumed in NEMS-RFF —the latter, as discussed earlier, being perhaps on the high side in light of recent research showing a fall over time in such responsiveness. Even so, the results show that the side effects of these policies are potentially as important as, or more important than, all of the costs that are conventionally measured.

6. Conclusions

NEMS-RFF is quite successful in depicting the workings of energy policies in transportation. Its detail and attention to technologies make it especially well suited to capturing technological changes to new motor vehicles, which are probably the most important response to any policy likely to be implemented in the United States.

The policies modeled here are draconian compared to any policies that have made serious headway in the U.S. political system. Possible exceptions are the Pavley CAFE and High Feebate policies, which have precedents, respectively, in the recent National Energy Program (for integrating fuel efficiency and GHG regulations) and the existing gas-guzzler tax. Nevertheless, the effects of the two policies just mentioned are modest: by 2030, they achieve reductions in energy use for LDVs of 8.4 percent and 7.1 percent, respectively—reductions that are important but far from the ambitious goals that many observers have set. Stronger effects are possible, but at increasing political difficulty and increasing cost per barrel of oil saved or per ton of CO_2 emissions reduced. Partly this is because even the milder policies come close to exhausting the set of possible technological improvements that are currently known to be possible at reasonable cost.

High fuel taxes, on the order of $2.00 per gallon in real 2007 dollars, have somewhat greater effects and achieve somewhat more favorable cost-effectiveness ratios, at least under middle assumptions about what costs should be included. One big advantage of the fuel tax is that its effects begin more quickly because the tax immediately affects the amount of driving of all vehicles as well as the fuel efficiency of new vehicles. By contrast, the benefits of CAFE or

feebate policies come slowly, only as the fleet turns over to incorporate the newer, more fuel-efficient cars. However, fuel tax increases anywhere near this magnitude do not appear to be politically feasible. These rates, for example, are many times higher than the price rises that would result from currently considered versions of cap-and-trade legislation for carbon emissions.

Hybrid-electric vehicles play an important role even in our baseline policy, reaching between 23 and 27 percent market share by 2030, depending on assumptions about consumer acceptance of this newer technology. This role is substantially enhanced by the fuel tax and feebate policies, although not much by Pavley CAFE. In our simulations, the reason the CAFE policy encourages fewer hybrids seems to be the details of how manufacturers trade off performance and fuel efficiency under regulation, compared to how they trade them off when given only financial incentives. It is not entirely clear whether this is an artifact of the model or a real policy difference.

Shifts among size classes of vehicles play a somewhat muted role. Nevertheless, the fuel tax policies make part of their gains by luring people out of light trucks and into cars—raising car market share by 6 percentage points in 2020 in the case of the High Fuel Tax. CAFE and feebate policies work in the opposite direction, causing significant shifts from cars to trucks, in part because they are specifically designed, as currently implemented and as modeled here, not to encourage smaller vehicles. The feebate with a single pivot point might discourage this shift to trucks, but current research has not shown this definitively.

Regarding the costs of policies, a number of interesting lessons emerge.

- Policy costs for fuel taxes are significant but reasonable, even under pessimistic assumptions. For example, our central cost estimate (excluding the external costs of driving) is $22 per metric ton of CO_2 for the High Fuel Tax.
- Policy costs for CAFE and feebates are also significant and are strongly dependent on why consumers value fuel savings at less than their objective economic value. These fuel savings are very large, but if one assumes that the more efficient cars have hidden amenity costs, causing the apparent consumer undervaluation of future fuel savings, then these amenity losses offset most or all of the fuel savings. Thus, depending on assumptions, these policies can be very cheap or very expensive per barrel of oil or per ton of CO_2 saved.
- According to NEMS-RFF's depiction of the larger energy markets, the policies considered here will cause a reduction in the pretax gasoline price of $0.08–$0.17 per

gallon in 2030. This may not seem like very much, but the associated cost savings, even within just the transportation sector, create substantial benefits for U.S. consumers—on the order of $9 billion to $14 billion just in that year. Most of these benefits are at the expense of oil-exporting nations.

- External costs of driving (congestion, accidents, and local air pollution) are very important side effects of these policies, and they play an important role in comparing them. Vehicle travel is mildly *encouraged* by CAFE and feebates (the so-called rebound effect), and strongly *discouraged* by the fuel tax. For this reason, counting external costs increases the policy costs of CAFE and feebates on one hand, and greatly decreases the policy costs of fuel taxes on the other, making them, in fact, negative—that is, these side benefits of the policy exceed the costs of more expensive vehicles and lost consumer surplus.

Appendix A: Costs of Policies

The social costs of energy policies for passenger transportation are measured by applying the usual microeconomic tools to the two primary markets affected, that for new vehicles and that for travel. The starting point for each market is the loss of consumer and producer surplus between the two situations being compared, calculated using the *rule of one-half* to approximate demand curves by straight lines. I first explain the rule for a general market, then apply it to the two interacting markets for motor vehicle purchase and use.

In a single market, the loss of consumer and producer surplus when the price rises can be decomposed into three parts:

(a) additional production costs;

(b) the loss of value to consumers due to a cutback in goods consumed; and

(c) the loss of net income to producers (including workers) due to a cutback in goods produced.

This decomposition is illustrated in Figure A.1 for an increase, Δc, in production cost, with fraction $(p^1 - p^0)/\Delta c$ passed through to consumers. The three components just enumerated can be seen in the diagram as:

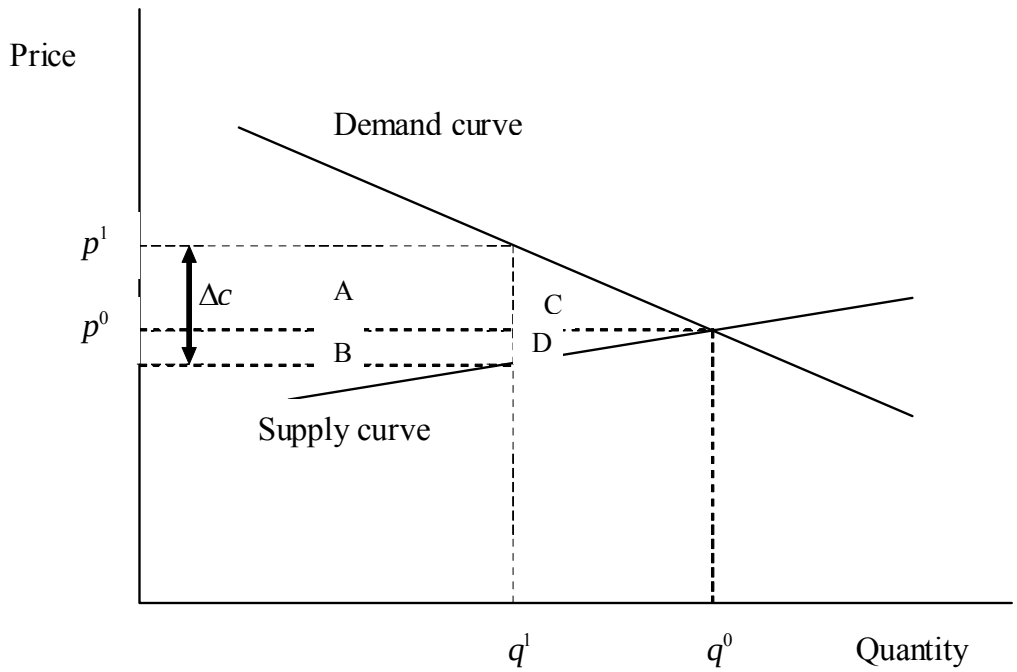
(a) additional production costs = areas A + B

(b) the loss of consumer surplus on reduced consumption = area C; and

(c) = the loss of producer surplus on reduced production = area D.

Note that if the supply curve is horizontal, areas B and D are zero, so component (a) is area A and component (c) is zero.

Figure A.1. Welfare Effects in General Market



We now turn to the complication of having two related markets, one for the purchase of vehicles and the other for their use. We must keep in mind that the first consumer decision is made once during the life of a vehicle, whereas the second is made on an ongoing basis. In what follows, I first illustrate in detail how these interacting consumer decisions can be analyzed in the case of fuel efficiency standards and then turn to the modifications needed for the case of fuel taxes.

Fuel Efficiency Standard

The costs of a higher fuel efficiency standard can be seen in common-sense terms as the combination of several categories:

- a higher cost of producing more fuel-efficient new vehicles, including lost consumer surplus from vehicles no longer purchased;
- offsetting fuel savings, including gained consumer surplus from increased travel due to lower fuel cost per mile;
- a loss of fuel tax revenues by governments; and

- additional external costs of driving.

The same considerations apply to fuel efficiency improvements induced by taxes or rebates based on new-vehicle fuel efficiency.

The diagrammatic interpretation of these categories can be seen by expanding the analysis of Figure A.1 to that of Figure A.2. I simplify by making use of the fact that NEMS-RFF allows for no rising producer supply curve, so that areas B and D in Figure A.1 are zero; this also means that all of the increased cost of manufacturing is passed through to consumers.[41]

To depict the interrelationship among the markets for new vehicles and that for travel, demand for vehicles is now shown as a function of net vehicle cost to the consumer π. Here, π is "full price," defined as vehicle price p plus expected lifetime fuel costs *as evaluated by the consumer according to the model assumptions governing purchase decisions*.[42] Specifically, $\pi = p + f$ where f is the perceived fuel cost over a payback period, T^P, during which the consumer evaluates fuel savings. For comparison, demand is also shown as a function of vehicle purchase price p, as before, but with fuel efficiency adjusted to reflect how it actually varies with p.

The change in perceived fuel cost, Δf, is portrayed in Figure A.3. It consists of two components: (a) the change in fuel expenditures incurred if mileage per vehicle were to remain the same as before, which is the negative of area A in Figure A.3, minus (b) any gain in consumer surplus resulting from increased mileage driven per vehicle due to a lower per-mile cost of driving (area C in Figure A.3). For a policy raising fuel efficiency standards, then, both components contribute to *reducing* annual perceived fuel cost by an amount equal to the trapezoidal area A + C.

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[41] These markets are analyzed by Fischer et al. (2007), who derive a formula for the welfare effect of an infinitesimal increase in the fuel efficiency standard. My results are essentially the same as their equation 13, but are categorized differently and apply to finite as well as very small changes. My analysis is very similar to that described by NHTSA in its cost–benefit analysis of fuel efficiency standards (NHTSA 2008, 24403–24416).

[42] This methodology is also adopted by NHTSA (2008), whose assumptions on consumer behavior are: five-year vehicle lifetime and no discounting of fuel costs.

Figure A.2. Welfare Effects in the Market for New Vehicles

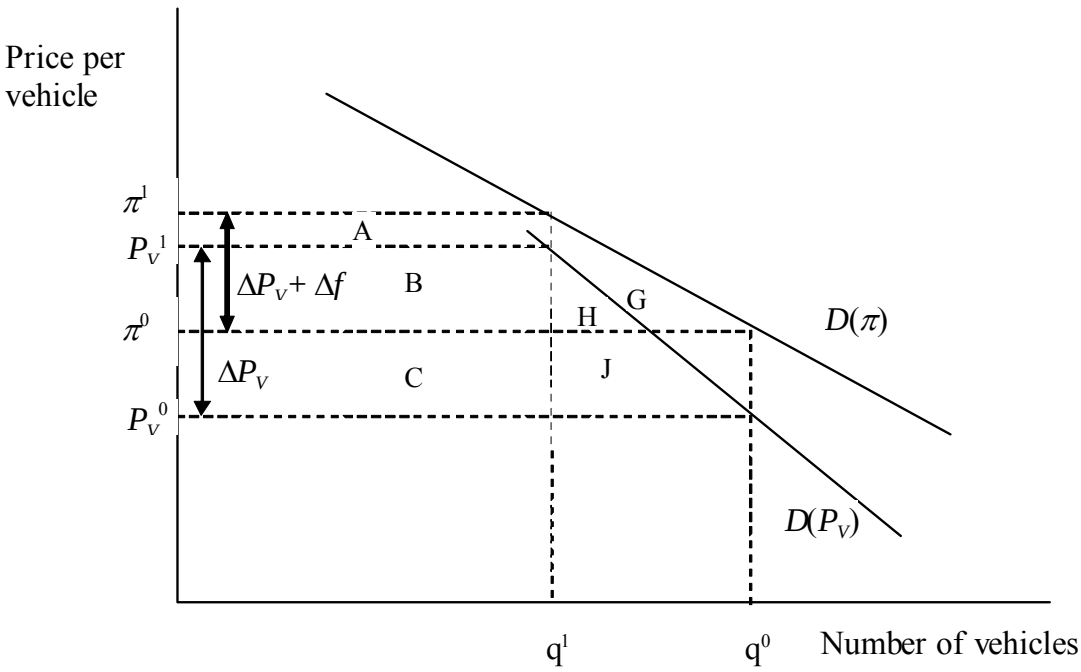
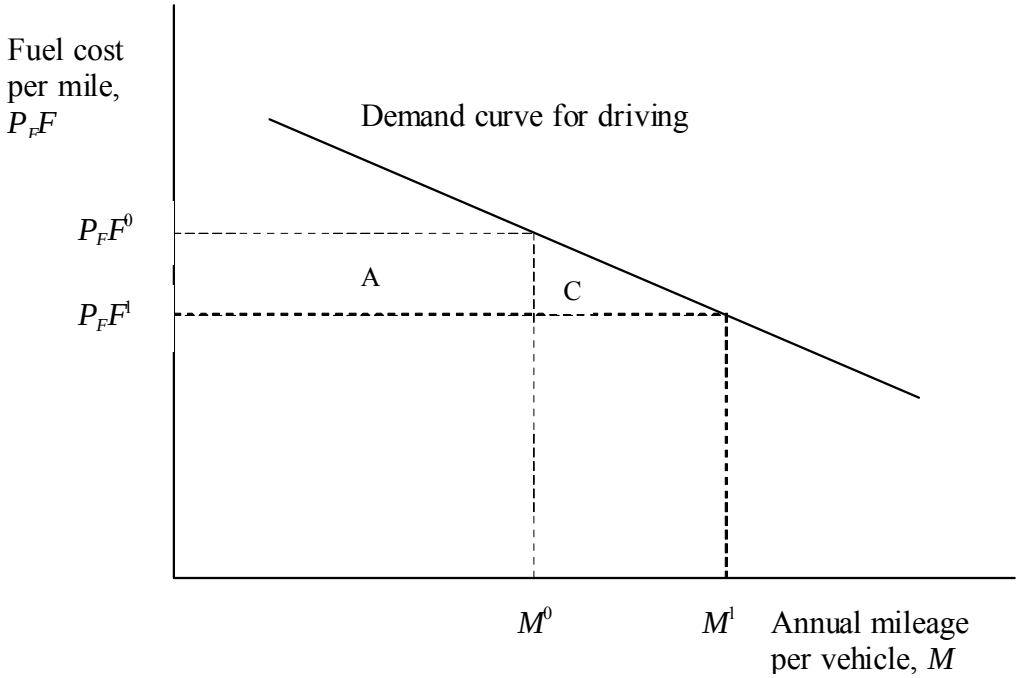


Figure A.3. Welfare Effects in Market for Vehicle Use



When cumulated over the payback period (three years in NEMS-RFF), we must account for both the real discount rate r^P assumed to be used by consumers (15 percent per year in NEMS-RFF) and the rate of decline r^f in real fuel savings over time (approximately 2 percent per year in our baseline scenario, consisting of a 3 percent per year decline in annual mileage offset by a 1 percent per year increase in fuel price).[43] To obtain a cumulative total, then, areas such as A + C in the diagram must be multiplied by the *annuity factor* $A(r^P,T^P)$ that converts an income stream of $1 per year to a present value

$$A(r^{Pf},T^P) = \frac{1-(1+r^{Pf})^{-T^P}}{r^{Pf}}$$

where $r^{Pf} = r^P + r^f$ (0.17 in our scenarios) and T^P is the payback period. The change in perceived fuel cost over the vehicle's life is then

$$\begin{aligned}\Delta f &= P_F \cdot \left(M^0 \Delta F + ½\Delta M \cdot \Delta F\right) \cdot A(r^{Pf},T^P) \\ &= \overline{M} P_F \Delta F \cdot A(r^{Pf},T^P)\end{aligned} \tag{A1}$$

where

P_F = fuel price;

M = annual mileage in the first year of the vehicle's life;

F = fuel intensity (gpm);

M^0, M^1 = mileage without policy and with policy (same for F);

$\Delta M = M^1 - M^0$ (same for F); and

$\overline{M} = ½(M^0 + M^1)$ (same for F).

We can now analyze perceived welfare cost as negative welfare gain, $-\Delta W_{VF}^P$, in vehicle and fuel markets together as shown in Figure A.2:

[43] NHTSA (2008, 24406–24407) assumes that $r^P = 0$ and T^P = five years, whereas the actual median lifetime of a vehicle is about T = 14 years (sections e and f, especially note 105). These assumptions imply that consumers value a considerably greater portion of lifetime fuel savings compared to the NEMS assumptions.

$-\Delta W_{VF}^{P}$ = (extra production cost for vehicles produced) – (perceived fuel cost savings on vehicles purchased) + (lost consumer surplus on vehicle no longer purchased)

= (areas B + C) – (areas C – A) + (areas G + H)

= areas B + A + G + H,

which is simply the total consumer surplus loss due to a net increase in full price, π, as measured by the change in area under the demand curve, $D(\pi)$, and above the price line. Evaluating the three parts of this equation, we find:

extra production cost = B + C = $q^1\Delta c > 0$;

– (fuel cost savings) = A – C = $q^1\Delta f < 0$; and

lost surplus loss on vehicles no longer purchased = G + H = $\frac{1}{2}\cdot(\Delta c+\Delta f)\cdot(q^0-q^1) > 0$.

The last term is presumed positive, indicating that $\Delta c+\Delta f > 0$, because otherwise, profit-maximizing manufacturers would voluntarily have offered vehicles with lower f—indeed they are assumed explicitly to do so in NEMS-RFF. (Recall, however, that f is perceived, not actual, lifetime fuel savings.)

Combining

$$\begin{aligned} -\Delta W_{VF}^{P} &= \left[q^1\Delta c + \tfrac{1}{2}\cdot(-\Delta q)\cdot\Delta c\right] + \left[q^1\Delta f + \tfrac{1}{2}\cdot(-\Delta q)\cdot\Delta f\right] \\ &= \bar{q}\Delta c + \bar{q}\Delta f \qquad \text{(A2)} \\ &\equiv -\Delta W_V - \Delta W_F^{P} \end{aligned}$$

where

$$\Delta q = q^1 - q^0$$

$$\bar{q} = \tfrac{1}{2}(q^0 + q^1)$$

$$-\Delta W_V = \bar{q}\Delta c \qquad \text{(A3)}$$

$$-\Delta W_F^{P} = \bar{q}\Delta f = \bar{q}\overline{M}P_F\Delta F\cdot A(r^{Pf}, T^{P}) \qquad \text{(A4)}$$

(The superscript P on W indicates that it uses perceived parameters for calculating cost savings.)

Thus, the perceived policy cost in the vehicle market, $-\Delta W_{VF}^{P}$, can be viewed according to (A2) as the sum of two conventional welfare measures: the first (positive) is the cost arising from the increase in vehicle price, including lost consumer surplus of vehicles no longer purchased; whereas the second (negative) is the offsetting fuel savings plus any consumer surplus change due to differences in the amount of driving.[44] To see how this decomposition works diagrammatically, note that we can depict $-\Delta W_V$ as the following areas in Figure A.2

$$-\Delta W_V = (B + C) + (H + J)$$

This geometric interpretation looks like a conventional welfare calculation in the new-car market, regarding π as price. Later, we will divide the perceived fuel cost savings, $-\Delta W_F^P$, into a portion reflecting the pretax cost of fuel and a portion reflecting changes in tax revenues; but it is more convenient to do this after accounting for differences between consumers' perceived fuel cost savings and those actually realized.

In practice, of course, many kinds of vehicles are offered for sale and the prices of each may change differently; so the right-hand side of (A3) is replaced by a sum over all of the vehicle classes. For conventional cars and light trucks (internal combustion engines powered by gasoline), the vehicle classes are the 12 size classes, 6 for cars and 6 for trucks. This procedure is accurate if shifts among the vehicle types are small; but a special problem is posed by unconventional engines such as hybrids and diesels, which attain significant market shares in some scenarios but are more expensive than conventional vehicles. To account for the high cost that consumers incur to buy these vehicles, I supplement any cost increases of the vehicles with unconventional engines themselves by assuming that these technologies are viewed as a way to obtain higher fuel savings by paying a higher price for the vehicle. For all new vehicles of this type sold because of a policy, then, I assign an additional increase in cost equal to the price difference between that vehicle and a conventional vehicle. The prices (but not the sales) of unconventional vehicles are broken out in the NEMS-RFF output by size class; I take an unweighted average of the price differences for just those few classes that appear to have some significant representation for this unconventional engine. In practice, this adjustment adds about

[44] The first is measured in NHTSA (2008, 24404, sections a and b); the second is measured in NHTSA (2008, 24405–24406, sections d and e, and 24409, section i).

10 percent to the cost increase resulting from the increased costs of the typical alternative-fueled vehicle, so is not very important to the overall result.

Adjustment for Consumer Myopia

Because consumers are assumed here to undervalue fuel savings, commonly called myopia, additional savings must be accounted for, namely, the difference between those calculated using social and perceived values of the interest rate and lifetime. Denoting the savings calculated using social values by $-\Delta W_F^G$ (the superscript G indicating that it is gross of fuel tax), the adjustment for myopia becomes

$$\begin{aligned} -\Delta W_{F+} &= -\Delta W_F^G + \Delta W_{F+f}^P \\ &= \bar{q}\overline{M}P_F \Delta F \cdot [A(r,T) - A(r^P, T^P)] \end{aligned} \tag{A5}$$

where $r^{+f} = r + r^f$ is the social discount rate augmented by 2 percent (to account for declining fuel cost savings with vehicle age), and where

$$-\Delta W_F^G = \bar{q}\overline{M}P_F \Delta F \cdot A(r^{+f}, T) \tag{A6}$$

is the social value of the gross-of-tax fuel savings.

At this point, it is convenient to separate ΔW_F^G into the real cost savings and the change in tax payments, the latter being a transfer rather than a real cost savings. We accomplish this by decomposing gross price P_F in (A7) into the net (pretax) price, $P^F - \tau^F$, and the excise tax rate, τ^F. This yields

$$\begin{aligned} -\Delta W_F^G &= \bar{q} \cdot (P_F - \tau_F) \cdot \overline{M}\Delta F \cdot A(r^{+f}, T) + \bar{q}\overline{M}\tau_F \Delta F \cdot A(r^{+f}, T) \\ &\equiv -\Delta W_F + \Delta W_R^F \end{aligned} \tag{A7}$$

where

$$-\Delta W_F = \bar{q}\overline{M} \cdot (P_F - \tau_F)\Delta F \cdot A(r^{+f}, T) \tag{A8}$$

is fuel savings at prices net of tax, and

$$\Delta W_R^F = \overline{q}\overline{M} \cdot \tau_F \Delta F \cdot A(r,T) \tag{A9}$$

is the change in government revenue (discounted and cumulated over the vehicle's life) resulting directly from the fuel efficiency improvement (but not accounting for induced changes in the amount of driving). For a fuel efficiency improvement ($\Delta F < 0$), (A8) is negative, implying a negative social cost from saving in fuel; whereas (A9) is positive, implying a positive social cost from reduced fuel tax revenues. (The next section considers the additional change in fuel tax revenues due to changed VMT.)

Lost Fuel Tax Revenues

As we have seen, a loss of government fuel tax revenues can be caused by fuel efficiency improvements. If the savings in those tax payments is counted as a benefit to consumers, as it is in equation (A7), then a portion of that benefit is a transfer rather than a benefit. We can account for this by adding the lost revenue as another policy cost. (For simplicity, I cumulate and discount the annual revenue losses over the vehicle's lifetime using the same annuity factor, $A[r,T]$, although fuel tax payments might actually decline over a vehicle's life at a rate different from that of total fuel cost, depending on tax policies.) Thus, this policy cost is

$$\begin{aligned} -\Delta W_R &= -\tau_F \cdot \left(q^1 M^1 F^1 - q^0 M^0 F^0\right) \cdot A(r^{+f},T) \\ &= -\tau_F \cdot \left[\overline{F} \cdot \Delta(VMT) + \overline{VMT} \cdot \Delta F\right] \cdot A(r^{+f},T) \\ &= -\Delta W_R^V - \Delta W_R^F \end{aligned} \tag{A10}$$

where $(VMT) \equiv qM$ and where

$$-\Delta W_R^V = -\tau_F \overline{F} \cdot \Delta(VMT) \cdot A(r^{+f},T) \tag{A11}$$

is the loss of revenues associated with changes in VMT (calculated at the average of the pre- and postpolicy fuel efficiencies). In (A10), I have used the approximation $\overline{VMT} = \overline{q}\overline{M}$ (valid if $\frac{1}{2}\Delta q \Delta M$ is small, as it is empirically).

Note that adding equation (A10) to the other components of policy cost results in a cancellation of the term ΔW_R^F, which appears with opposite signs in equations (A7) and (A10).

External Costs of Vehicle Use

Although it is not included in the main totals, we may also be interested in estimates of changes in the external costs of congestion, air pollution, and motor vehicle accidents brought about by changes in VMT. The existence and approximate magnitude of these external costs have been amply documented.[45] Computing them requires estimates of the per-mile marginal cost of these externalities, c_M, which I assume to be constant. I use the estimates of Parry and Small (2005), adjusting for changes in prices and wage rates, which leads to values of 4.6, 3.9, and 2.6 cents per mile for congestion, accidents, and pollution, respectively, in 2010 (real 2007$), or a total of 11.1 cents per mile, growing at 1.1 percent annually thereafter.[46] This leads to a welfare cost, cumulated and discounted over the expected vehicle life T

$$-\Delta W_E = c_M \Delta(VMT) \cdot A(r^{+f}, T) \tag{A12}$$

(I have assumed, for simplicity, that external costs decline with vehicle age at the same rate as fuel costs.) For convenience of interpretation, I exclude those external costs that are the presumed targets of the policy, namely, those resulting from petroleum consumption and GHG emissions. Thus, the result can be viewed as the cost of achieving the simulated improvements in petroleum consumption and GHG emissions.

In addition, I have argued earlier that there may be a positive external cost of shifts from cars to light trucks, or equivalently, a savings from shifts in the other direction. I calculate this as an "optional" item because it is not fully accepted in the literature and the source I use is unpublished. Specifically, Figure 1 of Li (2010) shows the total estimated annual number of U.S. traffic fatalities (including injuries converted to *equivalent fatalities*) as a function of the share of

[45] See, for example, Parry and Small (2005) and Small and Verhoef (2007, sect. 3.4.6). This external cost is also explicitly identified in NHTSA (2008, 24409–24412, sections j and l[i]).

[46] Parry and Small (2005) chose values from 2000 for U.S. external costs as 3.5, 3.0, and 2.0 cents per mile for congestion, accidents, and local air pollution, respectively. I adopt the procedure of Small and Verhoef (2007) of updating them by one-half the growth in real wages, based on the fact that all three depend heavily on the value of time or the willingness to pay to avoid the risk of fatality or injury, both of which are known to depend strongly on income or wage rates. Real wages are approximated by disposable personal income per member of the labor force. This adjustment inflates the 2000 costs by 5.9 percent in addition to the price-level adjustment of 20.4 percent in 2007, and (in real terms) by another 2.4 percent in 2010, resulting in the figures quoted in the text. These figures are increased (in real terms) by 1.1 percent per year over the simulation period 2010–2030 (this last figure is calculated from the Core 1 simulation results for real disposable income per member of the labor force).

light trucks. This figure shows an increase of 4,423 fatalities in a fleet of 230 million LDVs, as the truck share grows from zero to one (using the author's preferred intermediate value of the conversion factors between injuries and fatalities). Valuing the increased risk of death at $5.5 million per fatality (Small and Verhoef 2007, 101), we obtain the annual extra cost of replacing one car by a truck as ($5.5 million × 4423) / (230 million) = $106. This value is applied to the change in the percentage of trucks in use due to any given scenario in any year, multiplied by the total number of light-duty passenger vehicles in use in that scenario in the same year. This cost turns out to be positive for the CAFE and feebate scenarios and negative for the fuel tax scenarios.

Summary

The total cost of the energy and GHG savings from the higher CAFE standard applying in any given year is obtained by adding equations (A3), (A4), (A5), (A10), and (A12). With cancellations, it is simply

$$-\Delta W = -\Delta W_V - \Delta W_F - \Delta W_R^V - \Delta W_E \tag{A13}$$

This formula for the welfare cost of the policy requires tracking the fuel used by individual vehicles over time, which is tedious and could be regarded as misleading because one does not know in advance which fuel prices will apply. Thus, in practice, it is more convenient to consider the net costs incurred by society in a given calendar year, rather than those that are associated with the vehicles produced in that year. I accomplish this by dividing the last three terms in (A13) by the annuity factor $A(r,T)$ and interpreting the fuel efficiency, F, which appears in each of them, as referring to the average fuel efficiency of the fleet during a given calendar year. Using a lowercase w for these transformed quantities, this leads to the following summary calculation

$$-\Delta W = -\Delta W_V - \Delta w_F - \Delta w_R^V - \Delta w_E \tag{A14}$$

where

$$-\Delta W_V = \bar{q}\Delta P_V \tag{A14a}$$

$$-\Delta w_F = \overline{VMT} \cdot (P_F - \tau_F)\Delta F \tag{A14b}$$

$$-\Delta w_R^V = -\tau_F \overline{F} \cdot \Delta(VMT) \tag{A14c}$$

$$-\Delta w_E = c_M \Delta(VMT) \tag{A14d}$$

The annual policy cost in equation (A14) is interpreted as increased production costs (A14a), net of fuel cost savings (A14b) computed at pretax prices, minus additional tax revenues from increased vehicle travel (A14c), plus increased external costs from that same increased vehicle travel (A14d). For purposes of comparison with other studies, results are shown both with and without the external costs measured by (A14d).

Alternative Calculation with Hidden Amenity Costs

There is an alternative explanation for consumer myopia (the tendency to value fuel savings at less than their present discounted value when making purchase decisions): namely, that unobserved amenity losses are associated with the technologies producing fuel improvements. One reason for believing this is that manufacturers appear to forgo opportunities to extract a higher price for fuel-efficient vehicles by marketing these fuel efficiencies more forcefully.

At the extreme, if these amenity losses fully account for the apparent undervaluation of fuel savings by consumers, we can estimate them and add their value to consumers as an additional cost of the policy, here called *hidden amenity costs*. This is done by computing a ratio of perceived to realized cost savings, using the NEMS-RFF behavioral assumptions for perceived savings and objective measures for realized savings.[47] A plausible assumption for an "objective" measure of realized savings over a vehicle's lifetime would be based on some consumer borrowing rate of interest, which would still involve a social inefficiency of myopic choice if that borrowing rate exceeds the social discount rate. Thus, to represent the extreme possibility for amenity loss, in which the market for cars is fully efficient, I compute the

[47] Alternatively, the hidden amenity costs could be measured as a fraction of the extra cost of new vehicles incurred by manufacturers to increase fuel efficiency, by noting that manufacturers will be aware of consumers' perceived marginal value of improvements in fuel efficiency. This marginal value, which I have been calling *perceived* fuel savings, is now interpreted as actual fuel savings gross of tax, less amenity costs. The manufacturers are then presumed, both by economic theory and by NEMS, to offer fuel efficiency technology-based improvements to the point where the marginal cost of doing so equals that marginal value—in other words, the cost to the manufacturer = the perceived value of fuel savings = the actual value of fuel savings (gross of tax) – the amenity cost. By estimating the ratio of actual to perceived value, we can solve for a ratio of amenity cost to cost to manufacturer. This would allocate all of the amenity loss to the year in which the vehicle is purchased; but I prefer, instead, the formulation, used here, that more plausibly spreads the amenity losses over the years over which the vehicle is used.

objective value of realized savings using the same social discount rate used later for computing the present discounted value of costs: namely, $r = 0.05$.

In addition, we need to know how the cost savings for a given vehicle will change over its life. In our NEMS-RFF scenarios, fuel prices grow at about 1 percent per year in real terms, whereas annual mileage for a given vehicle is assumed in NEMS-RFF to decline at about 3 percent per year. Therefore, annual cost savings from a given fuel efficiency improvement decline at 2 percent per year. The perceived and objective savings are therefore discounted at effective interest rates of $r^{+f} = 0.05 + 0.02 = 0.07$ and $r^{Pf} = 0.15 + 0.02 = 0.17$, respectively. We can then find the amenity loss, $-\Delta W_A$, as a fraction of the realized fuel savings (gross of tax), ΔW_F^G, as follows

$$\begin{aligned} -\Delta W_V &= \Delta W_F^P \\ &= \Delta W_F^G + \Delta W_A \end{aligned}$$

which we can solve for the amenity cost

$$\begin{aligned} -\Delta W_A &= \Delta W_F^G - \Delta W_F^P \\ &= \Delta W_F^G \cdot \left[1 - \frac{\Delta W_F^P}{\Delta W_F^G} \right] \\ &= \Delta W_F^G \cdot \left[1 - \frac{A(r^{Pf}, T^P)}{A(r^{+f}, T)} \right] \end{aligned} \tag{A15}$$

where A is the annuity factor introduced earlier, and $r^f = 0.02$ is the rate of decline of annual fuel cost.[48] Using the parameter values just discussed, the two annuity factors in this equation are 2.21 and 8.75, respectively; so the term in square brackets is 0.747. I assume, for simplicity, that this amenity loss occurs over time in the same pattern as the fuel cost saving, so that the same fraction applies to the annual values for amenity loss and gross fuel tax saving

[48] The ratio of annuity factors in (A15) is identical to that in Fischer et al. (2007, 12) except for using different parameter values.

$$-\Delta w_A = \Delta w_F^G \cdot \left[1 - \frac{A(r^P + r^f, T^P)}{A(r + r^f, T)}\right] = 0.747 \cdot \Delta w_F^G \tag{A16}$$

Thus, under the extreme assumption that all consumer myopia represents hidden real amenity costs, the gross-of-tax fuel savings are reduced by nearly three-fourths once these amenity costs are added in. Because the gross-of-tax fuel savings, Δw_F^G, exceed the net-of-tax fuel savings, Δw_F, and it is the latter that enters the policy cost calculation, the amenity loss can more than offset the fuel cost savings in calculating the total policy cost; in fact, it does so in both of the fuel tax scenarios analyzed here.

In the welfare tables, I show first a subtotal (called the "lower estimate"), assuming that the hidden amenity loss is zero, and then provide an alternative total (called the "upper estimate"), assuming that it takes the value shown in equation (A16).

Fuel Tax

The costs of achieving energy reductions through a fuel tax include exactly the same costs listed in the previous section, although the last two (A14c–d) have the opposite sign because now VMT is reduced instead of increased by the policy. But now some of the equations have additional terms because the fuel price P_F and fuel tax rate τ_F, which were assumed constant in the previous section, change as part of the policy. This affects two of the terms in equations (A14), namely $-\Delta w_F$ and $-\Delta w_R^V$.

To see how, consider again equation (A1) for the change in per-vehicle fuel cost, Δf. With P_F no longer held constant, the second line of (A1) now has a second term

$$\begin{aligned} \Delta f &= \overline{M}\Delta(P_F F) \cdot A(r^{Pf}, T^P) \\ &= \overline{M} \cdot (\overline{P_F}\Delta F + \overline{F}\Delta P_F) \cdot A(r^{Pf}, T^P) \end{aligned} \tag{A1′}$$

where $\overline{P_F}$ is the average of pre- and postpolicy fuel prices, and ΔP_F is their difference. Then (A4) becomes

$$-\Delta W_F^P = \overline{q}\overline{M} \cdot (\overline{P_F}\Delta F + \overline{F}\Delta P_F) \cdot A(r^{Pf}, T^P) \tag{A4′}$$

The myopia adjustment has a similar term, so that (A6) becomes

$$-\Delta W_F^G = \overline{q}\overline{M} \cdot (\overline{P_F}\Delta F + \overline{F}\Delta P_F) \cdot A(r^{+f}, T) \tag{A6′}$$

Decomposing this quantity into a part net of the fuel tax and a part due to the fuel tax, as in (A7), now introduces new terms involving ΔP_F and $\Delta \tau_F$, as follows

$$-\Delta W_F = \overline{q}\overline{M} \cdot \left[(\overline{P_F} - \overline{\tau_F})\Delta F + \overline{F} \cdot (\Delta P_f - \Delta \tau_F)\right] \cdot A(r^{+f}, T) \tag{A8′}$$

$$\Delta W_R^F = \overline{q}\overline{M} \cdot \left[\overline{\tau_F}\Delta F - \overline{F}\Delta \tau_F\right] \cdot A(r^{+f}, T) \tag{A9′}$$

Next, consider the change in tax revenues in equation (A10). It now also includes a component due to the change in fuel tax rate—indeed, this is probably its biggest component. Thus, (A10) becomes

$$\begin{aligned} -\Delta W_R &= -\left(\tau_F^1 q^1 M^1 F^1 - \tau_F^0 q^0 M^0 F^0\right) \cdot A(r^{+f}, T) \\ &= -\left[\overline{\tau_F F}\Delta(VMT) + \overline{VMT}\Delta(\tau_F F)\right] \cdot A(r^{+f}, T) \\ &= -\Delta W_R^V - \Delta W_R^F \end{aligned} \tag{A10′}$$

where $\overline{\tau_F F}$ is the average of pre- and postpolicy scenarios of the quantity $\tau_F F$, and where

$$-\Delta W_R^V = -\overline{\tau_F F} \cdot \Delta(VMT) \cdot A(r^{+f}, T) \tag{A11′}$$

Note that the only difference between (A11′) and (A11) is that now the combined quantity $\tau_F F$, not just F, is averaged between pre- and postpolicy scenarios. (For this reason, $-\Delta W_R^V$ becomes very large for scenarios with high tax rates, and it is important to remember that this quantity includes the loss of value of forgone VMT—in other words, area C in Figure A.3.) Once again, the term $-\Delta W_R^F$ in (A10′) cancels (A9′) when all terms are combined.

Combining and dividing most equations by $A(r^{+f},T)$ as before, we again obtain equation (A14) but now with two of its components redefined

$$-\Delta w_F = \overline{VMT} \cdot \left[(\overline{P_F} - \overline{\tau_F})\Delta F + \overline{F} \cdot (\Delta P_F - \Delta \tau_F)\right] \tag{A14b′}$$

$$-\Delta w_R^V = -\overline{\tau_F F} \cdot \Delta(VMT) \tag{A14c′}$$

Note that when the tax rate is unchanged, (A14c′) is identical to (A14c); therefore (A14c′) is equally valid for all policies.

Equation (A14b′) contains a new term, the one involving ($\Delta P_F - \Delta \tau_F$), which is also valid for policies other than fuel tax if they cause the economywide pretax price of fuel to change. However, as explained in the text, it mostly represents not a policy cost, but rather one of the policy objectives: to lower the overall costs of energy (mainly petroleum) to the economy. For these reasons, I do not include this new term in the calculations reported here, and instead use (A14b) for this component of policy cost.

Loss of Consumer Value from Light Trucks

Another feature of fuel tax policies that differ from the others considered here is that a substantial portion of the fuel savings is due to shifts in the mix of cars and trucks. In NEMS-RFF, this shift is unaffected by vehicle prices, but it does depend (in somewhat unintuitive ways) on fuel price and on car and truck fuel efficiencies. Higher fuel price shifts the mix toward cars; higher car fuel efficiency shifts the mix toward trucks, whereas truck fuel efficiency has only a very small effect.

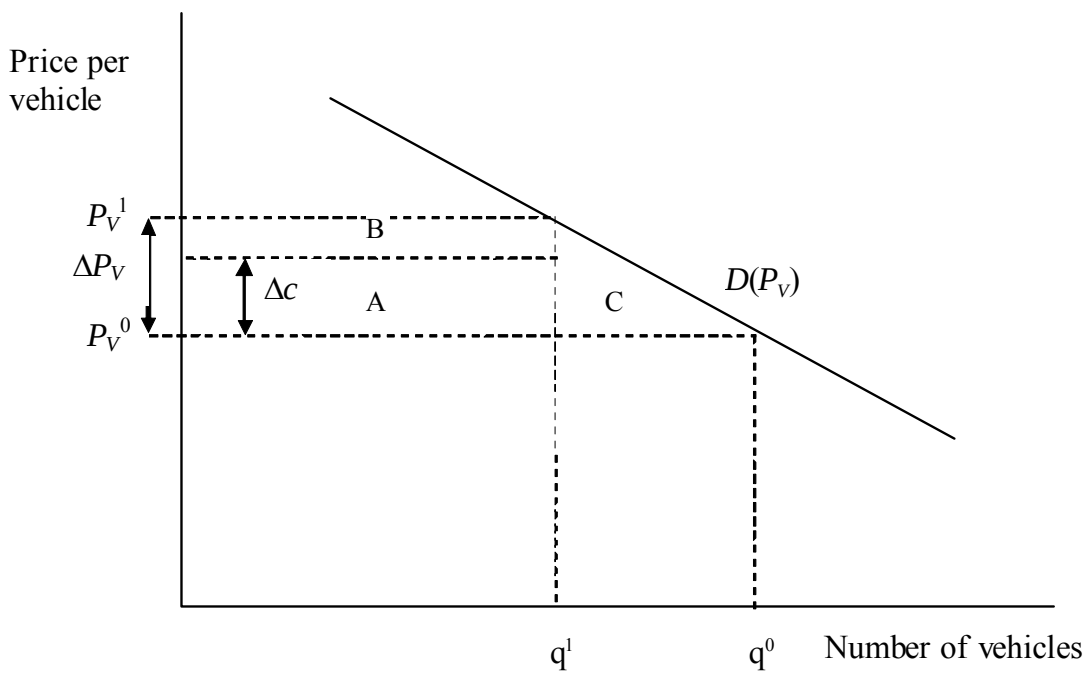
The shift caused by fuel prices presumably represents some loss of consumer value because it is largely "forced" on consumers. Unfortunately, it is impossible to calculate this loss through conventional means because we lack a demand curve for light trucks that has a clear price variable. Instead, I adopt the same approach as for the "alternative calculation with hidden amenity costs." The perceived value of fuel savings due to a shift from light trucks to cars is assumed to be equivalent to the amenity costs of the switch, and these perceived fuel cost savings are equal to actual fuel cost savings from that shift (gross of tax) multiplied by the quantity in square brackets in (A15). These actual fuel cost savings are approximated as the difference in truck share between the base scenario and the fuel tax scenario, multiplied by the difference in fuel intensity (the reciprocal of fuel efficiency) between cars and trucks in the base scenario, multiplied by total VMT and by gross fuel price (the latter two quantities measured at the average between the base and policy scenarios). This is a conservative estimate because, in NEMS-RFF, some of the shift in truck share due to the fuel tax scenario arises from the fuel efficiency changes themselves rather than directly from the fuel price change. Those fuel efficiency changes are of the opposite sign and so would tend to offset those arising directly from the huge increase in retail fuel price, but probably not very much because, based on model output

from various scenarios, we can see that truck share is predicted to be much more sensitive to fuel price than to fuel efficiency.

Feebates

In the case of a feebate policy that is not strictly revenue-neutral, some of the trapezoidal area represented by equation (A14a) may be net fees paid as part of the policy which, like production costs, are assumed in NEMS-RFF to be passed through entirely to consumers so that the change in production cost, Δc, is less than the change in vehicle price ΔP_V. Figure A.4 represents the case where the net fee is positive, so that the change in vehicle price overstates the change in average production costs. In that case, area B in the figure must be subtracted from the trapezoidal change in consumer surplus to obtain the social cost of the policy. (If there is a net rebate instead of a net fee, then $\Delta c > \Delta P_V$, and area B is negative.)

Figure A4. Welfare Effects from New-Vehicle Price Increases



Therefore, equation (A14a) is replaced by

$$-\Delta W_V = \bar{q}\Delta P_V - (\text{net fees paid by manufacturers}) \qquad \text{(A14a}')$$

Summary for All Policies

The result for welfare calculation is then simply the sum of the four components (A14a′), (A14b), (A14c′), and (A14d).

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