

## 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 in the United States, using a version of the National Energy Modeling System. 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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## Energy Policies for Passenger Motor Vehicles

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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 in the United States. It does so by defining specific measures as input parameters to a version of 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 at Resources for the Future using its own particular adaptation of NEMS, known as NEMS-RFF, 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 aimed directly at fuel consumption by light duty vehicles: higher fuel taxes, tighter vehicle efficiency standards, and financial subsidies and penalties for the purchase of high- and low-efficiency vehicles (*feebates*). These are among the most prominently discussed policies, but of course are only a subset of those that can be considered; for example, I do not examine transit subsidies or policies aimed at changing urban land use patterns, mainly because other studies suggest they are either too weak or too long-term to compete with these more direct policies in terms of medium-term cost-effectiveness. Two other direct policies are the subjects of other studies in the larger effort just described: subsidies to hybrid vehicles, which are found to be mostly redundant if a policy aimed at fuel efficiency is in place, and natural gas trucks, which appear potentially promising. Yet another policy worth considering, but not examined here, is natural gas for light-duty vehicles; this policy has lost favor due to the significant loss of storage space to fuel canisters, but it probably merits a reexamination now that newly cheap natural gas, including much produced within the U.S., has emerged on the world market.

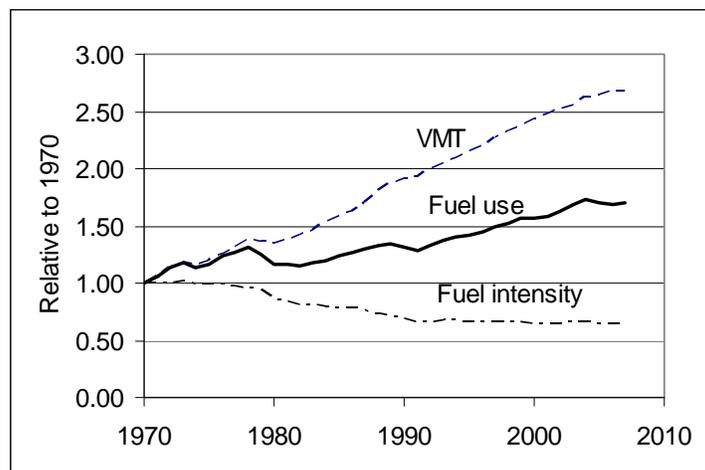
For each policy modeled, the effects are determined with respect to a baseline scenario. The baseline is a variant of the NEMS simulation (to 2030) contained in the updated *Annual Energy Outlook 2009* scenario of EIA (2009a), which includes the 2009 federal stimulus package; that simulation is further modified here to incorporate the National Fuel Efficiency Policy as announced by the President in May 2009. In the latter program, GHG standards have been 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 contain 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-RFF, 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-RFF, 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 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 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, 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.<sup>1</sup> 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

<sup>1</sup> Computed from EIA (2009d), Table 19, combined with the proportion of U.S. greenhouse-gas emissions consisting of energy-related carbon dioxide, which is  $5810 / 7049 = 82.4\%$ , from EIA (2010), Table 12.1.

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.<sup>2</sup> 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.<sup>3</sup>

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 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, based on a cross-sectional time series of U.S. states from years 1966-2001.<sup>4</sup>

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

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<sup>2</sup> 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-RFF and called “commercial light trucks,” although elsewhere they are called “intermediate trucks” or “Class 2b vehicles”.

<sup>3</sup> Calculated from data in Davis et al. (2009), Tables 4.7, 4.9.

<sup>4</sup> Small and Van Dender also measure a short-run (one-year) elasticity of 0.04. Li, Timmins, and von Haefen (2009) obtain similar results (short- and long-run elasticities 0.02 and 0.20) using micro data in 20 US metropolitan areas for years 1997-2005; they find this arises almost all from new-car sales and very little from vehicle scrappage. More recent papers demonstrating similar responses include Busse, Knittel, and Zettelmeyer (2009) and Gillingham (2010).

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**

<b>Vehicles</b>	<b>2004</b>	<b>2008</b>	<b>Change</b>
<b>Cars</b>			
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%
<b>Light Trucks</b>			
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%
<b>Total</b>	<b>100.0%</b>	<b>100.0%</b>	<b>0.0%</b>

*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.<sup>5</sup>

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

<sup>5</sup> 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.

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.<sup>6</sup> 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-RFF

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 relatively homogeneous product in terms of measurable characteristics valued by consumers.<sup>7</sup> 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.<sup>8</sup> Three of these groups represent foreign producers, whose reactions are fully integrated into the model; while their associated spending will not be reflected in the general economic results depicted in the model, their costs are fully included in the welfare calculations undertaken here and described in Section 5.

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).<sup>9</sup> The available technologies improve exogenously over time and their costs exhibit

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<sup>6</sup> 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 (2010a).

<sup>7</sup> 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.

<sup>8</sup> The groups are: domestic car manufacturers, imported car manufacturers, three domestic light truck manufacturers, and two imported light truck manufacturers (EIA 2008, 8, 11)

<sup>9</sup> 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

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).<sup>10</sup> 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.<sup>11</sup> 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.

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.

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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.

<sup>10</sup> 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.

<sup>11</sup> 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 NEMS and ran it as NEMS-RFF for this study.

Despite its advantages in comprehensiveness and realism, NEMS-RFF 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.<sup>12</sup> 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.<sup>13</sup> 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 (Greene 2010). The predominant view is that they do not; 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 consumers account for at most 61 percent of those fuel costs. 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.<sup>14</sup> 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*.

The empirical evidence is decidedly mixed, and a careful review concludes that there is

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<sup>12</sup> 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.

<sup>13</sup> The literature contains considerable variation in its findings about how important changes in sales mix are in response to policies aimed at fuel efficiency. Whitefoot, Fowlie, and Skerlos (2011), using a very thorough engineering model to simulate manufacturers' design responses, find that redesign, as opposed to sales mix, accounts for nearly two-thirds of the response to a tighter CAFE standard over even a short time horizon 2011-2014.

<sup>14</sup> This phenomenon probably is not caused by overly optimistic consumer price expectations, because direct measurement shows that on average consumers believe the current price will continue (Anderson et al. 2011).

no clear explanation for the diversity of research results (Greene 2010). Yet NEMS-RFF 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). Thus it is possible that the NEMS-RFF assumptions are biased toward finding a smaller response to incentives or regulations than would actually occur.

Even if consumer “myopia” is correctly measured, its source is unknown. But as I show in Section 5, differences in the assumed source strongly affect the interpretation of demand in terms of social costs. To cover a wide range of possibilities, I compute the costs of energy policies there under two different extreme assumptions: namely that the apparent myopia in NEMS-RFF is caused entirely by deficiencies in markets—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-RFF, fuel tax revenues simply go into the national budget and do not affect any other tax rates. For this reason, NEMS-RFF does not incorporate any exacerbation of deadweight losses from labor taxation, such as is discussed by Bovenberg and de Mooij (1994), Goulder et al. (1997), and Goulder and Williams (2003). I therefore refrain from discussing alternate uses of tax revenues, even though they could make a considerable difference to the net social costs of alternate policies. I return to the subject of deadweight loss in Section 5.

### 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 large vehicles 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.<sup>15</sup>

Thus there is evidence that widespread reductions in vehicle size and weight would be beneficial rather than harmful to safety, despite the remaining research uncertainties well described by Greene (2009). 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 pickup trucks.

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<sup>15</sup>White (2004), Brozović 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 1997–2001, 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.

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 accept NHTSA's footprint-based approach, and do not allow manufacturers to intentionally alter their vehicle mix through pricing. As a result, 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 now 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-RFF produces a value of around 17 percent; if this value overstates the rebound effect, NEMS-RFF will be unduly pessimistic about the effectiveness of a CAFE standard and unduly optimistic about that of a fuel tax.<sup>16</sup>

Two other features of CAFE standards, as modeled here, should be mentioned. First, for simplicity, the standard is applied to all fuels equally, after adjusting for energy density. Second, I do not explicitly incorporate trading of credits across manufacturers—that is, allowing one

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<sup>16</sup> Gillingham (2010) finds an average short- to medium-run elasticity of  $-0.15$ , and a cross-sectional pattern in which the elasticity is *rising* in magnitude with income except at the lowest incomes. This empirical result, based on micro data in California over the period 2001-09, is identified almost entirely on the time-series variation and thus mainly on the sharp price rise and collapse during 2006-09. While the author controls for economic conditions, they were so unusual during much of this period, especially during the price collapse, that further corroboration is needed.

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 incorporate differences among manufacturers. Furthermore, NEMS-RFF 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.<sup>17</sup> 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 too important, accounting for only about 4 percent of the change in average fuel efficiency caused by feebates with a single pivot point.<sup>18</sup> I found also through experimentation that NEMS-RFF produces only small shifts in vehicle mix when a single pivot point is used.

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<sup>17</sup> 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-RFF. 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. Sometimes the rebate is given directly to the consumer instead of the manufacturer; this makes no difference within the NEMS-RFF model, although there is suggestive evidence that actually consumers bear more of a tax or capture more of a rebate than they do if it is directed to the manufacturer (Sallee 2010).

<sup>18</sup> In contrast, Bunch et al. (2011, p. 23) find that sales mix accounts for 23% of the improvement in new-vehicle fuel economy over model years 2011-2018, even when the feebate is based on footprint and thus eliminates any incentive to downsize vehicles.

Therefore, the simulations shown here are with a separate pivot point for each of NEMS-RFF'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 (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.<sup>19</sup> 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

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<sup>19</sup> 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 a way to correct externalities. See Small (2010) for further discussion of its rationale.

toward cars.<sup>20</sup> Overall, however, these responses in fuel efficiency are small and result in less fuel savings that does the reduction in VMT. These results are broadly consistent with those of Morrow et al. (2010), also using a version of NEMS.<sup>21</sup>

**Table 2. Results: High Fuel Tax**

	Value in baseline	Values with policy		Change due to policy			
		2010	2020	2030	Absolute		Percentage
				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%
<b>Transportation outcomes</b>							
<i>New LDVs:</i>							
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%
<i>All LDVs (new and used):</i>							
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%
<b>Economy-wide outcomes</b>							
Energy-related CO <sub>2</sub> (mmt)	5,746	5,751	6,058	-130	-135	-2.2%	-2.2%
Oil consumption (mmbbl/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. Total U.S. energy-related CO<sub>2</sub> 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

<sup>20</sup> 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.

<sup>21</sup> 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-RFF models those sectors as extremely price-inelastic and so the policy is best viewed as applying only to LDVs.

gasoline, diesel, or closely related fuels. However, it appears that NEMS-RFF 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 2030. This is largely because in NEMS-RFF, consumers respond to fuel prices in their choice of vehicle type. Detailed results show 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 model’s implied overall 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.<sup>22</sup> Thus, the responsiveness of VMT in NEMS-RFF 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.

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<sup>22</sup> Parry and Small choose from that literature central values of -0.55 for the total price-elasticity and  $-0.55 \cdot 0.4 = -0.22$  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:  $\varepsilon_F = \varepsilon_{VMT} + \varepsilon_{FI} + \varepsilon_{VMT} \varepsilon_{FI}$  where  $\varepsilon_{VMT}$  and  $\varepsilon_{FI}$  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 Li, Timmins, and von Haefen (2009) and Small (2010).

## 4.2 Fuel Efficiency Standards

As already noted, 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 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.<sup>23</sup> Doing so implies a 48 percent increase in fuel efficiency standards between 2016 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, compared to the baseline scenario. Energy use from all LDVs is reduced by 8.4 percent relative to baseline, and total U.S. petroleum consumption is reduced by 4.0 percent.<sup>24</sup>

Several well-known defects of a CAFE policy can be seen in these results. First, the policy 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.

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<sup>23</sup> In October 2010, EPA and NHTSA announced an intent to promulgate joint greenhouse-gas emissions standards and CAFE standards for new light-duty vehicles for model years 2017-2025 (U.S. EPA and NHTSA 2010b). For the technical analysis, they have considered annual emissions reductions of 3, 4, 5, and 6 percent. The Pavley CAFE scenario analyzed in this paper reduces the permitted fuel intensity by an average of 3.03 percent per year over the same nine-year period. EIA (2011) analyzes two "sensitivity cases" that incorporate 3 percent and 6 percent versions of this proposal, acknowledging that the latter would create serious compliance difficulties (EIA 2011, section on "Issues in Focus," subsection on "Increasing Light-Duty Vehicle greenhouse Gas and Fuel Economy Standards for Model Years 2017 to 2025.")

<sup>24</sup> 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.

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.

**Table 3. Results: Pavley CAFE**

	Value in baseline	Values with policy		Change due to policy				
		2010	2020	2030	Absolute		Percentage	
					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%	
<b>Transportation outcomes</b>								
<i>New LDVs:</i>								
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%	
<i>All LDVs (new and used):</i>								
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%	
<b>Economy-wide outcomes</b>								
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%	

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 compared to the fines for non-compliance (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 (i.e. the sales-weighted percentage of manufacturers who pay fines) 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.<sup>25</sup> This may reflect NEMS-RFF’s limitations in modeling technological

<sup>25</sup> 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.)

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).

Another aspect of actual implementation of CAFE-like policies is that they invariably introduce discontinuities or "notches" into manufacturers' and consumers' constraints, leading to gaming behavior such as modifying vehicle design in order to reclassify them as light trucks (Sallee and Slemrod 2010). Even worse, some modeling evidence suggests that those firms choosing to pay fines (instead of meeting the standard) fill the market niche for high-performance cars that is partially abandoned by firms meeting the standards, thereby severely eroding the fuel savings (Whitefoot, Fowlie, and Skerlos 2011). These features are not explicitly modeled here.

### **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?

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			
		2010	2020	2030	Absolute		Percentage
	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%
<b>Transportation outcomes</b>							
<i>New LDVs:</i>							
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%
<i>All LDVs (new and used):</i>							
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%
<b>Economy-wide outcomes</b>							
Energy-related CO2 (mmt)	5,747	5,626	5,897	-263	-292	-4.5%	-4.7%
Oil consumption (mmbbl/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. 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,<sup>26</sup> which is phased in starting at a half this rate in 2017 and rising in equal increments through 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.<sup>27</sup>

<sup>26</sup> This basic rate of \$2,000/(0.01 gpm) is nearly twice that considered by Greene et al. (2005a,b), and slightly larger than that of Bunch et al. (2011). For a car driven 12,683 miles per year (our baseline 2021–2030 average) over a 14-year life, the rate implies a payment of  $(\$2,000/0.01\text{gpm})/(12,683 \times 14 \text{ miles}) = \$1.13$  per gallon of fuel consumed.

<sup>27</sup> 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.

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 feature may be an artifact of NEMS-RFF' modeling of 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			
		2010	2020	2030	Absolute		Percentage
				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%
<b>Transportation outcomes</b>							
<i>New LDVs:</i>							
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	26.5	40.5	45.4	3.3	6.6	8.9%	16.9%
Trucks	30.4	43.9	49.6	2.5	6.8	6.0%	15.9%
<i>All LDVs (new and used):</i>							
Fuel efficiency (mpg)	23.6	36.4	40.8	4.3	7.2	13.4%	21.3%
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%
<b>Economy-wide outcomes</b>							
Energy-related CO2 (mmt)	5,747	5,869	6,108	-20	-82	-0.3%	-1.3%
Oil consumption (mmbbl/day)	18.5	17.7	17.3	-0.1	-0.7	-0.7%	-3.7%

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-RFF 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. 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”.<sup>28</sup> Their ratio is shown as “cost-effectiveness”, a conventional but easily misunderstood term because a high number means a less favorable ratio. Note 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.

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

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<sup>28</sup>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.

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 annual 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 it is positive, a benefit (or 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:

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

where  $\bar{q}$  is the number of vehicles purchased, averaged between the pre- and post-policy scenarios, and where  $\Delta P_V$  is the change in vehicle price.<sup>29</sup>

*(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:

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

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<sup>29</sup> In practice I am unable through NEMS-RFF 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.

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  $\Delta F < 0$  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).<sup>30</sup> 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:

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

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.<sup>31</sup>

### (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

<sup>30</sup> 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.

<sup>31</sup> One can argue that changes in tax revenues should be multiplied by a factor reflecting the marginal cost of public funds, which implies that a dollar of tax revenues produces more than one dollar in revenue because it can replace other distorting taxes and thus eliminate the “excess burden” of their distortions. A factor commonly used for this purpose is 1.15, although the appropriate number can vary widely among nations; see Small and Verhoef (2007, pp. 177-178) for a discussion and references. Including it would mainly decrease the welfare cost of fuel taxes. However, in practice such tax revenues are often used to fund other projects, or are redistributed in such a way as to increase political support, so the reduction in “excess burden” may never be realized.

represent an “arms race” for safety thus not be a social value; but those safety costs will be 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:

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

where  $\Delta s_t$  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:

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

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.<sup>32</sup> This estimate of amenity losses in effect offsets about three-fourths of the fuel cost savings.

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<sup>32</sup> The annuity factor is  $A(r, T) = [1 - (1 + r)^{-T}] / r$ . 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-RFF 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:

$$-\Delta w_E = c_M \Delta(VMT) . \quad (6)$$

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.<sup>33</sup> 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:

$$\Delta w_S = c_S Q \Delta S_t \quad (7)$$

where  $Q$  is the number of vehicle in use under the policy and  $\Delta S_t$  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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<sup>33</sup> 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<sub>2</sub> 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
<b>Costs of policy (billions 2007 \$)</b>									
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
<b>Total (1–4) (lower estimate)</b>	<b>2.2</b>	<b>1.9</b>	<b>15.6</b>	<b>11.0</b>	<b>-2.3</b>	<b>-31.7</b>	<b>9.3</b>	<b>-1.3</b>	<b>-37.5</b>
<i>Alternative calculations:</i>									
5. Hidden amenity cost	5.8	11.8	75.4	4.8	36.1	152.5	6.8	35.1	158.8
<b>Total w/ hidden amnty cost (1–5) (upper estimate)</b>	<b>8.0</b>	<b>13.7</b>	<b>91.0</b>	<b>15.7</b>	<b>33.8</b>	<b>120.8</b>	<b>16.1</b>	<b>33.8</b>	<b>121.3</b>
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
<b>Total with external &amp; accident costs (1–4,6–7)</b>	<b>-18.2</b>	<b>-32.6</b>	<b>-234.0</b>	<b>11.4</b>	<b>8.6</b>	<b>5.9</b>	<b>11.4</b>	<b>11.1</b>	<b>12.9</b>
<b>Policy effectiveness (reduction from baseline)</b>									
Petroleum consumption (million barrels)	280	290	5,228	43	263	3,612	47	242	3,454
Energy-related CO <sub>2</sub> (million metric tons)	130	135	2,419	19	101	1,429	20	82	1,211
<b>Cost-effectiveness (based on "lower estimate")</b>									
Policy cost per:									
barrel petroleum consumption (\$/bbl)	8	7	3	255	-9	-9	198	-5	-11
metric ton CO <sub>2</sub> reduced (\$/tonne)	17	14	6	563	-22	-22	473	-16	-31
<b>Cost-effectiveness (based on "upper estimate")</b>									
Policy cost per:									
barrel petroleum consumption (\$/bbl)	29	47	17	366	129	33	344	140	35
metric ton CO <sub>2</sub> 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 (favorable) under the “market failure” interpretation—\$3 per barrel of oil or \$6 per metric ton of CO<sub>2</sub>—but several times higher (less favorable) 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.<sup>34</sup>

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<sub>2</sub> 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 (meaning policy effectiveness comes at negative cost) 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<sub>2</sub>.

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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<sup>34</sup> 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-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 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
<b>Effects of policies</b>						
Petroleum reduction (million barrels)	5,228	9,614	3,612	12,262	3,454	4,998
CO <sub>2</sub> reduction (million metric tons)	2,419	4,590	1,429	5,679	1,211	1,739
<b>Policy cost metrics</b>						
<b>Without external costs of driving:</b>						
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 <sub>2</sub> (\$/metric ton)	22.0	45.0	31.2	46.8	34.6	67.1
<b>With external costs of driving:</b>						
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 <sub>2</sub> (\$/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. Cost effectiveness is defined as cost divided by the particular effect (petroleum reduction or CO<sub>2</sub> reduction) being considered.

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<sub>2</sub> 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 available 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. Several of these are due to inherent properties of the policies and so are likely to generalize beyond the United States.

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<sub>2</sub> 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<sub>2</sub> 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-RFF'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. If such external costs were addressed with more direct policies, for example congestion pricing of roads, this category of costs would no longer exist and so the welfare estimates omitting them would be the appropriate ones; but in such a world several basic properties of the base case would be different, which would in turn change somewhat the impacts of the energy policies modeled here.

## References

Allcott, H., Wozny, N., 2010. Gasoline Prices, Fuel Economy, and the Energy Paradox. Working paper, New York University and Princeton University, March.

<http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf> (accessed May 15, 2010).

Anderson, S.T., Kellogg, R., Sallee, J.M., 2011. What Do Consumers Believe About Future Gasoline Prices? Working Paper 215, Energy Institute at Haas, Haas School of Business, Univ. of California at Berkeley, April. [http://ei.haas.berkeley.edu/pdf/working\\_papers/WP215.pdf](http://ei.haas.berkeley.edu/pdf/working_papers/WP215.pdf)

Austin, D., 2008. *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets*. Pub. No. 2883, January. Washington, DC: Congressional Budget Office.

Bento, A.M., Goulder, L.H., Jacobsen, M.R., von Haefen, R.H., 2009. Distributional and Efficiency Impacts of Increased U.S. Gasoline Taxes. *American Economic Review* 99(3): 667–699.

Bovenberg, A.L., de Mooij, R.A., 1994. Environmental Levies and Distortionary Taxation. *American Economic Review* 84: 1085–1089.

Brozovic, N., Ando, A.W., 2009. Defensive Purchasing, the Safety (Dis)advantage of Light Trucks, and Motor-Vehicle Policy Effectiveness. *Transportation Research Part B—Methodological* 43: 477–493.

Bunch, D.S., Greene, D.L., Lipman, T., Martin, E., Shaheen, S., 2011. Potential Design, Implementation, and Benefits of a Feebate Program for New Passenger Vehicles in California: Final Report. Report prepared for State of California Air Resources Board, Research Division, Sacramento, contract UCD 08-312, February. <http://www.arb.ca.gov/research/apr/past/08-312main.pdf>. Accessed April 14, 2011.

Busse, M.R., Knittel, C.R., Zettelmeyer, F., 2009. Pain at the Pump: The Differential Effect of Gasoline Prices on New and Used Automobile Markets. Working Paper 15590, National Bureau of Economic Research, December. [www.nber.org/papers/w15590](http://www.nber.org/papers/w15590). Accessed April 14, 2011.

CRS (Congressional Research Service). 2007. *Energy Independence and Security Act of 2007: A Summary of Major Provisions*. Order Code RL34294k, December 21. Washington, DC: CRS.

Davis, S.C., Diegel, S.W., Boundy, R.G., 2009. *Transportation Energy Data Book: Edition 28*. Oak Ridge, Tennessee: Oak Ridge National Laboratory. <http://cta.ornl.gov/data/index.shtml> (accessed May 21, 2010).

EIA (Energy Information Administration). 2008. *Transportation Sector Module of the National Energy Modeling System: Model Documentation 2008*. DOE/EIA-M070(2008), October. Washington, DC: EIA.

EIA. 2009a. *An Updated Annual Energy Outlook 2009 Reference Case Reflecting Provisions of the American Recovery and Reinvestment Act and Recent Changes in the Economic Outlook*. SR/OIAF/2009-03, April. Washington, DC: EIA.

[http://www.eia.doe.gov/oiaf/servicerpt/stimulus/pdf/sroiaf\(2009\)03.pdf](http://www.eia.doe.gov/oiaf/servicerpt/stimulus/pdf/sroiaf(2009)03.pdf) (accessed May 16, 2010).

EIA. 2009b. *The National Energy Modeling System: An Overview*. DOE/EIA-0581(2009), October. Washington, DC: EIA. <http://www.eia.doe.gov/oiaf/aeo/overview/index.html> (accessed April 15, 2010).

EIA. 2009c. Transportation Demand Module. In *Assumptions to the Annual Energy Outlook 2009*. DOE/EIA-0554(2009), March. Washington, DC: EIA, 59–85.

EIA. 2009d. *Annual Energy Outlook 2009 with Projections to 2030, Updated Annual Energy Outlook 2009 Reference Case with ARRA*. Projection Tables: Year-by-Year Updated Annual Energy Outlook 2009 Reference Case with ARRA Tables (2006-2030). Washington, DC: EIA. <http://www.eia.doe.gov/oiaf/servicerpt/stimulus/aeostim.html> (accessed Nov. 3, 2010).

EIA. 2010. *Annual Energy Review 2009*. Report No. DOE/EIA-0384(2009), August 2010. <http://www.eia.doe.gov/emeu/aer/> (accessed Nov. 3, 2010).

EIA. 2011. *Annual Energy Outlook – 2011*. EIA, April 26. <http://www.eia.doe.gov/forecasts/aeo/index.cfm> (accessed April 28, 2009).

GAO (Government Accountability Office). 2010. *Vehicle Fuel Economy: NHTSA and EPA's Partnership for Setting Fuel Economy and Greenhouse Gas Emissions Standards Improved Analysis and Should Be Maintained*. Report GAO-10-336, Washington, D.C.: GAO, February.

Gillingham, K., 2010. "How Do Consumers Respond to Gasoline Price Shocks? Heterogeneity in Vehicle Choice and Driving Behavior. Working paper, Dept. of Economics, Stanford University, Stanford, CA, December 15. [http://www.stanford.edu/~kgilling/Gillingham\\_JMP.pdf](http://www.stanford.edu/~kgilling/Gillingham_JMP.pdf)

Goulder, L.H., Parry, I.W.H., Burtraw, D., 1997. Revenue-Raising versus Other Approaches to Environmental Protection: The Critical Significance of Preexisting Tax Distortions. *RAND Journal of Economics* 28(4): 708–731.

Goulder, L.H., Williams, R.C. III, 2003. "The Substantial Bias from Ignoring General Equilibrium Effects in Estimating Excess Burden, and a Practical Solution," *Journal of Political Economy*, 111(4): 898-927.

Greene, D.L., 2009. Feebates, Footprints and Highway Safety. *Transportation Research Part D* 14: 375–384.

Greene, D.L., 2010. How Consumers Value Fuel Economy: A Literature Review. Report prepared for U.S. Environmental Protection Agency, Assessment and Standards Division, Office

of Transportation and Air Quality, EPA Contract No. DE-AC05-00OR22725, March.  
<http://www.epa.gov/oms/climate/regulations/420r10008.pdf>

Greene, D.L., 2011. Analysis of U.S. Light-Duty Vehicle Travel Statistics. *EnergyPolicy*, forthcoming (doi:10.1016/j.enpol.2010.03.083).

Greene, D.L., Patterson, P.D., Singh, M., Li, J., 2005a. Feebates, Rebates and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy. *Energy Policy* 33: 757–775.

Greene, D.L., Patterson, P.D., Singh, M., Li, J., 2005b. Corrigendum to “Feebates, Rebates and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy.” *Energy Policy* 33: 1901–1902.

Jacobsen, M.R., 2010. Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity. Working paper, January. San Diego, CA: University of California at San Diego. [http://econ.ucsd.edu/~m3jacobs/Jacobsen\\_CAFE.pdf](http://econ.ucsd.edu/~m3jacobs/Jacobsen_CAFE.pdf) (accessed May 15, 2010).

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

Kleit, A.N., 2004. Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard. *Economic Inquiry* 42: 279–294.

Krupnick, A.J., Parry, I.W.H., Walls, M., Knowles, T., Hayes, K., 2010. *Toward a New National Energy Policy: Assessing the Options: Full Report*. Washington, D.C.: Resources for the Future and National Energy Policy Institute, November.

Li, S., 2010. Traffic Safety and Vehicle Choice: Quantifying the Effects of the ‘Arms Race’ on American Roads. *Journal of Applied Econometrics*, published online DOI: 10.1002/jae.1161.

Li, S., Timmins, C., von Haefen, R.H., 2009. How Do Gasoline Prices Affect Fleet Fuel Economy? *American Economic Journal: Economic Policy* 1, 113-137.

Morrow, W.R., Gallagher, K.S., Collantes, G., Lee, H., 2010. Analysis of Policies To Reduce Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector. *Energy Policy* 38(3): 1305–1320.

NHTSA (National Highway Traffic Safety Administration). 2006. Average Fuel Economy Standards for Light Trucks: Model Years 2008–2011. *Federal Register* 71(66): 17566–17614, April 6 (49 CFR Parts 523, 533, and 537).  
<http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/2006FinalRule.pdf> (accessed June 4, 2010).

NHTSA. 2008. Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015; Proposed Rule. *Federal Register* 73(86): 24352–24487, May 2 (49 CFR Parts 523, 531, 533, 534, 536, and 537).

Parry, I.W.H., . Small, K.A., 2005. Does Britain or The United States Have the Right Gasoline Tax? *American Economic Review*, 95: 1276-1289.

Sallee, J., 2010. The Taxation of Fuel Economy. Working Paper 16466, National Bureau of Economic Research, October. [www.nber.org/papers/w16466](http://www.nber.org/papers/w16466).

Sallee, J., Slemrod, J., 2010. Car Notches: Strategic Automaker Responses to Fuel Economy Policy. Working Paper 212, Energy Institute at Haas, Haas School of Business, Univ. of California at Berkeley, February. [http://ei.haas.berkeley.edu/pdf/working\\_papers/WP212.pdf](http://ei.haas.berkeley.edu/pdf/working_papers/WP212.pdf)

Small, K.A., 2010. Energy Policies for Automobile Transportation: A Comparison Using the National Energy Modeling System. Background report for *Toward a New National Energy Policy: Assessing the Options*, Resources for the Future and National Energy Policy Institute, June. <http://www.rff.org/Documents/Features/NEPI/RFF-BCK-Small-AutoPolicies.pdf> (accessed June 29, 2010).

Small, K.A., Van Dender, K., 2007a. Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. *Energy Journal* 28(1): 25–51.

Small, K.A., Van Dender, K., 2007b. Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. Working Paper #05-06-03 (corrected), Department of Economics, University of California at Irvine, August. [http://www.socsci.uci.edu/~ksmall/Rebound\\_working\\_paper\\_corrected.pdf](http://www.socsci.uci.edu/~ksmall/Rebound_working_paper_corrected.pdf) (accessed July 22, 2010).

U.S. DOE (Department of Energy). 1996. *Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions: Lessons from Recent Literature*. Report No. DOE/PO-0047, US Department of Energy, Office of Policy and International Affairs, Washington, D.C., July.

U.S. EPA and U.S. DOT (Department of Transportation). 2009. *Notice of Upcoming Joint Rulemaking to Establish Vehicle GHG Emissions and CAFE Standards*. *Federal Register* 74(98): 24007-24012, May 22.

U.S. EPA and NHTSA. 2010a. Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule. *Federal Register* 75(88): 25324-25728, May 7.

U.S. EPA and NHTSA. 2010b. 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards; Notice of Intent. *Federal Register* 75(97): 62739-62750, Oct. 13.

Wenzel, T.P., Ross, M., 2005. The Effects of Vehicle Model and Driver Behavior on Risk. *Accident Analysis and Prevention* 37: 479–494.

White, M.J., 2004. The “Arms Race” on American Roads: The Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety. *Journal of Law and Economics* 47: 333–355.

Whitefoot, K., Fowlie, M., Skerlos, S., 2011. Product Design Response to Industrial Policy: Evaluating Fuel Economy Standards Using an Engineering Model of Endogenous Product Design. Working Paper 214, Energy Institute at Haas, Haas School of Business, Univ. of California at Berkeley, February. [http://ei.haas.berkeley.edu/pdf/working\\_papers/WP214.pdf](http://ei.haas.berkeley.edu/pdf/working_papers/WP214.pdf)