Energy Policies for Passenger Motor Vehicles

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Abstract

This paper assesses the costs and effectiveness of several energy policies for light-duty motor vehicles, using the National Energy Modeling System (NEMS). 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*). I find that tightening fuel-efficiency standards beyond those currently mandated through 2016, or imposing feebates designed to accomplish similar changes, can achieve by 2030 reductions in energy use by all light-duty passenger vehicles of 7.1 to 8.4 percent. A stronger feebate policy has somewhat greater effects, but at a significantly higher unit cost. High fuel taxes, on the order of $2.00 per gallon (2007$), have somewhat greater effects, arguably more favorable cost-effectiveness ratios, and produce their effects much more quickly because they affect the usage rate of both new and used vehicles. Policy costs vary greatly with assumptions about the reason for the apparent myopia commonly observed in consumer demand for fuel efficiency, and with the inclusion or exclusion of ancillary costs of congestion, local air pollution, and accidents.

Keywords: fuel efficiency, light-duty vehicles, energy policy, greenhouse gases, feebate, fuel tax

JEL codes: L92, R48, Q48, Q54, Q52

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The significant role of motor vehicles used for passenger travel in greenhouse gas emissions and petroleum consumption is well known. Consequently, most analysts believe that serious strategies to address climate change or energy dependence will require significant reductions from this sector.

This paper undertakes an assessment of effectiveness and costs of various policies aimed at such reductions. It does so by defining specific measures as input parameters to the National Energy Modeling System (NEMS), a comprehensive model of energy sectors used by the Energy Information Administration (EIA) for its regular projections and analyses (EIA 2009b). The paper is part of a larger suite of studies using NEMS and other tools to analyze a wide variety of energy and greenhouse gas (GHG) policies in a consistent manner facilitating comparison (Krupnick et al. 2010).

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's effects are determined with respect to a baseline scenario, which starts with a NEMS simulation (to 2030) of the updated *Annual Energy Outlook 2009* scenario of EIA (2009a) (including the 2009 federal stimulus package); that simulation is further modified to incorporate the National Fuel Efficiency Policy as announced by the president in May 2009. In the latter program, GHG standards are developed for passenger vehicles and integrated with fuel-efficiency standards.

Estimating the social costs of such policies 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), would contains all of the information needed for rigorous welfare analysis; but it would have the disadvantage of a limited range of mathematically tractable demand functions and market interactions. In contrast, a model such as NEMS, containing many empirically based components, can be more realistic but does not permit a direct calculation of consumer utility; instead, the components of social cost must be inferred

from the empirical demand and cost relationships. Doing so is complex because of the many interacting dimensions of behavior involved. Furthermore, certain well-established behavioral regularities represented in NEMS, such as consumers' use of short time horizons for their purchase decisions, are at least superficially inconsistent with standard assumptions of economic theory, and therefore require auxiliary assumptions to determine changes in well-being.

The study results show that even aggressive versions of these policies achieve only modest reductions in petroleum use and greenhouse gas emissions. Stronger policies are possible, but at diminishing effectiveness and increasing costs. Policy costs are found to depend greatly on two factors that are empirically uncertain. First, if consumers' hesitancy to fully value fuel savings is because those savings are tied to amenity losses that are hidden to analysts, then the policy costs are much higher, especially for policies aiming directly at fuel efficiency. Second, including external costs raises the costs of fuel-efficiency policies, but greatly lowers the costs of a fuel tax, making the latter negative. Finally, a fuel tax achieves its targeted policy gains much more quickly than fuel-efficiency policies because it relies more heavily on reductions in vehicle use, which apply to used as well as new vehicles.

1.   Passenger Highway Transportation in the United States

The relative contribution of transportation to energy problems is quite different depending on which problem one considers. According to EIA (2009a), light-duty vehicles (LDVs) —consisting of passenger cars, vans, sport utility vehicles, and pickup trucks— accounted for 44 percent of liquid fuels consumption but only 15 percent of all greenhouse gas emissions in 2008. Energy consumption by LDVs grew by 70 percent from 1970 to 2007, although the path was punctuated by occasional declines (Figure 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, while the fuel intensity of vehicles (i.e., the reciprocal of fuel efficiency), *declined* by 36 percent. Thus, vehicles became more efficient, but not enough so to overcome the huge increase in usage.
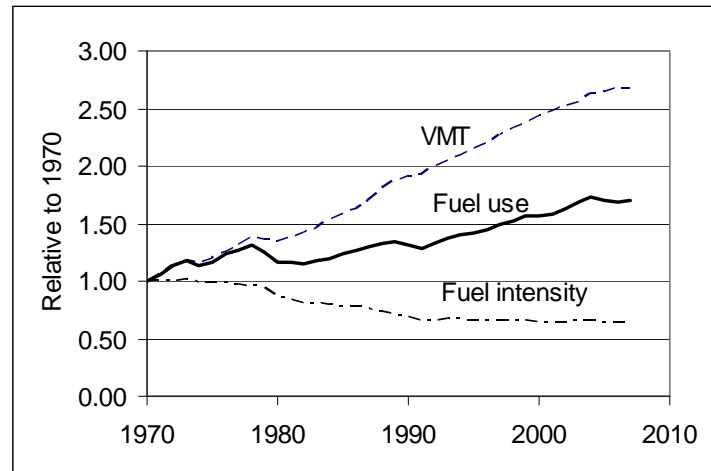
Figure 1. Changes in Fuel Use and Its Components

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 improvements in the fuel efficiencies of individual vehicles, somewhat counteracted in more recent years by adverse changes in the size mix of vehicles. For example, between 1980 and 2008, the fuel economies of small cars and midsize sports utility vehicles (SUVs) rose by 21 percent and 76 percent, respectively. But the market shares of small cars and midsize SUVs went in opposite directions over that period, that of small cars declining (by 23 percentage points) and that of midsize SUVs rising (by 16 percentage points), thereby eroding some of the energy savings from the technology changes. The relevance of this example is confirmed by disaggregating all LDVs into 15 size classes, six of cars and nine of light trucks.[1] Had market shares of these size classes remained at 1980 values, the sales-weighted average fuel efficiency of new LDVs in 2008 would have been 27.3 mpg rather than 24.0 mpg as it actually was.[2]

Fuel prices have played a significant role in driving vehicle fuel efficiency, and they promise to continue to do so in the future. Real gasoline prices in the U.S. declined sharply from

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[1] In this paper, LDVs consist of cars and light trucks, the latter including vans, SUVs, and pickup trucks with gross weight less than 8,500 pounds. Vans, SUVs, and pickup trucks with gross weight 8,500–10,000 pounds—including the Hummer—are treated differently in NEMS and called "commercial light trucks," although elsewhere they are called "intermediate trucks" or "Class 2b vehicles".

[2] Calculated from data in Davis et al. (2009), Tables 4.7, 4.9.

1982 through 1988, and remained low for a decade. A gradual rise began in 1999, accelerating sharply in 2003; but only in 2008 did it again reach its 1980-1982 value. The average fuel efficiency of new LDVs has moved inversely to these trends, as theory would predict. Studies that attempt to disentangle the effect of fuel price from other causes have generally found a consistent, though moderate, response of fleetwide fuel efficiency to price. This response is measured by Small and Van Dender (2007a, Table 5) as a long-run elasticity of fuel efficiency with respect to fuel price of 0.20.

Data on market shares of new-vehicle sales further illuminate the effect of the sharp run-up in prices in 2003–2008. Table 1 shows market shares for various LDVs in 2004 and 2008, grouped this time into six categories. During this time, the market share of cars rise 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), making a similar point for the 2004–2006 period, also models the response statistically using monthly data by vehicle category; he finds that a 20 percent increase in gasoline price raises the market share of cars among new LDVs by 2.6 percentage points.

Table 1. 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 Corporate Average Fuel Economy (CAFE) standards, which went into effect in 1978. Applied

separately to cars and light trucks, the standards rose gradually through 1984 and then were nearly flat for 20 years, at 27.5 mpg for cars and approximately 20.5 mpg for trucks. The standard for light trucks then began to rise again, starting in 2005.[3]

Two subsequent changes in fuel-efficiency regulations will bring significant new increases in fuel efficiency starting in 2011. The first is due to 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 change is that embodied in the National Fuel Efficiency Policy announced by President Obama in May 2009. Under this program, GHG and fuel-efficiency regulations are coordinated, resulting in an expected new-vehicle fuel efficiency of about 35 mpg by model year 2016.[4] Thus, current legislation and regulatory decisions provide for sharp increases in fuel efficiency through 2016 but little or no further tightening after that.

2.   Light-Duty Vehicles in NEMS

LDVs are divided in NEMS 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.[5] 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), and gasoline-electric hybrid. Finally, LDVs are produced by seven manufacturer groups, each treated by the model as a single manufacturer for determining CAFE compliance.[6]

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[3] Beginning in model year 2011, the standard for light trucks will be based on a footprint-based structure, meaning the average efficiency required of a given manufacturer's vehicles is based on the sizes of those vehicles. Furthermore, vehicles with gross weights of 8,500–10,000 pounds, known as medium duty passenger vehicles, are finally brought into CAFE regulation starting in 2011 (NHTSA 2006). See GAO (2010, pp. 3-9) for a succinct but detailed history of fuel efficiency regulations in the United States.

[4] More precisely, the new-vehicle fuel efficiency in 2016 would be 35.5 if the mandated GHG reductions were attained solely through fuel-efficiency improvements. See U.S. EPA and U.S. DOT (2009); U.S. EPA and NHTSA (2010).

[5] 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.

[6] The groups are: domestic car manufacturers, imported car manufacturers, three domestic light truck manufacturers, and two imported light truck manufacturers (EIA 2008, 8, 11)

Responses to energy markets occur in the model at several points. First, each manufacturer group chooses which technologies to adopt in a given year, taking into account consumers' valuation of attributes including fuel savings as well as CAFE regulations (EIA 2008, 10–45).[7] The available technologies improve exogenously over time and their costs exhibit learning by doing (EIA 2008, 20); but no explicit process of research and development is modeled, and the technologies are basically those known today, giving the model a somewhat conservative bias in analyzing very strong policies. Manufacturers' decisions about technologies produce a set of market shares for those technologies, which in turn determine the range of vehicle characteristics that are offered within each fuel type and size class.

Next, consumers as a group make several choices, modeled as aggregate demand functions (EIA 2008, 51–77).[8] 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 changes in variables including income, fuel price, and new-vehicle fuel efficiency.[9] 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, acceleration, and other factors (EIA 2008, 51–61). EIA has calibrated the coefficients of these aggregate choice models to match known market shares in recent years, and has added some projected variation in them over time representing judgments about the likely evolution of tastes and marketing practices.

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[7] Thus manufacturers are assumed to consider any applicable fines for CAFE violations, currently $50 per vehicle per unit mpg deficit, as part of production costs. I have increased the fine used in the model to $200, reflecting anticipated tougher enforcement. 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 political considerations) plus the cost of fines; he finds that the constraint is binding on the largest U.S. manufacturers, with shadow cost for passenger cars varying from $52 per vehicle for Ford (approximately equal to the actual fine) to $438 for GM. This result accords with the conventional industry view that U.S. manufacturers comply with CAFE even though it would be cheaper for them to pay fines.

[8] An additional, simpler, model replaces consumer choices in the case of fleet vehicles, such as those of government agencies or rental companies (EIA 2008, 61–62). Fleets account for 10–20 percent of vehicle sales.

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

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). These VMT are apportioned exogenously by vintage, a key part of determining total energy consumption.

Despite its advantages in comprehensiveness and realism, NEMS contains several limitations for our purposes. First, because the parameters affecting choice among vehicle types are constant, those choices cannot respond to long-term events that might be influenced indirectly by policy, such as marketing campaigns or changes in the perceived reliability of new technologies.[10] Second, manufacturers are assumed to set price of each vehicle type equal to its average production cost, including any fines, fees, or rebates; this assumption does not allow them to use price differentials to influence sales mix as part of a strategy to meet regulations. Third, there is no used-vehicle market, but rather scrappage of old cars is exogenous; this precludes some possibly important effects through postponement of scrappage (due to more expensive new vehicles) or differential scrappage of efficient and inefficient vehicles.

Consumer Myopia

Researchers have long debated whether consumers fully account for future operating-cost savings in their purchases of durable goods, including automobiles (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 decision making, and consumers' uncertainty about future fuel prices and the duration of their vehicle holdings (Greene et al. 2009). Whatever the reason, the phenomenon is often called *consumer myopia*, that is, apparent short-sightedness compared to a fully rational and informed consumer. Sometimes it is called the *energy paradox*.

NEMS assumes considerable such myopia in its default parameters, used here: a payback period of just three years, and discounting at a high interest rate of 15 percent (EIA 2009c, 59). These assumptions may bias the results toward a smaller response to incentives or regulations

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[10] I account for changing perceptions in a very limited way by adjusting a constant in the model of vehicle-type choice that expresses a preference against gasoline-electric hybrid technology, other things equal. Specifically, in analyzing the CAFE and feebate policies described below, I assume (both in the baseline and policy scenario) that this constant diminishes gradually to zero, meaning that consumers fully accept hybrid technology.

than would actually occur. Nevertheless, the evidence for at least some myopia is quite strong. For example, Allcott and Wozny (2010), using a very large data set of individual transactions and controlling for many potentially confounding effects, find that market prices for new and used automobiles respond as though at most 61 percent of those fuel costs are accounted for.

The assumed explanation for consumer "myopia" strongly affects the interpretation of demand in terms of social costs. To cover a wide range of possibilities, I compute the costs of energy policies in Section 5 under two different extremes: namely that the apparent myopia in NEMS is caused entirely by the factors just mentioned—the "market failure" interpretation—or that it is caused entirely by unobserved amenity losses that occur as part of fuel efficiency improvements—the "hidden amenity" interpretation. For the final policy comparison, I adopt an assumption exactly half-way between these extremes.

3.   Policy Options

3.1   Fuel Tax

The most direct policy to reduce fuel consumption is taxing fuel. This policy does not appear to have political support at this time, but is still a useful benchmark and also gives some idea of the types of results that could be expected from more broad-based policies that raise the price of carbon emissions. It has the advantage of promoting fuel conservation in many directions, not just one. In particular, it promotes reduced driving and changes in driving behavior, including speed, in all vehicles and not just new ones. Administrative mechanisms already exist. Furthermore, a single policy can easily target not only LDVs but also heavy trucks.

In NEMS, fuel tax revenues simply go into the national budget and do not affect any other tax rates. For this reason, NEMS does not incorporate any exacerbation of deadweight losses from labor taxation, such as is discussed by Bovenberg and de Mooij (1994) and Goulder et al. (1997). I therefore refrain from discussing alternate uses of tax revenues, even though they may make a considerable difference to the net social costs of alternate policies.

3.2   Fuel Efficiency Standards

Fuel efficiency standards (herein also called *CAFE standards*) aim at one component of energy use by passenger transportation, namely, the efficiency of the vehicles used. 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 an elaborately researched rationale for this approach, which is scheduled 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 in the lower portion of the range of vehicle sizes.

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. Indeed, several recent studies find considerable social safety benefits in shifting a driver from a large to a small passenger vehicle, especially from a light truck to a car.[11]

Thus, despite the remaining uncertainties in the role of vehicle size and weight (Greene 2009), there is some evidence that widespread reductions in vehicle size and weight would be beneficial rather than harmful to safety. Even if the overall effect is neutral, the safety *externality* is unambiguously in a direction that would favor policies to explicitly encourage downsizing of vehicles, especially the substitution of cars for midsize and full-size pickup trucks.

Because of the limitations on consumer behavior noted in Section 2, NEMS is not the ideal model for investigating this type of complex behavior. For this reason, the scenarios

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[11]White (2004), Brozovíc and Ando (2009), and Li (2010). The point is intuitively depicted by Wenzel and Ross (2005), who calculate the fatality experience of 92 popular models of LDVs covering model years 1997–200, using data from the Fatality Analysis Reporting System. The results show that the risk to other drivers—i.e. the externality—varies strongly by vehicle type, generally rising with vehicle size. Furthermore, there is great variation in safety records among specific models of the same vehicle class, much of which can be traced to specific technological differences; this suggests that safety technology and driver behavior are the main determinants of vehicle safety, with size and weight only secondary.

specified here accept NHTSA's footprint-based approach, and do not allow manufacturers to intentionally alter their vehicle mix through pricing. Therefore, the standards modeled here may appear 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 do allow for them (Kleit 2004; Greene et al. 2005a,b).

CAFE standards have considerable political appeal, compared to a fuel tax, because they avoid any explicit tax on a consumer good—although of course they do raise the price of vehicles. They also have some disadvantages. First, they provide 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 last-noted disadvantage is known as the *rebound effect*. Most research has found a long-run rebound effect of 10 to 30 percent: that is, 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 described (Small and Van Dender 2007a). In its rulemaking on CAFE standards, NHTSA (2008, 24409) highlights this study as crucial to its decisions about modeling the rebound effect but compromises on a long-term value of 15 percent (elasticity –0.15). NEMS produces a rebound effect of around 17 percent. If this value overstates the rebound effect, NEMS will be unduly pessimistic about the effectiveness of a CAFE standard and unduly optimistic about that of a fuel tax.

Two other features of CAFE standards, as modeled here, should be mentioned. First, for simplicity, the new tax increment is set per unit of energy, applying to all fuels equally. This is not as limiting as it might appear because a fuel-tax policy could be combined with others that specifically target alternative fuels—as is the case in current legislation, such as EISA, that is incorporated into NEMS. Second, I do not explicitly incorporate trading of credits across manufacturers—that is, 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; but they may be minor in practice because the footprint-based standards already allow for differences among manufacturers. Furthermore, NEMS models the manufacturer as a

broad category rather than as a real-life firm, so some credit trading among firms is implicitly allowed within the model.

3.3   Feebates

It is possible to combine some of the features of fuel efficiency regulations with those of tax incentives 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.[12] This policy has the advantage that it provides incentives to improve every vehicle, as opposed to a CAFE standard which may or may not be binding for a given manufacturer.

The pivot point can be set so that the program is approximately revenue-neutral. It can also be set differently for different classes of vehicles, just as CAFE standards are: Johnson (2006) stresses the political and administrative advantage of this approach because it produces much smaller magnitudes of fines and rebates. Although doing so foregoes the advantage of inducing vehicle-mix shifts, policy simulations by Greene et al. (2005a,b) suggest that such shifts would not be very important, accounting for only about 4 percent of the change in average fuel efficiency caused by feebates with a single pivot point. I found also through experimentation that NEMS produces only small shifts in vehicle mix when a single pivot point is used. Therefore, the simulations shown here are with a separate pivot point for each of NEMS's 12 vehicle size classes.

Greene et al. (2005a,b) find substantial gains in fuel efficiency from a policy 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 otherwise similar vehicles getting 30 and 31 mpg fuel efficiency. By making the schedule proportional to fuel intensity (gpm) rather than efficiency

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[12] This can be viewed as a major 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. In practice the gas guzzler tax affects only high-performance specialty cars and is not modeled in NEMS. A nonlinear feebate policy was introduced in the U.S. Senate by the chair of its Committee on Energy and Natural Resources in 2009, as the Efficient Vehicle Leadership Act.

(mpg), the policy provides a constant incentive rate for each gallon of fuel consumed, assuming that all vehicles are driven the same amount per year.

4.   Policy Specification and Results

This section describes the specific forms of the three policy types that are simulated—an increased fuel tax, stricter fuel efficiency standards (CAFE), and a tax/rebate schedule for new vehicles—and presents simulation results.

4.1   Fuel Tax

The "High Fuel Tax" scenario increases the gasoline tax by an amount, in constant 2007 dollars, that begins at $1.27 per gallon in 2010 and grows at an annual rate of 1.54 percent, reaching $1.73 per gallon in 2030.[13] The same tax increase (adjusted for energy density) is applied to diesel fuel, ethanol, and ethanol blends.

The results are shown in Table 2. The greatest impact is on vehicle travel, reducing VMT by 5 percent in 2020 and 6 percent in 2030—substantial but nowhere near enough to offset the increased VMT projected in the baseline scenario. The fuel tax also increases the fuel efficiency of new vehicles compared to the baseline, especially after 2016 when the CAFE requirements in the baseline stop rising. In 2030, the fuel efficiency of new LDVs would be 3.6 percent higher due to the fuel tax increase, part of which is caused by a small shift away from light trucks toward cars.[14] Overall, however, these responses in fuel efficiency are small and result in less

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[13] This particular choice, made early in the course of the RFF project, was based loosely on a second-best fuel tax estimated by Parry and Small (2005), with the idea of providing an externality rationale for the tax increase. However it is not exactly a second-best tax, nor can it be derived explicitly as as a way to correct externalities. See Small (2010) for further discussion of its rationale.

[14] In these results, efficiencies are stated as miles per gallon-equivalent, i.e. they are adjusted for energy density. The conversion factors are 1.133 gallon-equivalents per physical gallon of diesel, and 0.784 gallon-equivalents per physical gallon of E85. To put it differently, the tax is effectively placed on the energy content rather than the physical volume of motor-vehicle fuels.

fuel savings that does the reduction in VMT. These results are broadly consistent with those of
Morrow et al. (2010), also using NEMS.[15]

Table 2. Results: High Fuel Tax

	Value in baseline	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Gasoline price (2007$/gal)	2.14	5.00	5.43	1.40	1.65	39%	44%
Tax component	0.38	1.84	2.04	1.49	1.73	432%	544%
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):	26.5	37.7	40.5	1.0	1.4	2.8%	3.6%
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 (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)	16.4	14.5	14.8	-1.01	-1.40	-6.5%	-8.6%
Economy-wide outcomes							
Energy-related CO2 (mmt)	5,746	5,751	6,058	-130	-135	-2.2%	-2.2%
Oil consumption (mbbl/day)	18.5	17.1	17.2	-0.8	-0.8	-4.3%	-4.4%

This policy reduces overall energy use by LDVs by 8.6 percent in 2030 relative to that in
the baseline scenario. Energy-related CO_2 emissions, which include those from electricity
generation, are reduced by just 2.2 percent in 2030. The fuel tax policy, unlike others considered
in this paper, affects surface freight and air transportation, both of which use gasoline, diesel, or
closely related fuels. However, it appears that NEMS treats these sectors as very unresponsive to
energy prices, so effectively the economy-wide results reported here reflect changes in the LDV
sector.

Some of the improved fuel efficiency in this scenario comes about through a higher
market share of hybrids: 26.6 percent, compared to 23.4 percent for the baseline scenario, both in

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[15] See Small (2010) for a more detailed comparison with Morrow et al (2010). In the simulations, the tax increase
was also applied to diesel and jet fuel, so in principle would affect the heavy trucking and aviation sectors; however
NEMS models those sectors as extremely price-inelastic and so the policy is best viewed as applying only to LDVs.

2030. This is largely because in NEMS, consumers respond to fuel prices in their choice of vehicle type. Detailed results shown that with the fuel tax, CAFE is no longer binding as of 2016: that is, the average fuel efficiency exceeds the assumed legislative CAFE target of 34.9 mpg.

I also simulated a "Very High Fuel Tax" scenario (not shown in the tables): a tax increase of $3/gallon nominal in 2010, remaining constant in real terms. This scenario yields substantially greater effects: for example, it raises new-vehicle efficiency in 2030 by 3.1 mpg (rather than 1.4), and reduces LDV energy use by 14.8 percent (rather than 8.6 percent). As we shall see in the next section, this success comes at a considerably higher marginal cost.

This last scenario, involving a tax increase that remains constant for 20 years, permits calculation of the elasticities of VMT and fuel intensity with respect to fuel price: they are -0.16 and -0.10, respectively. By way of comparison, a literature review by Parry and Small (2005, 1283) finds central values for these elasticities to be -0.22 and -0.42, respectively.[16] Thus, the responsiveness of VMT in NEMS is slightly lower than that in the literature, while the responsiveness of fuel efficiency is much lower. This latter discrepancy is at least partly because here we are simulating a situation where strict CAFE standards are already included in the baseline scenario, so that higher fuel taxes do not further increase efficiency very much.

4.2   Fuel Efficiency Standards

The baseline scenario already has very ambitious fuel efficiency standards in place through 2016; achieving an average new-LDV fuel efficiency of 34.9 mpg in 2016. But what about after 2016? The National Fuel Efficiency Policy was driven in part by the desire to extend California's stringent policy targets to the federal level. It seems reasonable that another

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[16] Parry and Small choose from that literature central values of -0.55 for the total price-elasticity and -0.55·0.4 = -0.22 for the elasticity of VMT. To calculate the implied elasticity of fuel intensity, we need to know that the total price-elasticity of fuel consumption is: $\varepsilon_F = \varepsilon_{VMT} + \varepsilon_{FI} + \varepsilon_{VMT} \cdot \varepsilon_{FI}$ where ε_{VMT} and ε_{FI} are the elasticities of VMT and fuel intensity with respect to fuel price. This formula is derived by noting that $f=m+i$ where f, m, and i are logarithms of fuel consumption, VMT, and fuel intensity, respectively; assuming that m depends on the logarithm of fuel cost p_F+i; and taking the total derivative of f with respect to fuel price p_F. See U.S. DOE (1996, p. 5-11), or note 26 of Small and Van Dender (2007b). Thus the Parry-Small choices imply that $\varepsilon_{VMT} = (\varepsilon_F - \varepsilon_{VMT})/(1+ \varepsilon_{VMT}) = -(0.55-0.22)/(1-0.22) = -0.42$. The total price-elasticity of fuel consumption implied by the "Very High Fuel Tax" scenario estimated here is $\varepsilon_F = -0.16 - 0.10 + (0.16 \cdot 0.10) = -0.24$. For a discussion of more recent literature estimating these elasticities, see Small (2010).

aggressive policy would do the same for another four years (the limit of California's written targets). I therefore model a "Pavley CAFE" policy, named for the author of the California legislation, in which the federal standard follows the targets tentatively adopted by California for 2017–2020—namely, an increase of 3.7 percent per year—and continues to tighten after that at a rate of 2.5 percent per year. Doing so implies a 95 percent increase in fuel efficiency standards between 2010 and 2030, to an average of 52 mpg.

Results are shown in Table 3. The Pavley CAFE is moderately effective, achieving by 2030 an 18.8 percent increase in new-vehicle fuel efficiency and an 11.2 percent increase in the efficiency of the entire fleet. Energy use from LDVs is reduced by 8.4 percent relative to baseline, and petroleum consumption is reduced by 4.0 percent.[17]

Table 3. Results: Pavley CAFE

	Value in baseline	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Gasoline price (2007$/gal)	2.14	3.62	3.69	0.02	-0.10	0%	-3%
Tax component	0.38	0.35	0.32	0.00	0.00	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):	26.5	40.2	46.2	3.0	7.3	8.1%	18.8%
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 (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)	16.4	15.3	14.9	-0.21	-1.36	-1.4%	-8.4%
Economy-wide outcomes							
Energy-related CO2 (mmt)	5,747	5,869	6,088	-19	-101	-0.3%	-1.6%
Oil consumption (mbbl/day)	18.5	17.7	17.3	-0.1	-0.7	-0.7%	-4.0%

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[17] My results show bigger effects than do those of Morrow et al. (2010), as expected because they model a less aggressive policy. Jacobsen (2010), using an extension of the model of Bento et al. (2009), estimates what appears to be a greater response to CAFE tightening than shown here. The reason is that Jacobsen's CAFE simulations produce substantially *reduced* driving (in contrast to the usual rebound effect), apparently because his model assumes that people do not like the new mix of vehicles as well as the original one, and so drive them less.

It is worth noting that the policy as modeled does not actually achieve the legally set CAFE targets in the later years. This is because manufacturers are unable to find enough technologies at the rapid pace required, at least not at reasonable cost as embodied in the fines (assumed here to be $200 per unit improvement in mpg). 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 Pavley CAFE, the percentage of vehicles on which fines must be paid continues to rise, to 69 percent in 2020 and 100 percent in 2030—despite the fact that the market share of hybrids rises sharply over time.[18] This may reflect NEMS's limitations in modeling technological innovation. I also examined the Pavley CAFE policy under the EIA's more optimistic "high-tech" assumptions, resulting in 2030 fuel efficiency being by 9.1 mpg above baseline (instead of the 7.3 mpg shown in Table 3).

The CAFE policy suffers from other well-known defects. First, it affects only new vehicles, so it takes several years to achieve its fuel savings: for example, the efficiency of the overall fleet rises (compared to baseline) by only 0.4 mpg in 2020. Second, as noted earlier, the policy does nothing to discourage driving and even encourages it somewhat. Third, the policy does not encourage a shift to smaller vehicles and, in fact, results in a slight shift away from cars toward light trucks.

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

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[18] Comparing with Table 2, it might appear that CAFE favors hybrids more than does the High Fuel Tax, but actually the policy impact is less: 1.6 rather than 3.6 percentage points (these numbers are rounded to 2 and 4 in the tables). Because the CAFE and feebate scenarios use a more optimistic demand constant for hybrids than do the fuel tax scenarios (in both the baseline and the policy simulations), as explained in Section 2, the hybrid shares in their baselines are somewhat higher: 26.6 percent in 2030, rather than 23.4 percent for the fuel tax. (These numbers, except for rounding, are the differences between the entries for "change due to policy" and "value with policy" in Tables 2 and 3.)

Table 4 shows the result, using the more aggressive fuel tax mentioned at the end of Section 4.1. Although the effects are somewhat less than additive, the combined policy does indeed achieve much of the advantages of each component. For example, consider the policy impact in 2030. The Very High Fuel Tax and the Pavley CAFE policy, each taken alone, increase the fuel efficiency of the average new LDV by 7.8 and 18.8 percent, respectively; together they improve it by 24.3 percent. This is somewhat less than their sum because, for some kinds of vehicles, the CAFE standard become nonbinding with the Very High Fuel Tax. The VMT changes are essentially additive. The net result of this combined policy (in 2030) is a reduction of 20.7 percent in energy use by LDVs.

Table 4. Results: Combined Pavley CAFE and Very High Fuel Tax

	Value in baseline	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Gasoline price (2007$/gal)	2.14	6.38	6.84	2.78	3.05	77%	81%
Tax component	0.38	3.42	3.49	3.07	3.17	889%	999%
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):	26.5	41.8	48.3	4.6	9.4	12.4%	24.3%
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 (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)	16.4	13.6	12.9	-1.91	-3.36	-12.3%	-20.7%
Economy-wide outcomes							
Energy-related CO2 (mmt)	5,747	5,626	5,897	-263	-292	-4.5%	-4.7%
Oil consumption (mbbl/day)	18.5	16.4	16.3	-1.5	-1.7	-8.2%	-9.6%

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. Thus, it is possible to design them to have similar effects. I have modeled a "High Feebate" policy aimed at achieving results roughly comparable

to those of the Pavley CAFE policy. It has a basic rate of $2,000 per 0.01 gpm in 2007 dollars,[19] which is phased in starting at a half this rate in 2017 and rising in equal increments until 2021. The rate is then further increased at 2.5 percent per year (still in real terms), so that in 2030 it is $2,969 per 0.01 gpm. The pivot points are chosen to approximate a revenue-neutral policy within each vehicle size class.[20]

Results are shown in Table 5. The feebate performs similarly to the Pavley CAFE, but it achieves more of its efficiency gains through the use of hybrids and diesels; this may be an artifact of NEMS' taking hybrids as a consumer choice rather than a manufacturer's strategy for meeting CAFE standards. Also, the feebate causes an even larger shift from cars to trucks— about twice the impact of Pavley CAFE—for reasons that are unclear.

Table 5. Results: High Feebate

	Value in baseline	Values with policy		Change due to policy			
				Absolute		Percentage	
	2010	2020	2030	2020	2030	2020	2030
Gasoline price (2007$/gal)	2.14	3.59	3.67	-0.01	-0.12	0%	-3%
Tax component	0.38	0.35	0.32	0.00	0.00	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):	26.5	40.5	45.4	3.3	6.6	8.9%	16.9%
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 (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)	16.4	15.3	15.1	-0.20	-1.16	-1.3%	-7.1%
Economy-wide outcomes							
Energy-related CO2 (mmt)	5,747	5,869	6,108	-20	-82	-0.3%	-1.3%
Oil consumption (mbbl/day)	18.5	17.7	17.3	-0.1	-0.7	-0.7%	-3.7%

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[19] This basic rate of $2,000/(0.01 gpm) is nearly twice that considered by Greene et al. (2005a,b). For a car driven 12,683 miles per year (our baseline 2021–2030 average) over a 14-year life, the rate is analogous to ($2,000/0.01gpm)/(12,683*14 miles) = $1.13/gallon.

[20] 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.

A "Very High Feebate" policy (not shown in the table), which sets the feebate rates to be exactly twice as large, was also simulated. It is correspondingly more effective on all measures: average fuel efficiency for new vehicles in 2030 rises to 48.3 mpg, while LDV energy use in 2030 is reduced by 10 percent. 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.

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 (which incorporates the market for fuel, as a derived demand). The full theory of welfare calculations in these interrelated markets is described in Small (2010, Appendix A); here I present an abbreviated and more intuitive version.

Annual costs and cost offsets (such as fuel savings), as well as policy effects (such as oil consumption), are taken from the NEMS output at five-year intervals over the policy period (2010–2030). Through interpolation and extrapolation, these are converted to annual values for each year, including approximate values covering the remaining lifetimes of vehicles purchased during the policy period. These annual values are then cumulated, with discounting at a five percent real social discount rate in the case of costs.[21] In the tables that follow, both the net present value (NPV) of costs and the total undiscounted amount of policy benefits are shown under the row "NPV". Their ratio is shown as "cost-effectiveness"; note however that this ratio can be lower than the cost-effectiveness in any single year because the cost measures are discounted but the effectiveness measures are not.

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[21]NPV is in year 2007, and all costs are in real 2007 dollars. All categories except manufacturing costs (category 1) are extrapolated to year 2045 for those vehicles put in place by 2030, based on the assumption that each value would decline linearly from its 2030 value over the ensuing 15 years. Results for each year are then discounted to 2007 and added. In order to obtain aggregate effectiveness measures, I do the same interpolation and extrapolation of policy effects, but they are added without discounting. These discounting decisions were made to conform to other projects in the larger study.

The annual net costs of each policy are categorized similarly to the analysis by NHTSA (2008). The values in some categories are negative, indicating offsetting benefits. Those benefits exclude the targets themselves, e.g. oil consumption or GHG emissions. Thus the result is not a cost–benefit calculation, but rather is solely the cost side of a cost-benefit or cost-effectiveness calculation, describing 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 a cost if positive, a benefit or a cost offset if negative.) The categories 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 approximately 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. In the case of a feebate policy that is not strictly revenue-neutral, some of this area reflects fees paid (net of rebates received); these are not social costs and so are subtracted off, leading to:

$$- \Delta W_V = \overline{q}\Delta P_V - (\text{net fees paid by manufacturers}) \tag{1}$$

where $\overline{q}$ is the number of vehicles purchased, averaged between the pre- and post-policy scenarios, and where ΔP_V is the change in vehicle price.[22]

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

　　　In order to include only social values, I multiply fuel savings by the pretax fuel price. The resulting offset to policy cost is therefore the following quantity, which is negative:

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[22] In practice I am unable through NEMS to distinguish price changes caused by changes in fuel efficiency from those caused by changes in performance. Performance changes seem to be most pronounced in the feebate scenarios, which result in considerably greater horsepower even while vehicle weight is also being reduced. I therefore make an adjustment to this scenario as follows. I assume that performance changes account for negligible cost in the CAFE scenario, and that the welfare measure $-\Delta W_V$ has the same ratio to fuel efficiency improvements for feebates as it does for Pavley CAFE. This assumption seems quite reasonable for the High Feebate scenario because it and Pavley CAFE use similar technologies and achieve similar changes in fuel efficiency. It is admittedly more tenuous for the Very High Feebate scenario because it implies a linear cost function for fuel efficiency improvements.

$$- \Delta w_F = \overline{VMT} \cdot \left[\overline{(P_F - \tau_F)} \Delta F \right] \tag{2}$$

where $\overline{VMT}$ is the average of before- and after-policy VMT, $\overline{(P_F - \tau_F)}$ is the average pretax fuel price, and $\Delta F < 0$ 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).[23] This estimate of fuel savings may be said to be based on a "market failure" interpretation of apparent consumer myopia, because it assumes that the full present discounted value of fuel savings is a social benefit whether or not it is accounted for by consumers in their purchase decisions.

(3) Loss of Tax Revenues

The changes in tax revenue due to changes in fuel efficiency were excluded in (2), so do not need to be added back as an offset to costs. However, a change in tax revenues also occurs as a result of changes in VMT, and was implicitly included in category (2), so it is subtracted out here:

$$- \Delta w_R^V = -\overline{\tau_F F} \cdot \Delta(VMT) \tag{3}$$

where $\overline{\tau_F F}$ is the average of pre- and post-policy values of tax revenue per vehicle-mile. If (3) is negative, representing an increase in revenues due to $\Delta(VMT) > 0$, then (3) is interpreted as an offset to policy costs.

(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 we also need to account for the value that consumers placed on trucks now foregone. Part of this value may represent an "arms race" for safety thus not be a social value; but those safety costs will be

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[23] Because it is based on average rather than pre-policy VMT, this value incorporates a small amount representing consumer surplus gained or lost because of increased or decreased VMT resulting from fuel efficiency improvements.

accounted for separately in category (7), so the full value needs to be included here. This is done by imputing the value from the extra private fuel costs that would have been incurred to drive those trucks had the shift not occurred:

$$\Delta w_T = \Delta s_t \cdot (F_t - F_c) \cdot \overline{VMT} \cdot \overline{P_F} \tag{4}$$

where Δs_t is the change in truck share due to the policy, and F_t and F_c are the fuel efficiencies of trucks and cars, respectively. In practice, this category turns out to be small.

(5) Hidden Amenity Losses (optional calculation)

    Aside from inducing shifts in vehicle mix, the fuel-efficiency improvements brought about by policies may directly cause a loss of amenities to drivers—for example, by making cars less reliable. This is one possible explanation for why drivers appear to consider less than the full present discounted value of fuel savings when making purchase decisions. I have developed a very approximate measure of the maximum such amenity losses, based on the assumption that they account for the full difference between the true discounted value of private fuel savings (as given by equation 2) and the part accounted for by consumers according to the model. That difference is:

$$-\Delta w_A = \overline{VMT} \cdot \overline{P_F} \Delta F \cdot \left[1 - \frac{A^P}{A^S} \right] \tag{5}$$

where A^P and A^S are the annuity factors giving the present values of a \$1 annual income stream computed, respectively, at the perceived and social values for discount rate and lifetime.[24] This estimate of amenity losses in effect offsets about three-fourths of the fuel cost savings.

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[24] The annuity factor is $A(r,T) = \left[1 - (1+r)^{-T} \right] / r$. The discount rates incorporate an annual growth rate in fuel price of 2 percent, which approximates the 2010-2030 price change in the baseline scenario and is assumed to be anticipated by users. Therefore A^P is computed using $r=0.17$ and $T=3$ (reflecting NEMS assumption including 15 percent private discount rate), whereas A^S is computed at $r=0.07$ and $T=14$ (reflecting project assumptions including 5 percent social discount rate, and the actual average car lifetime).

(6) External Cost of Changed Amount of Driving (optional calculation)

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

$$- \Delta w_E = c_M \Delta(VMT) \ . \tag{6}$$

This component turns out to be quite important 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, based on adjusting estimates in Parry and Small (2005) for changes in prices and wage rates.

(7) Accident Costs from Trucks (optional calculation)

I also compute 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.[25] Applying a medium estimate of the value of a statistical life of \$5.5 million, as does Li, gives an accident cost of c_S=\$112 per year for each car that is replaced by a truck in the overall fleet. Thus the safety costs are:

$$\Delta w_S = c_S Q \Delta S_t \tag{7}$$

where Q is the number of vehicle in use under the policy and ΔS_t is the policy-induced change in the fraction of trucks in the entire fleet of new and used vehicles.

5.2   Results

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[25] 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.

Table 6 shows selected results of these calculations. Three subtotals of categories are calculated. The first ("lower estimate") includes only categories (1)–(4), thus implicitly assuming that the fuel-cost savings achieved by correcting consumer "myopia" are social savings. The second ("upper estimate") adds category (5) for hidden amenity losses, thus assuming instead that the original consumer decisions were already socially efficient. The cost-effectiveness measures (both for petroleum consumption and for CO_2 emissions) are calculated using each of these alternate subtotals. In addition, a third subtotal is shown omitting category (5) but adding (6) and (7); the difference between this subtotal and the "lower estimate" reflects changes in the external costs of congestion, air pollution, and safety.

Table 6. Policy Costs: Fuel Tax and Feebate Policies

	High Fuel Tax			Pavley CAFE			High Feebate		
	2020	2030	NPV	2020	2030	NPV	2020	2030	NPV
Costs of policy (billions 2007 $)									
1. Extra cost of new, more fuel-efficient vehicles sold	1.1	3.9	11.3	16.7	42.5	156.6	17.8	42.3	159.4
2. –Fuel cost savings from more fuel-efficient vehicles	-5.8	-11.7	-74.5	-5.7	-44.0	-185.5	-8.3	-42.7	-193.0
3. Lost tax revenue & consumer value from less driving	6.6	9.2	75.3	0.0	-0.8	-2.8	-0.2	-0.9	-3.8
4. Loss of value from light trucks (fuel tax only)	0.3	0.6	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Total (1–4) (lower estimate)	**2.2**	**1.9**	**15.6**	**11.0**	**-2.3**	**-31.7**	**9.3**	**-1.3**	**-37.5**
Alternative calculations:									
5. Hidden amenity cost	5.8	11.8	75.4	4.8	36.1	152.5	6.8	35.1	158.8
Total w/ hidden amnty cost (1–5) (upper estimate)	**8.0**	**13.7**	**91.0**	**15.7**	**33.8**	**120.8**	**16.1**	**33.8**	**121.3**
6. –External cost savings from of less driving	-19.1	-32.8	-235.8	0.3	10.3	35.4	2.0	11.6	47.1
7. –Accident cost savings from shift in car–truck mix	-1.3	-1.7	-13.8	0.1	0.6	2.2	0.1	0.8	3.3
Total with external & accident costs (1–4,6–7)	-18.2	-32.6	-234.0	11.4	8.6	5.9	11.4	11.1	12.9
Policy effectiveness (reduction from baseline)									
Petroleum consumption (milllion barrels)	280	290	5,228	43	263	3,612	47	242	3,454
Energy-related CO2 (million metric tons)	130	135	2,419	19	101	1,429	20	82	1,211
Cost-effectiveness (based on "lower estimate")									
Policy cost per:									
barrel petroleum consumption ($/bbl)	8	7	**3**	255	-9	**-9**	198	-5	**-11**
metric ton CO2 reduced ($/tonne)	17	14	**6**	563	-22	**-22**	473	-16	**-31**
Cost-effectiveness (based on "upper estimate")									
Policy cost per:									
barrel petroleum consumption ($/bbl)	29	47	**17**	366	129	**33**	344	140	**35**
metric ton CO2 reduced ($/tonne)	62	102	**38**	808	334	**85**	820	412	**100**

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.

Table 6 shows the results for two selected years and for the aggregate over all years. Consider first the fuel tax, shown on the left side of the table. Consistent with the modest gains in

technological efficiency it elicits, the costs to manufacturers in this policy are modest. But as we have seen, fuel savings are large because the increased efficiency is supplemented by a substantial reduction in driving. This pattern causes several notable features. First, there is a large loss in tax revenue and consumer surplus from driving (category 3), whose NPV is estimated at $75 billion. Under the "market failure" interpretation of myopia, that loss is entirely offset by the market value of less fuel used (category 2); whereas under the "hidden amenity" interpretation, those fuel savings are just a compensation for the loss in amenities (category 5)— losses that are made larger by the high fuel prices occurring in this scenario. The end results are cost-effectiveness measures that are quite low under the "market failure" interpretation—$3 per barrel of oil or $6 per metric ton of CO_2—but several times higher under the "hidden amenity" interpretation. If external costs of driving are counted, however, the policy costs are strongly negative under either interpretation: that is, the ancillary benefits of reduced external costs outweigh the other costs of the policy.[26]

Now consider the Pavley CAFE policy. Because it relies so heavily on new-car fuel efficiency, the CAFE policy alone produces high costs but few benefits in the early years of the simulation. 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 2030 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.

Finally, consider the feebate policy shown on the right side of Table 6. As expected, the pattern of costs is very similar to that of the Pavley CAFE policy, which it was designed to mimic. One difference, seen in the detailed model results, is that with feebates, manufacturers use somewhat fewer technological means to improve efficiency, selling more hybrids instead. This occurs because they pass through the rebates, which are considerable for hybrids, to consumers.

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

Another 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 increase driving more than could be accounted for in this way. The reason is that the energy sector part of NEMS 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 per unit effectiveness of the feebate policy relative to CAFE when such external costs are included. Some of these economy-wide 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.

5.3   Summary Comparison of Policies

Table 7 presents summary cost and cost-effectiveness estimates for all six policies: 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: that is, they assume that half of the discrepancy between perceived and objective fuel-cost savings represents a real economic distortion and half is caused by hidden amenity losses associated with those cars.

Table 7. Summary Comparison of Policies' Costs and Cost-Effectiveness

	High Fuel Tax	Very High Fuel Tax	Pavley CAFE	Pav. CAFE & Very High Fuel Tax	High Feebate	Very High Feebate
Effects of policies						
Petroleum reduction (million barrels)	5,228	9,614	3,612	12,262	3,454	4,998
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: Monetary figures are in 2007 dollars. All policies are relative to the 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. Welfare costs are the average of the "lower" and "upper" estimates in Table 6.

The table shows that, for each of the pairs of policies, the average cost-effectiveness rises substantially as policy stringency is increased. For example, in the "Very High Fuel Tax" scenario, manufacturers adopt the most aggressive of the five available material-substitution technologies for 23 percent of new cars in 2030, compared to 12 percent with the "High Fuel Tax" and just 6 percent under the baseline scenario. Comparing the "High" and "Very High" feebate policies, the latter is about 50 percent more effective but costs twice as much or more, resulting in notably higher cost-effectiveness numbers. This pattern reflects diminishing returns to policies aimed at any particular set of responses.

The table also confirms that the fuel tax Pavley CAFE policies are complementary. The combined policy achieves the greatest reductions in petroleum use and CO_2 emissions of any policy simulated, yet its cost-effectiveness (excluding external costs of driving) is barely higher than that of the fuel-tax policy alone.

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 that even the small increases in VMT resulting from CAFE and feebate policies add substantially to their policy costs when external costs are included. Even more dramatically, the large reductions in VMT from the scenarios involving higher fuel taxes bring policy benefits which, in these calculations, more than offset all the policy costs. These 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

The policies modeled here are as strong as or stronger than any policies that have made serious headway in the U.S. political system. Nevertheless, their effects are modest. Stronger effects are possible, but at increasing political difficulty and worsening cost-effectiveness. 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 have considerable advantages: their effects begin quickly, and they are not counteracted by the "rebound effect". Furthermore, a high fuel tax can be combined effectively with a policy mandating new-vehicle fuel efficiency, providing greater effectiveness at a unit cost comparable to that of the fuel tax alone.

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.

Regarding the costs of policies, a number of interesting lessons emerge. First, policy costs for fuel taxes are significant but reasonable, even under pessimistic assumptions. For example, the central cost estimate presented here (excluding the savings on external costs of driving) is $22 per metric ton of CO_2 for the High Fuel Tax.

Second, policy costs for CAFE and feebates are also significant and depend strongly on why consumers value fuel savings at less than their objective economic value. Fuel-cost savings are undeniably large, but most or all of them are offset if the fuel-efficient cars have hidden amenity costs. Thus, depending on assumptions, these policies can be very cheap or very expensive per barrel of oil or per ton of CO_2 saved.

Third, under intermediate assumptions, the CAFE and fuel tax policies are complementary, achieving much greater effects but with cost-effectiveness only slightly inferior to that of the fuel tax alone. Thus there is a strong case for supplementing CAFE policies with some policy to raise the price of fuel. Not only does this counter the rebound effect, it should

make it easier for manufacturers to sell the more efficient cars mandated under CAFE, and so should facilitate implementation and enforcement.

Fourth, according to NEMS's depiction of the larger energy markets, the policies shown in Section 4 will cause a reduction in the pretax gasoline price of $0.08–$0.12 per gallon in 2030 (Tables 2–5). The associated cost savings, even within just the transportation sector, create substantial benefits for U.S. consumers. Most of these benefits are at the expense of oil-exporting nations and are not shown in the policy cost calculations presented here, but could be considered another of the desired effects of these policies.

Finally, the external costs of driving—congestion, accidents, and local air pollution—are very important side effects of these policies. Vehicle travel is mildly *encouraged* by CAFE and feebates (the so-called rebound effect), and *discouraged* by the fuel tax. For this reason, counting external costs increases the policy costs of CAFE and feebates but greatly decreases the policy costs of fuel taxes.

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