Savings from CAFE

Projections of the Future Oil Savings from Light Vehicle Fuel Economy Standards

John M. DeCicco

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ABSTRACT

This paper presents estimates of the effect of strengthened Corporate Average Fuel Economy (CAFE) standards on light duty vehicle oil consumption in the United States. Projections are made of the expected oil savings and reductions in carbon dioxide (CO_2) and hydrocarbon (HC) emissions. Five CAFE standards scenarios, some of which correspond to recent legislative proposals, are considered, ranging from CAFE increases of 15% to 60% by 2001 with similar rates of improvement through 2010. The most critical underlying assumption is that of the baseline, that is, the extent of fuel economy improvement or decline in the absence of strengthened standards. Choice of a baseline is discussed; results are presented relative to a middle baseline of rated fuel economy frozen at the 1991 level and alternative baselines of rising and falling fuel economy. Light duty vehicles consumed an estimated 6.1 Mbd (million barrels per day) of motor fuel in 1991. In the absence of new standards or other significant changes in policy, consumption is projected to grow to 9.2 Mbd by 2005.

For the scenario of a 40% CAFE increase by 2001, the mid-range projections are oil savings of 2.4 Mbd by 2005 and corresponding emissions reductions of 440 million tons per year of CO_2 and 410,000 tons per year of HC. Assumption of a higher or lower baseline gives a $\pm$25% change in the projected savings. Similar results are provided for other scenarios and other years through 2010. Other factors affecting the achieved levels of fuel economy and overall fleet fuel consumption are also examined, including timing, CAFE credits, potential rollbacks of standards, upper and lower bounds on a percentage increase standard, and uncertainties regarding light duty vehicle market shifts, growth in vehicle miles of travel (VMT), VMT "rebound," and fuel economy shortfall. Compared to the baseline assumption, these factors have smaller effects on the projections, resulting in an overall uncertainty of $\pm$30%. In summary, strengthened CAFE standards would be an effective means of controlling future oil consumption by automobiles and light trucks in the United States.

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INTRODUCTION

Corporate Average Fuel Economy (CAFE) standards have been the primary policy tool for improving the efficiency of automobiles and light trucks in the United States. These federal regulations specify a minimum sales-weighted average fuel economy to be met by each manufacturer selling cars and light trucks in the United States. The CAFE standards enacted in 1975 have been the principal force behind a doubling of rated automobile fuel economy since 1973 (Greene 1990b). Although the impetus for the regulation was the 1973 oil embargo and the energy crises of 1973 and 1979 did temporarily raise fuel prices, CAFE standards provided the steady signal to manufacturers which has led to the acceptance of more efficient vehicles in the marketplace.

The existing regulatory mandate took effect for automobiles in 1978. The highest level specified in the law, 27.5 mpg, was first established for 1985 and is the automobile standard level in effect as of this writing.[1] The standard was rolled back by the Reagan administration for four years, from 1986 through 1989. Figure 1 shows historical average EPA-rated fuel economy of new vehicles through 1990, along with various future projections (described below). The average fuel economy achieved by new automobiles peaked at 28.6 mpg in 1988 and has subsequently declined by about 3%. Standards for light trucks were left to the discretion of the Department of Transportation and have greatly lagged the standards set for automobiles. The 1991 light truck average standard is 20.2 mpg, 61% higher than the 1973 new fleet average of about 12.5 mpg; the automobile standard is 27.5 mpg, 94% higher than the 1973 average of 14.2 mpg. New light truck fuel economy peaked at 21.6 mpg in 1987 and has subsequently declined by about 4%. The portion of the new light vehicle market categorized as light trucks increased from 20% in 1977 to 33% presently. Meanwhile, the gap between the fuel economy of light trucks and that of cars rose from 15% in 1977 to 25% presently.

The existing law on automotive fuel economy enables the administration to set CAFE standards at a "maximum feasible level," considering technical practicality, economic impacts, and other factors. There have been ongoing advances in automotive technology, including many technologies that can be applied to improve fuel economy. The present U.S. administration has not, however, indicated an interest in increasing the standards. Strengthening the CAFE standards was not included in the National Energy Strategy, for example.

[1] Unless otherwise noted, fuel economy values cited here are all EPA (U.S. Environmental Protection Agency) test values, as used for compliance purposes, and given as the 55% city and 45% highway weighted average of driving cycle test results. For the purposes of this paper, such values are termed *rated* or *compliance* fuel economy values. Historical statistics on new vehicle fuel economy are from Heavenrich *et al.* (1991) and do not include test procedure adjustments; standards are from NHTSA (1991).

There is a need to reduce light vehicle petroleum consumption for a number of reasons. Petroleum fuel use is a major source of greenhouse gas emissions (EPA 1989; OTA 1991a), contributing to risks of global climate disruption. Concerns persist about rising imported oil dependence, because of its contribution to the trade deficit and national security implications (OTA 1991b). While they are not a large share of individual consumer expenditures,[2] overall motor fuel costs are a large drain on the U.S. economy, since the revenues flow to the relatively few oil producers, a growing number of which are overseas.[3] The technology available for improving automotive efficiency has greatly advanced over the past decade and the feasibility of significant improvement is established.[4] The greater certainty with which fuel supply requirements can be predicted when vehicles meet mandated efficiency levels is seen by some as a benefit of such standards, apart from the direct benefits of petroleum savings. There has been consistent public option support for improving fuel economy standards as a way to address these problems related to motor vehicle fuel consumption.[5] For these reasons, a number of proposals for increasing the fuel economy standards have been introduced in the U.S. Congress. A critical question for policy makers contemplating strengthened CAFE standards is how much oil savings can be expected.

This paper provides estimates of the savings in petroleum fuel consumption that are expected to occur as under strengthened standards and as newer, more efficient vehicles replace older ones in the light vehicle stock. Also provided are the associated reductions in emissions of carbon dioxide (CO_2) and hydrocarbons (HC), two pollutants for which the link to motor fuel consumption is clearly established. This analysis addresses, among others, the CAFE standards scenario of a 40% increase in CAFE levels by the year 2001, as proposed by Bryan (1991).[6] Other standards levels have also been proposed, with higher and lower targets. For example, Boxer (1991) proposed an increase of 60% by 2001; Johnston (1991) proposed increases of roughly 20% by 2001 and 30% by 2006.[7] Various provisions of existing and proposed fuel economy regulations can affect the CAFE levels actually achieved with a given targeted

[2] Annual motor fuel expenditures average about $1000 per household (EIA 1990b, Table 7), amounting to just under 4% of the median household income of $26,000 (Bureau of the Census 1988, Table 715, p. 442).

[3] The estimated U.S. oil import bill in 1991 was $45 billion, about two-thirds of the trade deficit (EIA 1991, Table 1.6).

[4] See, for example, Bleviss (1988); Difiglio, Duleep, and Greene (1990b); OTA (1991c); Ross, Ledbetter, and An (1991); EEA (1991).

[5] Polls, such as Breglio and Lake (1991) and Schneiders (1992), indicate public preference for standards over a gasoline tax, even if improved fuel economy may add to the price of a new car.

[6] Senate Bill S. 279 in the 102nd Congress, introduced by Senators Richard Bryan and Slade Gorton. Legislative proposals are cited here by the name of their principal sponsor and year of introduction.

[7] The exact level specified by a percentage increase type of standard depends on the base year, which is 1988 for the Bryan and Boxer proposal and 1990 for the Johnston proposal. Different manufacturers shifted their CAFEs by different amounts in the past several years; the overall average for automobiles dropped from 28.6 MPG in 1988 to 27.8 MPG in 1990.

increase. Therefore, a general analysis is presented, showing the projected savings for various levels of fuel economy achieved by a given future year. Finally, differences among the reported savings estimates are examined by explicitly tracing them to differences in underlying assumptions.

Computing the savings from fuel economy improvement is a relatively straightforward exercise. The principal inputs needed are estimates of future travel (VMT) and the age distribution of the vehicle population. Savings projections have been recently reported by Greene and Duleep (1992), CRA (1991), OTA (1991c), Farmer (1991a,b), DOE (1991), Watson (1991), Greene (1990a), Leone and Parkinson (1990), and earlier by ACEEE.[8] Some of the savings projections for the Bryan proposal were compared by OTA (1991c, pp. 99ff). A major source of differences among projections is the assumed baseline fuel economy, that is, the future CAFE levels in the absense of higher standards. Differences also arise because of uncertainties in the VMT projection, including the effect of improved fuel economy on the amount of driving. There are also issues regarding the extent to which mandated fuel economy improvements might raise the cost of new cars, so that older, less efficient vehicles remain in the stock for a longer period of time. There is also a related issue of attribution, namely, the extent to which the fuel savings are an effect of the regulatory intervention rather than a market response to changes in fuel price. This latter issue has been examined in retropective analyses of the existing CAFE regulations.[9] Given the variety of assumptions that can be made about all of these factors, it is not surprising that the range of predicted savings estimates may appear to be quite wide. Estimates regarding the Bryan (1991) proposal, for example, have been reported as varying by as much as a factor of five, from 0.5 Mbd (million barrels per day) to 2.5 Mbd.[10]

The focus of this paper is on the direct oil savings from future CAFE increases. The technical feasibility of various CAFE levels is not re-examined.[11] The broader issue of overall economic costs and benefits is not addressed. Estimation of net societal economic benefits to the U.S. would involve considering the cost of the technology improvements, costs and benefits to consumers due to the regulatory constraint on the new vehicle market, costs to automakers of regulatory contraints on their business, costs due to the oligopoly nature of the automobile industry, income distributional effects, various external costs associated with oil consumption (environmental and national security costs, for example), effects due to the cartel nature of oil supply and the monopsony nature of U.S. oil demand, and transfer of wealth abroad due to oil imports. Many of these have been addressed by Greene and Duleep (1991), who found that the direct

[8] Ledbetter and DeCicco (1991) reported projections that were also cited in other testimony by ACEEE. These estimates were documented by the author in a series of technical memoranda, which this paper collects and supercedes.

[9] Greene (1991); Leone and Parkinson (1990); among others.

[10] Dillin (1991); OTA (1991c), pp. 99ff.

[11] The feasibility of CAFE increases is addressed by Bleviss (1988); Difiglio, Duleep, and Greene (1990b); OTA (1991c); Ross, Ledbetter, and An (1991); and SRI (1991), among others.

fuel cost savings approximately balance the costs of fuel economy improvement up to about 36 mpg for automobiles; that the next largest benefit was less transfer of wealth abroad; and that other factors were generally smaller in effect.

Savings from Past CAFE Standards

Before developing projections for future standards, it will be useful to provide an estimate of the impact that existing CAFE standards have had to date. Various analysts have estimated the fuel savings due to past improvements in automotive fuel economy, ranging from 2 Mbd to 4 Mbd depending on the period and vehicle classes covered,[12] although none explicity broke the savings down by cause (standards or price). For calculating the effect of the existing standards, an appropriate base year is 1977. This is the year before the automobile standards went into effect and is after the initial response to the 1973 oil crisis, which caused an initial round of fuel economy improvement prior to CAFE standards. The average on-road fuel economy of cars and light trucks subject to CAFE regulation rose from about 13 mpg in 1977 to 20 mpg in 1991; annual travel (VMT) by light vehicles now runs 1.9 trillion miles.[13] The savings estimate relative to frozen fuel economy is therefore

$$\frac{(1.9x10^{12} miles/year)}{(42 gal/bbl)(365 days/year)}\left(\frac{1}{13mpg}-\frac{1}{20mpg}\right) = 3.3\,Mbd$$

The question of how much of the savings is attributable to CAFE standards as opposed to changes in fuel price was addressed by Greene (1990b), who found a strongly significant CAFE effect but only a marginally significant price effect. This is not surprising, since prices fluctuated and, through mid-1990, were lower in real terms than they were in 1973. Greene's coefficients suggest about a 75% effect for CAFE, but he could not reject the hypothesis that price had no effect. It is fair, therefore, to assign 75% of the savings to CAFE, resulting in an estimate of 2.5 Mbd. Therefore, light vehicle fuel consumption (estimated below at 6.1 Mbd in 1991) would have been 40% higher if CAFE standards had not been enacted and over 50% higher if no improvement in fuel economy (CAFE induced or otherwise) had occurred.

[12] Greene, McNutt, and Sperling (1988); Schipper *et al.* (1990); OTA (1991c); Ross *et al.* (1991).

[13] New vehicle fuel economy statistics from Heavenrich *et al.* (1991); an assumed shortfall of 20% in both years; the author's stock model estimates for overall on-road average fuel economy; and VMT estimates as derived from FHWA (1990) for this paper.

METHODOLOGY

The basic relation for fuel use by a population of motor vehicles is

$$Fuel\ \ Use = \frac{VMT}{MPG} \tag{1}$$

Vehicle fuel economy, represented by MPG (miles per gallon), refers to the stock average of the vehicle population under consideration. Actual on-road fuel economy must be used for MPG in Equation (1) rather than the compliance fuel economy ratings, which are biased high (see "Shortfall," below). Stock average MPG depends on the fuel economy of all vehicles in the stock, weighted according to their usage by vehicle age (vintage) and other attributes that might be used to classify vehicle for the purpose of analysis (such as cars vs. trucks). Vehicle miles travelled (VMT) depends on the size of the driver population, their income, and the cost of driving, as well as structural factors (related to land use and availability of alternative modes of transportation). VMT's cost of driving dependence links it to fuel economy (MPG), since

$$Fuel\ \ Cost\ \ per\ \ Mile = \frac{Fuel\ \ Price}{MPG} \tag{2}$$

Thus, an improvement in fuel economy may induce induce additional driving--what is known as the "rebound" effect (Greene 1991)--thereby offsetting some of the potential fuel savings.

Shortfall in On-Road Fuel Economy

Because of increasing congestion, urbanization, higher road speeds, and other factors, actual on-road fuel economy is less than the EPA-test fuel economy used for CAFE compliance purposes. The gap between on-road MPG and EPA test values is termed fuel economy *shortfall*. The fuel economy estimates given in the EPA Gas Mileage Guide and printed on new vehicle sales stickers reflect an average downward adjustment of 15%, based on EPA analysis from the early 1980s, which at least partly corrects for shortfall. The analysis given here assumes that shortfall grows linearly from 15% in 1986 to 30% in 2010 (Westbrook and Patterson 1989). This would place the 1991 estimate at 18%, for example, and superimposes an average declining trend of 0.8%/yr on any improvements in rated fuel economy that might be made. The estimated value in 2005 is therefore 27% (meaning that actual on-road fuel economy is 73% of the EPA-rated value). Shortfall is dependent on the year in which a vehicle is used, not the year in which it was made.

We apply the same shortfall assumptions to all vehicle classes, although there is evidence that the situation is worse for light trucks.[14] An underestimate of shortfall implies a proportionate underestimate of both fuel consumption and fuel savings; the reverse is also true.

Fuel Economy Projections

Baseline. Estimating the savings due to a policy such as CAFE standards involves computing the difference between two projections of fuel use, that is, fuel use projected under some *baseline* assumptions minus fuel use projected under assumptions of the CAFE standard. For the purpose of comparing several potential policy changes, such as a variety of CAFE proposals, fuel taxes, or other options, it is sufficient that they be compared to a common baseline. Ideally, the baseline should represent an expectation of what would occur in the absence of policy change (a "null" policy case). The issue of what changes in new vehicle fuel economy would occur in the absence of policy change is often contentious.

The null policy change case selected here has new light vehicle *rated* (EPA compliance) fuel economy frozen and *on-road* fuel economy declining at 1.3%/yr. The justification is as follows. The 1990-91 Middle East crisis had a relatively small and temporary impact on oil prices. There appears to be no market expectation of a lasting or severe supply disruption. Price rises are expected to be modest, for example, the Department of Energy projects average gasoline prices of $1.30/gallon in 2000 and $1.50/gallon in 2010.[15] New light vehicle rated fuel economy has been declining at about 1%/yr since 1988, coincident with increases in power performance, luxury, or other amenities.[16] Most recent announcements in the automotive trade suggest a continuation of these trends for at least the next few model years. Even if these trends saturate, allowing an increase in fuel economy in the late 1990's, it appears that fuel economy levels might at best return to the 1990 average by 2001. An assumption of frozen EPA-rated fuel economy would then be a conservative baseline for CAFE savings projections, because the shallow trough we seem to be presently entering would not be accounted for, even though the somewhat less efficient vehicles of the early 1990's will remain in the vehicle stock.

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[14] P. Patterson (U.S. Dept. of Energy), pers. comm., 1991.

[15] From EIA (1990a), in constant 1990 dollars including federal and state taxes; the 1990 average was $1.17/gallon.

[16] Heavenrich *et al.* (1991) report: since 1982, falling 0-60 mph acceleration times (also increases in estimated top speed ability, reaching 118 mph in 1990), which we interpret as power performance; since 1987, increasing weight, which we interpret as "luxury" or other amenities that would be difficult to measure but which generally add weight to a vehicle.

A higher baseline case assumes that new fleet fuel economy is fixed through 1996 and then improves at 1.2%/yr through 2010. A rationale for this scenario would be an expectation that technology advances and a diminishing marginal value of vehicle amenities adverse to fuel economy will eventually allow the market to yield a slow improvement. This rate of improvement is the same as that used by EIA (1990c) in their "reference case" projection for 2000-2010. The EIA reference case also uses a 1.2%/yr improvement starting at present, but that seems very unrealistic given current trends.

A lower baseline case would have ongoing declines in rated fuel economy, continuing the 1.2%/yr decline experienced since 1988. With the growing shortfall already assumed, this case would project on-road fuel economy declining at 2.0%/yr through 2000 and leveling off thereafter. Such a downward trend might be expected in the absense of new standards, ongoing low oil prices, or an administrative rollback of the current standards.

As noted above, choosing a high baseline (e.g., new cars reaching 33 mpg in about 10 years without stronger standards) appears unsupportable given current trends and an expectation of slowly rising fuel prices. The choice of such a high baseline by DOE (e.g., in EIA 1990c) results in low oil savings impact from proposed standards. Farmer (1991a,b) also chooses this high rate of improvement for his "low-CAFE impact" scenarios. Given current trends and fuel price assumptions, use of such a high near-term rate of improvement to represent what will happen in the absence of new CAFE standards would appear to be misleading to policy makers and the public.

Standards scenarios. Six scenarios of fuel economy improvement due to strengthened CAFE standards are considered. The assumed levels of fuel improvement for each case with respect to stringency of standards are summarized in Table 1. As noted above, our nominal baseline scenario assumes rated fuel economy frozen at the 1990 level through 2010. The other cases are identified by a target new fleet improvement level for 2001 and assume a similar rate of improvement continuing through 2010. Percentage improvements are given as rounded, nominal targets relative to the new fleet in 1988. The 2010 levels are taken as twice the percentage improvement of the 2001 levels. The resulting projections for rated new automobile fuel economy are shown in Figure 1. Proportionate improvement rates are assumed for light trucks; however, because of the increase in the light truck share of sales, the net light duty vehicle improvement is somewhat lower than the percentages shown here in Table 1. Details by vehicle type and year are given in Table A1 at the end of the paper.

Table 1. Scenarios of automobile fuel economy improvement under varying degrees of regulatory pressure				
	2001		2010	
Case	Rated MPG	Percent increase	Rated MPG	Percent increase
Frozen rated MPG baseline	27.8	-3%	28.8	-3%
(A) 15% by 2001 (DOE)	32.9	15%	37.2	30%
(B) 20% by 2001 (Johnston)	34	20%	40	40%
(C) 30% by 2001	37	30%	45	60%
(D) 40% by 2001 (Bryan)	40	40%	51	80%
(E) 60% by 2001 (Boxer)	45	60%	63	120%

Rated MPG values are compliance fuel economy levels for automobiles.
Percent increases are given relative to the 1988 level of 28.6 MPG (the 3% decline in the baseline reflects the drop that has already occurred through 1990). Light trucks are assumed to improve proportionately from their 1988 new fleet average of 21.2 MPG.

The 15% improvement case is similar to that used in EIA (1990c) as a reference case. The 20% improvement is similar to the nominal level proposed by Johnston (1991). The Johnston proposal included a target of 37 MPG by 2006, which would lie on a path leading to about 40 MPG by 2010. The 30% case is an intermediate level, which corresponds to the level that would be achieved with the Bryan proposal allowing for administrative rollback in 2001. The 40% case is the target level of the Bryan proposal for 2001. A similar rate of improvement after 2001 could lead to a 2010 level of 51 MPG, which is bracketed by the 45 MPG "low risk" and 55 MPG "medium risk" levels identified by EEA (1991) for automobiles in 2010. The most ambitious case considered is 60% by 2001, similar to the Boxer proposal, but with ongoing improvement to a level of 63 MPG by 2010. This level falls between the 55 MPG "medium risk" and 75 MPG "high risk" levels identified by EEA (1991) for 2010.

VMT Growth

Light duty vehicle miles of travel (VMT) was estimated based on statistics from the Federal Highway Administration.[17] To project future travel, annual VMT growth rates of 2.5% through year 2000 and

[17] FHWA (1991), supplemented by FHWA (1989) and Traffic Volume Trends Tables (2 Jan. 1991), pers. comm. from K.H. Welty, Office of Highway Information Management, Federal Highway Administration (FHWA), Washington, DC.

1.5% from 2000-2010 were used, based on ACEEE analysis.[18] The portion of VMT attributed to light trucks was assumed to increase from 19% in 1990 to 25% for 2000 and thereafter.[19] This was used to infer different VMT growth rates for automobiles and light trucks between 1990 and 2000. A graph of historical VMT and our projections through 2010 is shown in Figure 2 (see also Table A1).

The resulting projection is for cumulative VMT growth of 28% by 2000 and 49% by 2010. Therefore, absent significant measures to dampen travel demand, an average on-road fuel economy increase of 28% is needed by 2000 just to keep motor fuel consumption from rising. This will require a significantly higher increase in new vehicle CAFE by 2000 because of the growing shortfall, the increasing VMT share of light trucks, and the lag time for more efficient vehicles to penetrate the stock as the present cohort of vehicles with flat or declining efficiencies ages. Many other factors determine the overall amount of driving. For example, VMT can increase if demographic and geographic factors result in greater suburban sprawl or a greater diffusion of the population and commerce into areas that are now largely rural. VMT can decrease through factors or policies that reduce the need for motor vehicle travel, increase vehicle occupancy, or increase alternate modes of travel. No attempt is made here to address these other effects on light duty VMT and fuel consumption. However, a comprehensive analysis that evaluated the possible effects of ambitious efforts to decrease VMT as well as improve vehicle efficiency found that about three-fourths of the projected reduction in transportation energy consumption was due to improved vehicle efficiency and one-fourth due to factors resulting in reduced VMT (DeCicco *et al.* 1991).

Rebound. The forgoing base projection of VMT does not reflect changes in the cost of driving, either through increased fuel prices or increased fuel economy. VMT can be related to the cost per distance of travel through an empirically determined elasticity parameter. Using C to represent the cost of driving (Equation 2, e.g., cents per mile) and subscripts *1* and *2* to represent base and adjusted projections, respectively, integration of the definition of elasticity yields

$$\frac{VMT_2}{VMT_1} = \left(\frac{C_2}{C_1}\right)^{\epsilon} \tag{3}$$

[18] VMT growth rates were from the personal travel reference scenario of ACEEE *et al.* (1991), Chapter 4 and Appendix C.

[19] These fractions may appear lower than other estimates of the light truck share of personal VMT, as given in ACEEE *et al.* (1991) and EIA (1990), for example. However, the definitions are different; the present analysis uses the same classifications as FHWA Highway Statistics, counting minivans, small utility vehicles, and some station wagons among cars, in contrast to including them with pickup trucks and large vans in a light truck category. See DeCicco (1992) for further discussion.

The elasticity ϵ is taken to be -0.07, as used in EIA (1990d). This is slightly smaller in magnitude than the range of -0.10 to -0.15 estimated by Greene (1991) using historical data. However, it is consistent with the downward trend indicated by the analysis, which suggests that an elasticity as small as -0.05 may be appropriate for more recent conditions. If fuel prices are relatively stable as fuel economy goes up, then fuel cost becomes an ever smaller share of overall operating costs, and one would expect a lower sensitivity. That is to say, elasticity is not constant, but is proportional to expenditure share, although we do not model this effect and assume that a constant elasticity is sufficiently representive for the range considered in this analysis. The resulting change in VMT is applied as a percentage adjustment to the base VMT projection. The maximum rebound effect obtained for the scenarios analyzed here and our nominal elasticity assumption of -0.07 is shown as the dashed line projection in Figure 2. Since we do not analyze effects of reduced U.S. fuel demand on oil prices, the fuel price projection is fixed and our cost of driving adjustments depend only on vehicle fuel economy.

Other Assumptions

Several other assumptions enter into the methodology, representing the evolution of the vehicle stock and manufacturers' compliance behavior. It is assumed that the mix of light vehicles on the road remains fixed over the projection years with respect to vehicle age and miles driven by age. New vehicle market shares by vehicle class and manufacturer are also assumed to be fixed. Under these assumptions, new vehicle sales growth tracks VMT growth, and there is no need to make an explicit projection of new vehicle sales. In any given year, sales of new motor vehicles are strongly dependent on the state of the economy, which is also a key factor in determining VMT. Since we do not attempt to analyze economic growth, our stock model represents only vintaging effects. Annual miles and survival fraction by vehicle age as used in the stock model are based on Davis and Hu (1991). Historical data on new light vehicle fuel economy are from Heavenrich *et al.* (1991) and are plotted in Figure 1. In order to explicitly analyze a uniform percentage increase CAFE formulation, including the effects of floors and ceilings, base year CAFE and sales data by manufacturer are used. Tabulations of these statistics and other model inputs are given in DeCicco (1992).

In responding to strengthened standards, it is assumed that manufacturers make no increases in CAFE through at least model year 1993. That is, new fleet averages are held at the 1990 values of 27.8 mpg for passenger cars and 21.0 mpg for light trucks. In the cases C and D, the delay lasts through 1994 and in cases A and B, through 1995. CAFEs then increase linearly toward the new targets. Except in the weakest case (A), it is further assumed that in meeting new standards, manufacturers on average exceed the overall CAFE target by a margin of 0.3 mpg. The effect of such a safety margin is small; for example, if the fleet average exactly matched the Case D fuel economy target rather than slightly exceeding it, there would only be a 2%-3% reduction in savings. We are therefore assuming that at least all of the major manufacturers (in terms of sales volume) comply with the law. This has been the case historically, with only limited volume luxury and specialty producers paying fines for CAFE non-compliance.

ANALYSIS AND RESULTS

Table A1 at the end of the paper lists the principal assumptions and results, for each scenario and three key years (2001, 2005, and 2010). Given in the table are the assumed fuel economy levels for new vehicles, average fuel economy of the light duty stock (all vehicles on the road, new and used), with both EPA-rated and estimated on-road values. Also listed in Table A1 are light duty stock fuel consumption and savings estimates for the key projection years. The fuel consumption estimates for each projection year (1990-2010) are plotted in Figure 3. Total motor gasoline consumption rate in the U.S. was 7.4 million barrels per day (Mbd) during 1990,[20] of which about 6.1 Mbd was consumed in light vehicles covered by CAFE standards.[21] By way of comparison, total U.S. petroleum products consumption in 1990 was 17.4 Mbd, of which 44% percent is met by petroleum imports.[22] The baseline projection shows that, in the absence of CAFE improvement, overall light duty vehicle fuel consumption will rise to 9.2 Mbd by 2005, a 50% increase over the 1990 level. The higher and lower fuel economy baselines, shown as the dashed lines in Figure 3, give a variation of about ±6% from the middle (frozen rated fuel economy) baseline consumption projection for 2005.

Fuel consumption continues to rise in cases A and B, as the fuel economy improvements are not sufficient to overcome the growth in VMT. Case C is notable because it represents approximately the CAFE improvement needed to balance growth in VMT. Assuming that CAFE levels start to improve in 1995 in anticipation of the higher standards, with achievement of a 30% CAFE increase by 2001, light duty fuel consumption will peak in 2000 at 7.3 Mbd by 2000, a level 20% higher than in 1990. As shown for Case C in Figure 3, there would be a slow decline in consumption thereafter provided a similar rate of CAFE improvement were maintained. Case D represents the level targeted by the Bryan (1991) proposal, a 40% CAFE increase by 2001. Case E represents the level targeted by Boxer (1991). In this case, we

[20] EIA (1990a); our estimates for 1990 and projections for 2010 use EIA's base case forecast.

[21] Based on the calculations reported here. An estimate of 6.0 Mbd for 1987 is obtained by apportionning the total motor gasoline consumption by the shares for automobiles and 74% of light trucks, as reported in Davis *et al.* (1989).

[22] DOE Monthly Energy Review (EIA 1991).

assume that improvement starts almost immediately (by 1994) in anticipation of strong standards. Fuel consumption would then peak in 1997 and then decline sufficiently to drop to 5.5 Mbd, 10% lower than in 1990, by 2010. Thus, an improvement schedule along the lines of case E would be needed to obtain significant absolute reductions in light duty oil consumption over the next two decades. All of these scenarios assume, of course, no changes in fuel pricing policy or other measures to significantly dampen travel demand.

A savings estimate is the difference between a scenario's consumption projection and whatever baseline is selected. Savings projections for the nominal (middle) baseline are shown in Figure 4 as a function of percent increase and in Figure 5 as a function of time. All standards cases result in some oil savings, projected to exceed 1 Mbd by 2005 and 2 Mbd by 2010 in all cases. A 40% CAFE improvement, if achieved by 2001 and with a similar rate of improvement thereafter, would yield an oil savings of 2.4 Mbd in 2005, or a reduction by 26% of what consumption would otherwise be. If the standards plateau after 2001, the savings in 2005 would be 2.2 Mbd.[23] Reaching the highest standards considered here (case E) would yield savings of 3.2 Mbd by 2005 and a 10% absolute reduction from 1990 consumption level by 2010.

The gross value of the oil savings to consumers may be found by multiplying the savings estimate by an assumed future retail fuel price. Based on the gasoline price projections from EIA (1990a),[24] for example, the gross annual savings for Case D are $52 billion in 2005 and $85 billion in 2010. These direct consumer cost savings include taxes and would also have to be balanced by the investment costs associated with making the fuel economy improvements.

Table 2 summarizes effect of higher and lower baseline projections on savings estimated for years 2005 and 2010. A higher baseline fuel economy results in lower savings and *vice versa*. For the 40% improvement by 2001 scenario, for example, the rising baseline lowers the year 2005 savings estimate from 2.5 Mbd to 2.0 Mbd and the declining baseline raises the savings estimate to 3.1 Mbd. Thus, these fairly modest variations in baseline assumptions imply a ±25% variation in the savings estimate for this particular case. Similarly significant variations in savings occur for the other cases as shown in Table 2.

[23] This estimate is about 12% lower than the corresponding 2.5 Mbd estimated earlier by the author ("Savings from CAFE" memoranda, Feb. and Mar. 1991). The present estimate includes a "rebound" effect and uses corrected VMT estimates, both of which adjustments are discussed in other sections of this paper.

[24] The EIA (1990a) projections are equivalent to 20, 21.5, and 23 $\$10^9$/yr per Mbd in 2000, 2005, and 2010, respectively--see footnote 15.

Table 2. Variation of projected savings according to assumed baseline fuel economy			
(a) Projections for 2005	Savings (Mbd) relative to baseline fuel economy		
MPG improvement scenario:	(a) Fixed	(b) Falling	(c) Rising
(A) 15% by 2001, 30% by 2010	1.2	1.7	0.7
(B) 20% by 2001, 40% by 2010	1.5	2.0	1.0
(C) 30% by 2001, 60% by 2010	2.0	2.5	1.5
(D) 40% by 2001, 80% by 2010	2.4	3.0	1.9
(E) 60% by 2001, 120% by 2010	3.1	3.6	2.6
(b) Projections for 2010	Savings (Mbd) relative to baseline fuel economy		
MPG improvement scenario:	(a) Fixed	(b) Falling	(c) Rising
(A) 15% by 2001, 30% by 2010	1.9	2.5	0.9
(B) 20% by 2001, 40% by 2010	2.4	3.0	1.4
(C) 30% by 2001, 60% by 2010	3.1	3.6	2.0
(D) 40% by 2001, 80% by 2010	3.7	4.3	2.7
(E) 60% by 2001, 120% by 2010	4.7	5.2	3.6
Based on ACEEE VMT growth projections, -0.07 VMT rebound elasticity, 0.3 mpg margin for compliance.			

Based on a Department of Energy model, Greene (1990) reported savings estimates for various scenarios of fuel economy improvement. The combinbation of his "max tech." and "MPG gap" scenarios matches many of the assumptions of our Case D and yields a savings projection of 1.8 Mbd in 2005, compared to our estimate of 2.4 Mbd. Major reasons for the difference are somewhat lower VMT base and growth rate estimates and a higher fuel cost-of-driving elasticity than used here. Farmer (1991a) also made savings projections, reporting an estimate of 0.88 Mbd in 2006 from a 40% CAFE increase by 2001. The range of estimates he reports for 2006 is 0.45 Mbd to 1.42 Mbd; his lower estimate ("low CAFE impact" scenario) appears to reproduce the DOE (1991) estimate. Reasons for such significantly lower estimates include: a higher baseline fuel economy which continues to rise while the standards increases are assumed to level off after 2001, lower initial VMT and lower VMT growth over the next decade, a higher rebound elasticity but a rebound calculation based on new vehicles rather than the entire stock. There may be other differences related to use of the DOE model, which is different than the ACEEE model.

The effects of some of these variations in assumptions are discussed in the sections below. Some of the assumptions are determined by policy choices, such as the implementation schedule of new standards or the credits towards a CAFE requirement provided by alternative fuels. Other assumptions relate to projection methodology and various factors that may affect driving and the mix of vehicles on the road. The estimates discussed here are all relative to the reference baseline scenario; the compound effect of different baseline assumptions can be determined in manner similar to that described above.

Dependence on Achieved CAFE and Year

Figure 4 shows the projected oil savings as a function of CAFE percentage increase for specific future years. Some savings are obtained from any increase in achieved CAFE. The additional savings from higher CAFE values tend to level off. This is because CAFE measures the inverse of fuel consumption, so that a given percentage increase in fuel economy corresponds to a smaller percentage decrease in fuel consumption. A 40% increase in CAFE results in savings of 2.4 Mbd by 2005. A 20% increase, one-half as large, yields 1.5 Mbd, or 63% of those savings, and a 30% increase yields 83% of the savings. Note that these results are for an *achieved* value of CAFE increase. As discussed later, a number of factors can result in achievement of lower CAFE levels than targeted by legislation.

Figure 5 shows how savings grow with time, as newer, more efficient vehicles displace older vehicles in the on-road stock. This is also illustrated by the higher respective savings levels by year (2001, 2005, 2010) shown in Figure 4. Note that steadily increasing standards and achieved new vehicle CAFE levels results in steadily increasing savings relative to a fixed frozen efficiency baseline. If standards were increased to a certain level, say, by 2001, and then not increased further, savings would continue to rise for a while but then level off, as they have in recent years as the fuel economy improvements of the 1980's have leveled off. Delays in the standards would have the effect of shifting the curves to the right, so that comparable savings are achieved in a later year.

Table 3 lists the cumulative savings in 2001, 2005, and 2010. Cumulative savings continue to grow through time, exceeding 11 billion barrels by 2010 if a 40% CAFE improvement is achieved by 2001.

Table 3. Cumulative savings from various level of CAFE increase			
	Billion (10^9) barrels* saved cumulatively from 1990 through year		
MPG improvement scenario:	2001	2005	2010
(A) 15% by 2001, 30% by 2010	0.7	2.2	5.5
(B) 20% by 2001, 40% by 2010	0.8	2.7	6.8
(C) 30% by 2001, 60% by 2010	1.4	4.0	9.2
(D) 40% by 2001, 80% by 2010	1.7	4.8	11.1
(E) 60% by 2001, 120% by 2010	2.6	6.6	14.5

* Energy end-use conversion is 5.25 Quads per 10^9 bbl gasoline.
Results are based on frozen fuel economy baseline with ACEEE VMT growth projections, zero rebound, and 0.3 mpg CAFE compliance margin. Accounting for VMT rebound, the cumulative savings would be about 6% lower on average.

Emissions Reductions

In addition to saving oil, fuel economy improvement will reduce emissions of greenhouse gases and some local air pollutants. Calculating the carbon dioxide (CO_2) emissions reductions from reduced petroleum fuel consumption is straightforward, because CO_2 emissions are essentially proportional to the amount of the fuel used based on its carbon content. A full determination will also include "upstream" petroleum consumption in the extraction, refining, and transportation processes, as well as the effects of associated methane (CH_4) and nitrous oxide (N_2O) emissions. These indirect factors increase the greenhouse impact by about 15% above that of the direct CO_2 emissions of fuel combustion.[25]

One might also expect that improved fuel economy will yield a reduction of other pollutants generated in the combustion process--the carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO and NO_2, i.e., NO_x) that are local air pollutants. Practically speaking, however, the relation between emissions and fuel economy is more complex. This is because of the dominance of catalytic control for tailpipe emissions, combustion process control trade-offs for engine-out emissions, particularly NO_x, and the various factors affecting volatile hydrocarbon (HC) emissions in vehicle fueling systems, both on-board and in the supply system. As for tailpipe emissions, a properly functioning catalytic converter eliminates

[25] See, for example, MacDonald (1990) and DeLuchi (1990).

at least 90% of the HC, CO, and NO_x from the exhaust stream.[26] However, because significant hydrocarbon emissions occur in fuel supply processes (literally, between the oil well and the intake manifold), it is possible to establish a quantitative link between HC emissions and fuel economy.

Regarding CO_2 emissions, each 1 million barrels per day (Mbd) of gasoline end-use results in 180 million short tons per year (Mt/yr) of carbon dioxide emissions, which includes upstream emissions during the production and transportation of petroleum products.[27] Table 4 shows the projected annual reductions in CO_2 emissions which correspond to the oil savings for selected levels of CAFE improvement. Following the 40% CAFE increase scenario (Case D) would result in CO_2 emissions reduction of 440 Mt/yr by 2005 and 680 Mt/yr by 2010. This is a 36% reduction compared to what light vehicle CO_2 emissions would otherwise be in 2010. Dependence on percentage increase and timing will follow the patterns shown earlier for oil savings in Figures 4 and 5. The projected CO_2 emissions reduction in 2010 is plotted as the lower curve in Figure 6. Total direct CO_2 emissions from U.S. fossil fuel use are about 5300 Mt/yr at present, of which one-third are from the transportation sector. Total U.S. CO_2 emissions are projected to increase to 7100 Mt/yr by 2010.[28]

Table 4. Projected reductions in carbon dioxide emissions resulting from light duty vehicle CAFE increases

MPG improvement scenario:	in 2001	CO_2 emissions reductions (millions of tons per year) in 2005	in 2010
(A) 15% by 2001, 30% by 2010	100	210	350
(B) 20% by 2001, 40% by 2010	130	270	440
(C) 30% by 2001, 60% by 2010	190	360	560
(D) 40% by 2001, 80% by 2010	230	440	680
(E) 60% by 2001, 120% by 2010	320	560	840

Relative to frozen fuel economy baseline with ACEEE VMT growth projections, -0.07 rebound elasticity, and 0.3 mpg CAFE compliance margin. Full fuel cycle CO_2-equivalent emissions computed at 10.72 $kgCO_2$/gallon (181.3 x 10^6 tons/yr per Mbd) and rounded to two significant digits.

[26] Ross *et al.* (1991), pp. 19-20.

[27] Based on the estimate of 81 $kgCO_2$/GJ (10.72 $kgCO_2$/gallon) for gasoline use, including CO_2 emissions from direct combustion, production, and transportation of the fuel, plus CO_2-equivalent greenhouse effects of associated N_2O and CH_4 emissions (DeLuchi 1990). Greene (1990) also projects CO_2 reductions from improved fuel economy, but bases his estimates only on the direct carbon content of gasoline (his factor is equivalent to 8.9 CO_2/gallon).

[28] From the CO_2 emissions projections of ACEEE *et al.*, with the 2010 reference case adjusted upward by 300 Mt/yr to account for the difference between our frozen MPG baseline and the rising DOE baseline (like case A here) assumed for the ACEEE *et al.* reference case. This adjustment is 15% lower than the corresponding emissions reduction of 350 Mt/yr in Table 4 in order to represent only direct combustion CO_2 emissions, not including fuel cycle impacts.

An additional benefit of increased CAFE is air quality improvement due to reduced emissions of hydrocarbons (HC), which are major contributors to smog and regional air pollution. The particular hydrocarbons regulated for air pollution control are termed volatile organic compounds (VOC). Since increased fuel economy will lead to a decrease in the overall quantity of motor fuels supplied in the country, there will be corresponding decreases in the VOC emissions associated with the production, refining, and distribution of the fuel, which comprise a significant portion of overall VOC emissions in the country. (Petroleum refineries also emit significant amounts of pollutants that result in acid precipitation.) There will also be reductions in emissions due to gasoline vapors escaping from vehicle fuel tanks and other on-board mechanisms before fuel reaches the engine. Tailpipe emissions are, however, primarily a function of engine tune-up condition and catalyst performance.

Recent work by DeLuchi *et al.* (1992) provides estimates of fuel fuel cycle VOC emissions in the U.S. which can be used to project future VOC emissions as a function of fuel economy, accounting for expected future improvements in air pollution controls. A mid-range estimate is that average VOC emissions of 10 grams/gallon are associated with light vehicle gasoline use, based only on the fuel supply system and non-tailpipe portion of vehicle emissions.[29] This estimate could be 20% lower or higher depending on the effectiveness of air pollution controls yet to be implemented in response to recent Clean Air Act amendments. The resulting projected HC (VOC) emissions reductions are shown in Table 5. For the 40% CAFE increase scenario, HC emissions reductions would reach 630,000 tons per year by 2010 compared to what they would be with frozen fuel economy. On a per vehicle mile basis, a 40% improvement of the average light duty vehicle from the present on-road average of 20 mpg to 28 mpg (as would be achieved by 2010 following the 40% new vehicle improvement by 2001 CAFE scenario) would yield a nationwide average HC emissions reduction of about 0.14 g/mi, a magnitude comparable to the 0.16 g/mi reduction in tailpipe emissions required by the 1990 Amendments to the Clean Air Act.[30] The upper curve of Figure 6 shows the projected nationwide HC emissions reduction in 2010 as a function of percentage improvement in new vehicle fuel economy over 1988 CAFE levels.

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[29] Inclusion of possible linkages of fuel economy to tailpipe HC emissions might raise the impact further; however, this effect is very uncertain. DeLuchi *et al.* (1992) note that the empirical evidence is weak and Ross *et al.* (1991) point out that it may be an artifact of a few cars which are outliers in terms of tailpipe emission and fuel economy characteristics.

[30] The present federal standard for automobile HC emissions is 0.41 g/mi; it drops to 0.25 g/mi for non-methane hydrocarbons (NMHC) by 1996 (EPA 1990).

Table 5. Projected reductions in hydrocarbon emissions resulting from light duty vehicle CAFE increases			
	HC emissions reductions (thousands of tons per year)		
MPG improvement scenario:	in 2001	in 2005	in 2010
(A) 15% by 2001, 30% by 2010	100	200	330
(B) 20% by 2001, 40% by 2010	120	250	410
(C) 30% by 2001, 60% by 2010	180	330	530
(D) 40% by 2001, 80% by 2010	220	410	630
(E) 60% by 2001, 120% by 2010	300	520	790

Relative to frozen fuel economy baseline with ACEEE VMT growth projections, -0.07 rebound elasticity, and 0.3 mpg CAFE compliance margin. Full fuel cycle HC (VOC) emissions computed at 10 g/gallon (0.17 x 10^6 tons/yr per Mbd) and rounded to two significant digits.

CAFE Credits

There are a number of provisions that enable a manufacturer to comply with CAFE regulations at a level less than the standard set for a given year. The mechanism for determining compliance levels below the standard is the CAFE "credit," measured in MPG. The current CAFE law provides for carry-forward credits, which manufacturers earn by exceeding the standard in a given year and which can be applied against their standards requirement in a future year. Japanese manufacturers currently have such credits available because of their historically higher CAFE averages. The Alternative Motor Fuels Act provides credit for vehicles that can operate on a fuel other than gasoline, including a more limited credit for vehicles that can use either gasoline or an alternative fuel (flexible fuel vehicles). Other types of credit schemes have been proposed, for example, allowing manufacturers to trade credits among each other or among separately regulated fleets, and credits for certain safety devices, such as airbags.

Several analysts have examined the potential impact of CAFE credits. Farmer (1991b) estimated the impact of credits for alternative and flexible fuel vehicles. OTA (1991c) discussed credits and gave attention to the idea of marketable CAFE credits trading, but did not quantify fleet impacts. Ditlow (1991) provided some estimates of the extent of available carry-forward and alternative fuel credits. It is difficult to determine the extent to which manufacturers will avail themselves of various credit options. More broadly, there is the question of whether the existence of strengthened standards will itself induce automaker decisions (such as provision of flexible fuel vehicles) that would not occur with weaker or abolished standards. The Clean Air Act Amendments of 1990 and California Air Resources Board regulations are likely to require some number of alternatively fueled vehicles in areas having severe difficulty in attaining air quality standards, such as parts of California.

For a CAFE improvement scenario similar to case B above, Farmer (1991b) found that the credits could lower achieved CAFE levels sufficiently enough that gasoline consumption would rise relative to regulation without the credits. The reason is that, under the most likely assumptions, there would be insufficient alternative fuel use to offset the reduced fuel economy of most vehicles. Farmer projected that the vehicles earning CAFE credits, particularly over the next decade, will mainly be flexible fuel vehicles which continue to operate primarily on gasoline. Credits are not linked to an actual amount of gasoline displaced but do serve to lower the fuel economy requirements for the whole vehicle fleet. Therefore, overall fleet gasoline consumption can be higher than it would under CAFE standards without flexible fuel vehicle credits.

Table 6. Potential fuel economy decrements due to CAFE credits

	Number of MPG by which new light fleet average is lowered, in year:			
Type of CAFE credit:	1996	2001	2006	2010
Alt. fuel, with baseline	0.2	0.4	0.5	0.5
Alt. fuel, with standards	0.3	0.7	1.4	1.5
Carry forward, all cases	0.5	0.2	0	0

Alternative fuel credits are for both flexible and dedicated fuel vehicles, from Farmer (1991b), Table 3.
Carry forward credits are author's estimates, based on current CAFE achievement levels and assuming that manufacturers follow an improvement path which uses up their earned credits by 2006.

Table 6 shows the effect of CAFE credits as the difference in achieved fuel economy for various scenarios. Although the extent of alternative fuel credit utilization may depend on the stringency of standards, for simplicity, only two levels of alternative fuel vehicle credits are analyzed here. A lower level of credit utilization is used for baseline cases, shown as the first row in Table 6. The higher level shown in the second row is for cases of strengthened standards. The same level of carry-forward credits is used in all cases, based on the assumptions that carry forward is limited to three years and all manufacturers use up their earned credits by 2006. Under these assumptions, only alternative fuels credits affect new fleet fuel economy in the later projection years.

The effects of CAFE credits on projected savings are given in Table 7 for two levels of future standards: (case D), 40% improvement by 2001; and (case B), 20% improvement by 2001, as defined in Table 1. For each of these CAFE improvement levels, four subcases are shown: (1) achievement of the targeted level of increase; (2) effect of use of carry-forward CAFE credits; (3), like (2), plus use of credits for alternative and flexible fuel vehicles; (4), like (3), plus administrative rollback of standards (discussed below). Legally speaking, only a rollback changes the standard level that applies to a manufacturer; the various credits are added to a manufacturer's achieved CAFE when determining compliance with the standard. For reference, also shown are consumption projections for the baseline (frozen rated fuel economy) scenario and for a baseline accounting for carry forward and alternative fuel credits. Only petroleum fuel consumption is shown in Table 7; there would also be some level of alternative fuel consumption which we make no attempt to quantify.

Table 7. Comparisons of light vehicle oil consumption projections for 20% and 40% CAFE increases when accounting for rollbacks and various credit provisions

	Fuel consumption (Mbd)		
MPG improvement scenario:	in 2001	in 2005	in 2010
40% CAFE increase (case D)	7.03	6.80	6.60
carry foward credits	7.08	6.86	6.62
carry fwd + alt fuel credits	7.15	6.97	6.81
all credits plus rollback	7.33	7.38	7.45
20% CAFE increase (case B)	7.60	7.73	7.90
carry foward credits	7.63	7.75	7.90
carry fwd + alt fuel credits	7.71	7.92	8.18
all credits plus rollback	7.84	8.21	8.68
Baseline (case a)	8.31	9.22	10.35
with all credits	8.44	9.39	10.59

Carry-forward credits, of course, represent fuel economy improvements achieved in advance of standards increases. The fact that such credits have been earned is reflected in the baseline average fuel economy (e.g., the overall 1990 average), which would otherwise be lower. Therefore, baseline consumption would otherwise be higher, since fleets more efficient than the standard would not have already entered the vehicle stock as they in fact have. One can expect manufacturers who would otherwise be constrained by a future standard to eventually fully avail themselves of any credits they have earned.

To be consistent, one should judge the impact of credits relative to a baseline which also accounts for credits. Doing this, one sees that accounting for credits increases the projected oil consumption by approximately the same amount, about 0.2 Mbd in 2005 and 0.3 Mbd in 2010, for similar cases. Therefore, credits alone have little effect on the absolute value of a "savings" projection. In relative terms, these increases represent up to a 3% increase in light duty consumption over the baseline not accounting for credits. For flexible and alternative fuel vehicle credits, consumption is higher than it would be without such CAFE credits. These results are generally qualitatively consistent with those of Farmer (1991b), since his alternative fuel vehicle credit assumptions were used here, although his significantly different assumptions for other factors result in lower overall differences between consumption levels with and without standards. Farmer estimated, moreover, that removing the current cap on flexible fuel vehicle credits would cause further increases in gasoline consumption. In any case, the general conclusion is that the small amount of alternative fuel use likely over this time period is not enough to offset the excess consumption due to the loss in fuel economy of gasoline vehicles due to the credits.

A Comment on CAFE Credit Trading

Currently, CAFE credits may only be applied to the manufacturer's fleet on which they are earned. Credits cannot be moved from one fleet to another (e.g., between an automakers car and light truck fleets) and there are no provisions for trading of credits among manufacturers.[31] Credits trading is seen as a market mechanism which can be used to improve the economic efficiency of environmental regulations. For example, the recent Clean Air Act Amendments include provisions for banking and trading of air pollution emission allowances (EPA 1990). There have also been proposals for CAFE credits trading, in order to incorporate similar flexibilities into the framework of CAFE standards.[32] Nevertheless, under current and proposed CAFE penalty systems, there may not be much incentive for manufacturers to make credits available for trading (OTA 1991c, p. 84).

If tradable CAFE credits trading are measured in MPG (miles per gallon), a concern arises that credits trading can result in a reduction of overall fleet fuel economy, which is equivalent to expected excess gasoline consumption. Fuel use is gallons consumed, not miles per gallon, so credits measured in MPG units (as in current law) will result in lost savings whenever the credits are transferred from a fleet of higher fuel economy to a fleet of lower fuel economy. For example, consider a fleet that achieves

[31] As of this writing, it is unresolved whether the Department of Transportation will allow use of credits earned by American Motors before its acquisition by Chrysler to be used to offset Chrylser's CAFE requirements after the acquisition (Kahn 1992).

[32] For example, Johnston (1991), and as discussed in OTA (1991c).

35 MPG rather than a hypothetical future requirement of 30 MPG (actual on-road fuel economy), thereby earning a "credit" of 5 MPG. Assuming lifetime driving of 100,000 miles, the expected fuel savings represented by this 5 MPG difference would be 476 gallons. Now consider the effect of applying this 5 MPG credit to a fleet averaging 20 MPG, so that it is treated for compliance purposes as if its average fuel economy were 25 MPG. A similar calculation shows that the additional consumption would be 1000 gallons. The added consumption of the lower mileage fleet is therefore more than double the fuel savings of the higher mileage fleet, resulting in an expected net excess consumption (lost savings) of 524 gallons.[33] The correct way to value the added fuel economy is in terms of the fuel savings expected over the life of an average vehicle. In this example, the higher fleet's expected savings of 476 gallons would then allow an offsetting increase of only 2.1 MPG in the lower fleet, so that it would be treated at 22.1 MPG rather than 25 MPG.

Therefore, to avoid compromising potential oil savings, a system for trading CAFE credits should be based on the expected number gallons saved or wasted (or equivalently, gallons/mile or liters/100 km) rather than differences in MPG. This is consistent with proposals for emissions trading, which are based on expectations of avoided air pollution emissions as measured, for example, in tons per year. In fact, automotive fuel use credits based on avoided CO_2 emissions would work correctly, since CO_2 emissions are directly proportional to fuel consumption. Use of CO_2 emission rates (e.g., grams/mile) is also one way to permit exchange of credits among vehicles that utilize different fuels.

Rollbacks

CAFE law includes provisions for the administering agency to set a standard lower than the legislatively targeted standard by conducting a rulemaking proceeding to determine a "maximum feasible" average fuel economy level under various considerations. Such "rollbacks" were used when the 27.5 MPG automobile standard first set for 1985 was lowered to 26.0 MPG for 1986-1988 and 26.5 MPG for 1989. The standard was returned to 27.5 MPG as of 1990. The additional fuel consumption from this rollback is estimated to be 50,000 bbl/day at present, since vehicles less efficient than would otherwise have been required still remain in the fleet.[34] For standards cases (D) and (B) discussed here, the rollback assumptions are for a 30% rather than 40% targeted increase and a 15% rather than 20% targeted increase, respectively. The Bryan (1991) proposal, for example, limits the rollback in 2001 so that the standard would specify at

[33] Because of the inverse relation between fuel consumption and fuel economy, it can be shown that when trading credits from a higher to lower fleet, the ratio of differences in expected fuel consumption increases with the square of the ratio of the respective fleet CAFEs.

[34] Author's estimate for 1991-92, based on a stock model run not tabulated here.

least a 30% improvement in CAFE. A full rollback of this extent would increase fuel consumption by 0.4 Mbd in 2005, or 6%, for example. The effect of rollbacks as assumed here can also be seen in Table A1, e.g., by comparing cases D and C. If instead of a strengthening of the present CAFE standards, there were to be an administrative rollback of 1 MPG, the excess consumption would be 0.10 Mbd in 1995, rising to 0.25 Mbd by 2001 if a stronger standard were not restored in the intervening years.[35]

Floors and Ceilings

A CAFE standard formulated as a uniform percentage increase may contain "floors" and "ceilings" which set lower and upper bounds, respectively, on the CAFE standard pertaining to any manufacturer. For example, Bryan (1991) proposal specifies that manufacturers achieve a CAFE increase of 40% by 2001 and that passenger car fleets must reach at least 33 MPG (the floor) but are not required to go above 45 MPG (the ceiling). In this case, the range of MPG standards across manufacturers is therefore constrained from 7 MPG below to 5 MPG above the 40 MPG average that would be achieved by the fleet as a whole if all manufacturers meet their respective standards.

There is a continuous range of floor and ceiling levels consistent with a given average improvement in fuel economy. In the limiting case, the floor meets the ceiling at a single standard for all manufacturers, like the present CAFE standards. Tightening the floor and ceiling boundaries could be considered as a way to change the relative burden among manufacturers presently having lower or higher fleet ratings. It would also make the achieved fleet fuel economy more resistant to changes in market shares. The particular floor and ceiling adjustments needed to maintain a given average CAFE level depend on the market share mix by manufacturer, so maintaining simple numerical symmetry of the bounds may not be sufficient to maintain a given average.

The stock model was modified to perform a manufacturer-by-manufacturer analysis, permitting explicit specification of floors and ceilings. This analysis was done only for the 40% increase scenario similar to the Bryan proposal. Comparisons of CAFE standards for varying the floors and ceilings around an average CAFE of 40 mpg by 2001 are tabulated by manufacturer in DeCicco (1992). A summary of the results is given here in Table 8. The six MPG columns show, for cars and light trucks, the fuel economy values for new vehicles in 2001. The expected average (avg) of all manufacturers' fleets is shown, as well as the assumed floor (min) and ceiling (max). The final column shows the oil savings

[35] Author's estimate, based on stock model run not tabulated here.

expected in 2005 for the combined car and light truck fleet. Averaged over all manufacturers, the effect of floors and ceilings on projected fuel consumption is quite small. For example, removing the ceilings would decrease consumption by 1%, increasing the savings relative to frozen fuel economy by about 4%.

Table 8. Effects of varying floors and ceilings on expected oil savings from standards requiring a 40% CAFE increase by 2001

(min=floor, max=ceiling)	Automobile MPG			Light truck MPG			Savings in 2005
Case:	avg	min	max	avg	min	max	(Mbd)
(1) As specified in the Bryan (1991) proposal	40	33	45	29.5	24	35	2.44
(2) Tighten min and max bounds by 2 MPG	39.7	35.0	43.0	29.4	26.0	33.0	2.42
(3) Tighten min and max bounds by 2.5 MPG	39.6	35.5	42.5	29.4	26.5	32.5	2.41
(4) Like (3), except truck max of 35 MPG	39.6	35.5	42.5	29.6	26.5	35.0	2.42
(5) Lower only max by 2.5 MPG, min as in (1)	39.5	33.0	42.5	29.3	24.0	32.5	2.39

Savings projection relative to frozen fuel economy baseline, with zero rebound and 0.3 mpg CAFE compliance margin.

Five cases are shown, starting with the standards proposed in Bryan (1991) as case (1). Case (2) shows the effect of raising the floor and lower the ceiling by 2 MPG each and case (3) shows a similar modification by 2.5 MPG. Case (4) is the same as case (3) except that the Bryan (1991) ceiling of 35 MPG for light trucks remains unchanged. Case (5) shows the results of only lowering the ceiling, without an attempt to compensate with a higher minimum standard. In all cases, the effect on savings is very slight, little more than 1% when both floors and ceilings are adjusted and only 2% when the ceiling is lowered by 2.5 MPG without raising the floor.

The narrowness of the MPG range specified by the floors and ceilings affects the relative burden of improvement on manufacturers. This depends on the fuel economy mix of their current fleets, which is related to the size class mix of their fleets. To the extent that the relative burden is seen as a less than ideal compromise among the requirements on manufacturers, an adjustment can be made by changing the floors and ceilings. This analysis shows that such changes can be made while the expected oil savings resulting from the legislation are essentially preserved.

Uncertainties

Any projections such as these involve a number of uncertainties. For savings projections, the largest uncertainty has to do which the baseline assumption, i.e., the projection of what will happen in the absence of policy change. Since the choice of baseline was addressed earlier, it will not be discussed further here. The largest remaining uncertainties pertain to the current and future levels of VMT. VMT depends on demographic factors, economic activity, and fuel prices. It also depends on transportation policies, particularly those that may be implemented to control congestion or determine land use patterns, but a discussion of these later factors is beyond the scope of this paper. VMT becomes less certain farther into the future. If the uncertainty of the present VMT estimate is $\pm 5\%$ and the uncertainty of the future growth rate is $\pm 20\%$ (e.g., $\pm 0.5\%$/yr out of the 2.5%/yr average rate assumed over the next decade), then the uncertainty of future VMT projection is $\pm 9\%$ after ten years and $\pm 13\%$ after 20 years. Uncertainties in VMT propagate directly to uncertainties in projections of fuel consumption or fuel savings. Another aspect of VMT uncertainty is the rebound effect, which is estimated here using a price elasticity of -0.07. A zero rebound effect would result in a 2% decrease in consumption and a 6% increase in projected savings; doubling it would have a reverse effect of similar magnitude.[36]

The analyses presented here hold market shares constant at 1988 levels. Changes in prices, consumer tastes, marketing strategies of manufacturers, CAFE standards, and other factors could result in a different mix of vehicles. Changes in manufacturers' market shares will affect the outcome of a percentage increase type of standard. For example, consumption will be reduced if fleets that are now more efficient than average gain market share; the converse is also true. The effect of market share changes is damped by floors and ceilings, as noted above.

The possible magnitude of market shift effects can be estimated by examining historical changes in the mix of cars and light trucks as fractions of the total light duty fleet. The market share of light truck classes increased from about 20% in 1975-77 (just before CAFE standards took effect) to about 33% presently.[37] The 1991 average new car and light truck fuel economies were 27.8 mpg and 20.8 mpg, respectively, yielding an average of 25.0 mpg. If the light truck market share dropped back to 20% while fuel economy levels were the same, the average would be 26.0 mpg, or 4% higher. In 1975-77, light truck fuel economy averaged 15% lower than that of cars; the gap is now 26% (1988-91 average). If both market share and the truck/car fuel economy ratio were restored to the earlier level while keeping the same new car fuel economy level, the light duty fleet average would be 26.9 mpg, or 7% higher than the

[36] VMT projections and related uncertainty calculations are detailed in DeCicco (1992).

[37] Heavenrich *et al.* (1991), Table 1.

actual 1991 value. The increased sales share of light trucks is considered a significant market shift, and so this 4%-7% effect on fuel economy is suggestive of the potential impact of future market shifts. Therefore, with a significant strengthening of CAFE standards, e.g., a 40% increase, a continuing adverse (to overall fuel economy) market shift of such a magnitude would reduce the savings, but not severely. A reverse of the past car-to-truck shift would have a beneficial impact on overall fuel economy. Such a shift is conceivable if, in response to new standards requiring the same percentage increases in cars and light trucks, manufacturers found it easier to comply by reducing the market share of less efficient trucks.

The discrepancy between rated and on-road fuel economy is another potential source of error. As noted earlier, the projections given here assume a shortfall growing linearly from 15% in 1986 to 30% in 2010. Fuel consumption and savings projections are both inversely proportional to one minus the assumed shortfall. If shortfall remained at 20% rather than reaching 30% in 2010, the resulting projections would be 7/8 of the given projections. That is, both consumption and savings estimates would be 12.5% lower in 2010; they would be 4.2% lower in 2005. A comparison of vehicle stock estimates to fuel consumption statistics suggests that the actual average shortfall may already be larger than 20%; the uncertainty due to shortfall is therefore probably 5%-7% in 2010 and smaller for previous years.

An minor uncertainty is introduced by the assumption that manufacturers will meet the CAFE standards with some safety margin, i.e., that the fleet averages will actually be a little higher than what is actually mandated by the standards. A "zero overshoot" assumption would have manufacturers exactly meeting their CAFE targets, rather than exceeding them by a safety margin. Historically, in attempting to meet CAFE standards, manufacturers have exceeded CAFE targets with a safety margins of about 0.7 MPG for passenger cars and 0.2 MPG for light trucks. A somewhat lower overshoot averaging 0.3 MPG was assumed in modeling the new CAFE levels. The effect of this safety margin is small; if targeted standards were reached exactly, there is a reduction in savings of 2% or less.

Other sources of uncertainty involve the rates of vehicle stock turnover and the annual miles driven by vehicles of different ages; we do not attempt to quantify these here and assume that they are small. There may be relationships among the various sources of error and some effects may balance out. The overall error in a projection is calculated by taking the geometric mean of the uncertainties from various sources.[38] This yields a net uncertainty of $\pm$19% for 2010, not considering the uncertainty in the baseline projection of fuel economy. As noted earlier, the effect of the baseline is quite large, changing the projected savings by as much as $\pm$25% for the cases considered here. Combining the baseline uncertainty with that from the other factors increases the overall uncertainty to $\pm$30%. In summary, then, we assume an

[38] This assumes independence of error sources; see, e.g., Tukey (1958).

uncertainty of about ±30% for the 2010 projections; the uncertainty is smaller for earlier years. For an achieved CAFE increase of 40% by 2001, for example, given the nominal estimate of 2.4 Mbd oil savings in year 2005 and an uncertainty level of ±25% for that projection year, there is reasonable confidence that the actual savings will be between 1.8 Mbd and 3.0 Mbd. For policy makers, this should provide sufficient certainty that improving CAFE standards will be effective in addressing the problems of imported oil dependence and environmental impacts from petroleum use by motor vehicles.

CONCLUSION

Strengthening the Corporate Average Fuel Economy (CAFE) standards for light duty vehicles in the United States will result in significant reductions in petroleum fuel consumption and attendant reductions in carbon dioxide (CO_2) and hydrocarbon (HC) emissions. A number of factors affect the consumption and savings projections, but in all instances, the expected savings increases with the stringency of the standards. Five CAFE standards scenarios, some of which correspond to recent legislative proposals, were analyzed in detail. These scenarios covered CAFE increases ranging from 15% to 60% by 2001, with similar rates of improvement through 2010. Results are given for key projection years of 2001, 2005, and 2010. Light duty fuel consumption is projected to grow from a 1991 estimate of 6.1 Mbd to 9.2 Mbd by 2005 in the absence of new standards or other significant changes in policy or the economy.

The most critical underlying assumption regarding savings projections is that of the baseline, that is, the extent of fuel economy improvement or decline in the absence of strengthened standards. Considerations regarding the choice of a baseline were discussed, and a baseline of frozen rated fuel economy was chosen as the middle case for the analyses presented here. Results were also presented for alternative baselines of rising and falling fuel economy, which were found to give a $\pm 6\%$ variation in light duty fuel consumption around the middle baseline projection.

For the scenario of a 40% CAFE increase by 2001, the mid-range projections are oil savings of 2.4 Mbd by 2005 and corresponding emissions reductions of 440 million tons per year of CO_2 and 500,000 tons per year of HC. Assumption of the higher or lower baseline gives a $\pm 25\%$ change in the projected savings. Similar results are provided for other scenarios and other years through 2010. Other factors affecting the achieved levels of fuel economy and overall fleet fuel consumption were also examined, including timing, CAFE credits, potential rollbacks of standards, upper and lower bounds on a percentage increase standard, and uncertainties regarding light duty vehicle market shifts, growth in vehicle miles of travel (VMT), VMT "rebound," and fuel economy shortfall. Compared to the baseline assumption, these other factors are found to have smaller effects on the projections, amounting to an added uncertainty of $\pm 20\%$ or less.

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Table A1. Summary of consumption and savings projections by scenario

	1990	2001	2005	2010	
Base VMT (10^12 mi)	1862	2420	2568	2767	
Light truck share of miles	25%	33%	33%	33%	
Shortfall, on-road vs. EPA	18%	24%	27%	30%	
BASELINE SCENARIOS					
(a) Reference (frozen mpg)					
New automobile EPA mpg	27.8	27.8	27.8	27.8	
New light truck EPA mpg	20.6	20.6	20.6	20.6	
New LDV average EPA mpg	25.2	24.9	24.9	24.9	
Stock average EPA mpg	24.3	25.0	24.9	24.9	
Stock average on-road mpg	19.9	19.0	18.2	17.4	
Fuel consumption, Mbd	6.1	8.3	9.2	10.3	
(b) Declining (lower mpg)		-13.1%	-10.0%	-6.5%	**
New automobile EPA mpg		25.1	26.0	27.0	
New light truck EPA mpg		18.6	19.3	20.0	
New LDV average EPA mpg		22.5	23.3	24.2	
Stock average EPA mpg		24.1	23.4	23.6	
Stock average on-road mpg		18.3	17.1	16.5	
Fuel consumption, Mbd		8.6	9.8	10.9	
Savings relative to (a), Mbd		-0.3	-0.6	-0.5	
(c) Rising (higher mpg)		2.1%	7.3%	13.9%	
New automobile EPA mpg		29.5	31.0	32.9	
New light truck EPA mpg		21.9	23.0	24.4	
New LDV average EPA mpg		26.4	27.8	29.5	
Stock average EPA mpg		25.5	26.4	28.0	
Stock average on-road mpg		19.4	19.3	19.6	
Fuel consumption, Mbd		8.2	8.7	9.3	
Savings relative to (a), Mbd		0.2	0.5	1.1	

** Percent changes relative to 1988 new fleet averages of 28.6 MPG for cars, 21.2 MPG for light trucks, and 25.9 MPG for the overall new light duty fleet.

(continued)

Table A1, continued

POLICY SCENARIOS	2001	2005	2010
(A) 15% by 2001 (DOE)	15%	21%	30%
New automobile EPA mpg	32.9	34.7	37.2
New light truck EPA mpg	24.4	25.7	27.6
New LDV average EPA mpg	29.5	31.1	33.3
Stock average EPA mpg	27.0	28.9	31.2
Stock average on-road mpg	20.5	21.1	21.8
Fuel consumption, Mbd	7.7	8.0	8.4
Projected savings, Mbd	0.6	1.2	1.9
(B) 20% by 2001 (Johnston)	20%	30%	41%
New automobile EPA mpg	34.3	37.3	40.3
New light truck EPA mpg	25.4	27.6	29.9
New LDV average EPA mpg	30.8	33.4	36.2
Stock average EPA mpg	27.5	30.1	33.3
Stock average on-road mpg	20.9	22.0	23.3
Fuel consumption, Mbd	7.6	7.7	7.9
Projected savings, Mbd	0.7	1.5	2.4
(C) 30% by 2001	31%	42%	59%
New automobile EPA mpg	37.3	40.7	45.4
New light truck EPA mpg	27.7	30.2	33.7
New LDV average EPA mpg	33.5	36.5	40.7
Stock average EPA mpg	28.9	32.3	36.6
Stock average on-road mpg	22.0	23.6	25.6
Fuel consumption, Mbd	7.3	7.2	7.2
Projected savings, Mbd	1.0	2.0	3.1
(D) 40% by 2001 (Bryan)	41%	57%	80%
New automobile EPA mpg	40.3	44.9	51.3
New light truck EPA mpg	29.9	33.3	38.1
New LDV average EPA mpg	36.2	40.3	46.0
Stock average EPA mpg	29.9	34.5	40.4
Stock average on-road mpg	22.7	25.2	28.3
Fuel consumption, Mbd	7.0	6.8	6.6
Projected savings, Mbd	1.3	2.4	3.7
(E) 60% by 2001 (Boxer)	59%	84%	121%
New automobile EPA mpg	45.4	52.6	63.3
New light truck EPA mpg	33.6	39.0	46.9
New LDV average EPA mpg	40.7	47.2	56.8
Stock average EPA mpg	32.3	38.5	47.4
Stock average on-road mpg	24.5	28.1	33.2
Fuel consumption, Mbd	6.5	6.1	5.7
Projected savings, Mbd	1.8	3.1	4.7

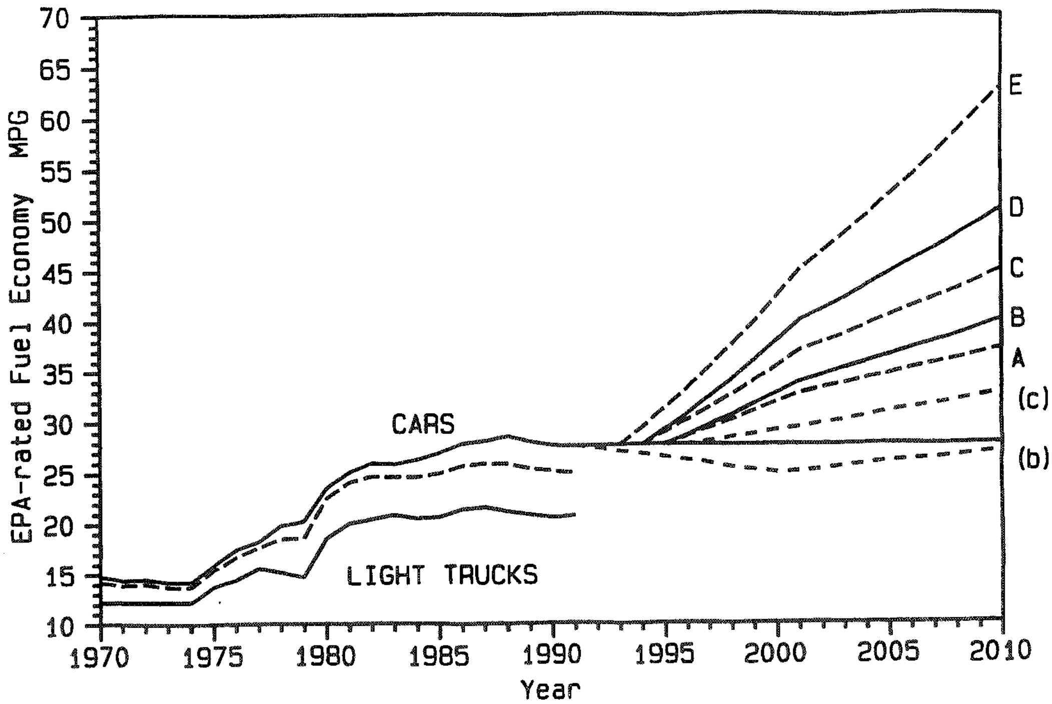

Figure 1. Historical new light vehicle EPA-rated fuel economy levels through 1991, plus various scenarios for cars through 2010.

Historical data are shown separately for cars, light trucks, and their average, from Heavenrich *et al.* (1991), Table 1. For the future projections, only the car levels are shown; light trucks are assumed to have parallel, proportionate levels of increase for each case.

(a) Nominal baseline used for analyses reported here; rated fuel economy frozen at 1990 level of 27.8 mpg.

(b) Declining baseline, assumes decline at 1.2%/yr through 2000 and then 0.8%/yr improvement of rated MPG (for frozen on-road MPG) through 2010.

(c) Rising baseline, frozen through 1996, then 1.2%/yr improvement.

(A) Slow rise in fuel economy, for a roughly 15% improvement by 2001, reaching 37 mpg by 2010; similar to DOE/NES "market driven" reference case.

(B) Slow rise in fuel economy, driven by standards, to 34 mpg by 2001 (20% improvement) and 40 mpg by 2010.

(C) Modest rise in fuel economy, driven by standards, to 37 mpg by 2001 (30% improvement) and 45 mpg by 2010.

(D) Moderate rise in fuel economy, driven by standards, to 40 mpg by 2001 (40% improvement) and 51 mpg by 2010.

(E) Rapid rise in fuel economy, driven by standards, to 45 mpg by 2001 (60% improvement) and 63 mpg by 2010.

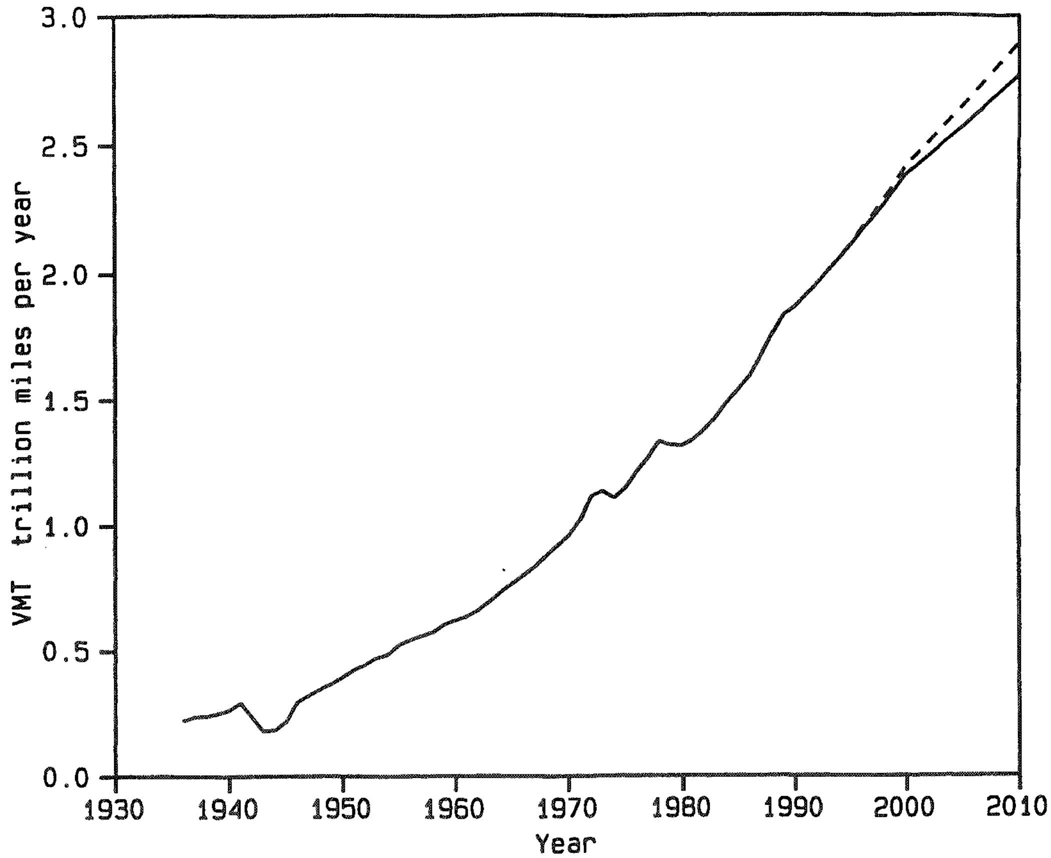

Figure 2. Past and projected light duty vehicle miles of travel in the U.S.

VMT for cars and light trucks covered by CAFE regulations, in trillion (10^{12}) miles/year. Past data based on FHWA Highway Statistics; projections based on ACEEE analysis, with average growth rates of 2.5%/yr 1990-2000 and 1.5%/yr 2000-2010. Solid projection line is without cost of driving adjustment; dashed projection line is maximal estimated "rebound" effect, based on fuel economy improvement Case E (CAFE increases of 60% by 2001 and 120% by 2010) and a fuel cost of driving elasticity of -0.07.

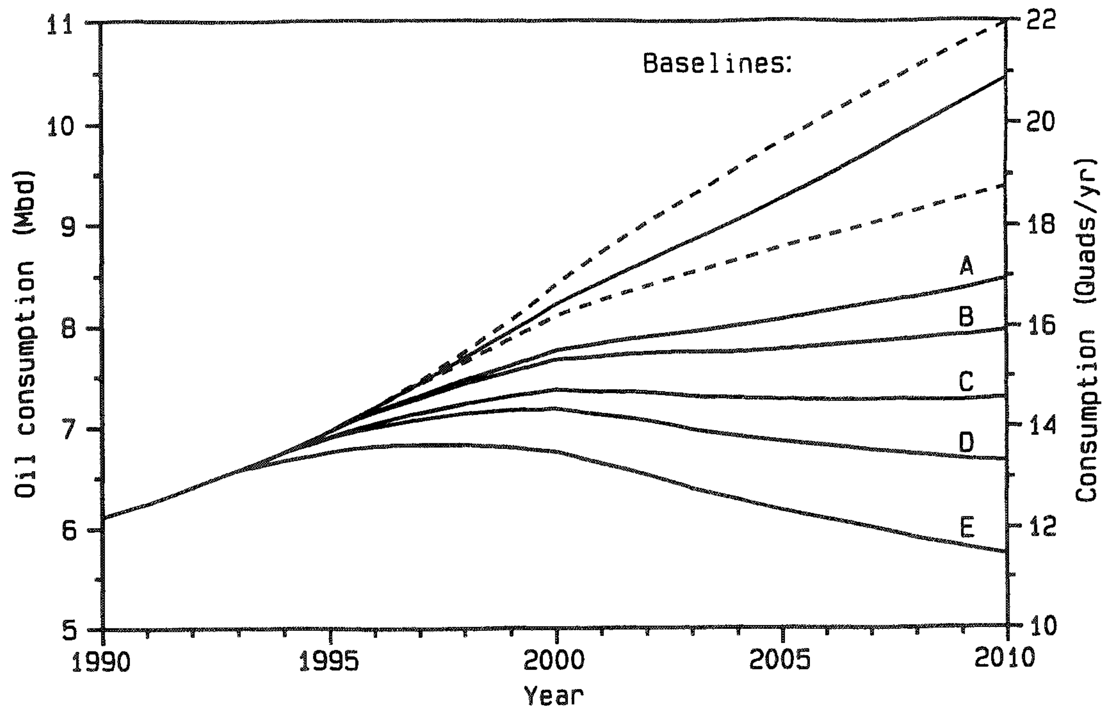

Figure 3. **Projected U.S. light duty vehicle fuel consumption, baselines and selected CAFE standard scenarios.**

The solid line baseline is the main reference level used for analyses reported here, with rated fuel economy frozen at 1990 level of 27.8 mpg, i.e., case (a) in Table 1. The declining (b) and rising (c) baselines are shown as the dashed lines above and below the main baseline. In all cases, trucks are assumed to have proportionate increases.

(A) 15% improvement (33 mpg cars) by 2001, 37 mpg by 2010.

(B) 20% improvement (34 mpg cars) by 2001, 40 mpg by 2010.

(C) 30% improvement (37 mpg cars) by 2001, 45 mpg by 2010.

(D) 40% improvement (40 mpg cars) by 2001, 51 mpg by 2010.

(E) 60% improvement (45 mpg cars) by 2001, 63 mpg by 2010.

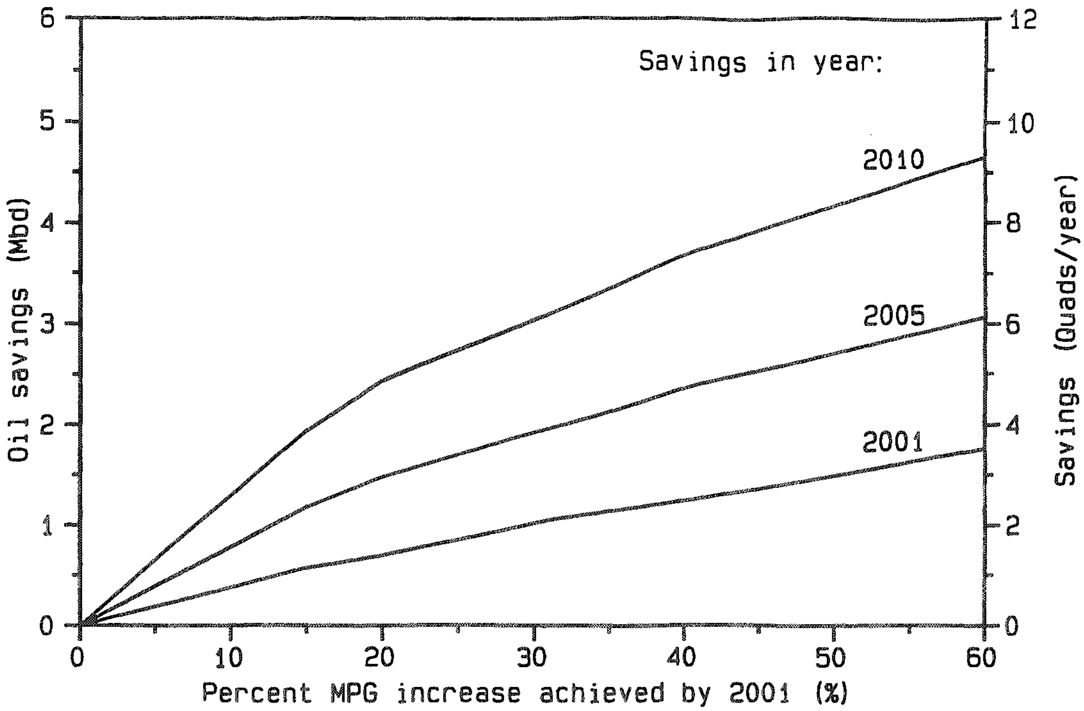

Figure 4. **Projected oil savings by percentage increase achieved by 2001.**
Calculated relative to rated fuel economy frozen at 1990 level; see Table A1 for other projection assumptions.

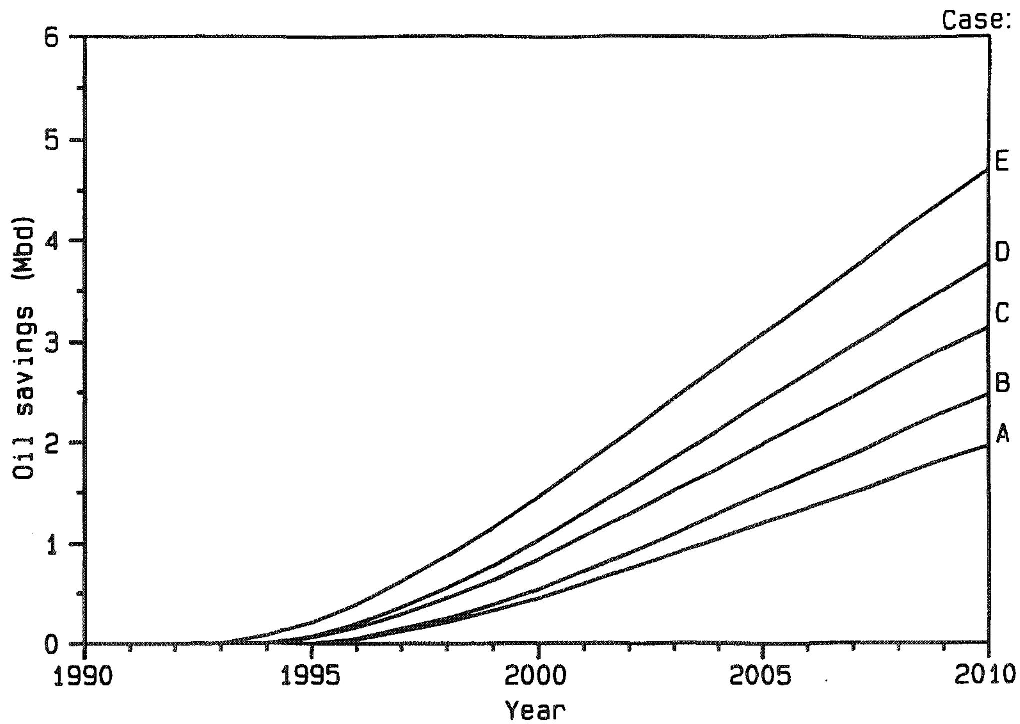

Figure 5. **Projected oil savings by year for various levels of CAFE increase.**
Relative to rated fuel economy frozen at 1990 level; see Table 1 for case definitions and Table A1 for other projection assumptions.

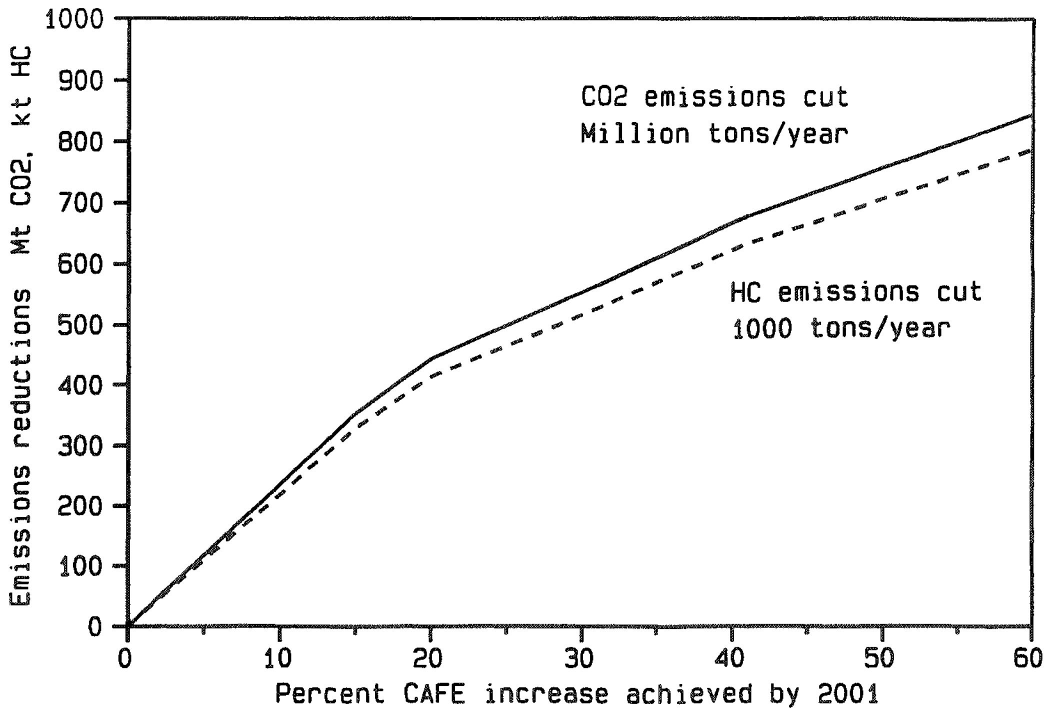

Figure 6. Reductions of U.S. carbon dioxide and hydrocarbon emissions in 2010 as a function of CAFE improvement achieved by 2001.

See Table 1 for CAFE percentage increase scenario definitions. Projections are relative to a frozen fuel economy baseline, using ACEEE VMT growth projections, -0.07 rebound elasticity, and 0.3 mpg CAFE compliance margin. Full fuel cycle CO_2-equivalent emissions are computed at 10.72 kgCO_2/gallon (181.3 x 10^6 tons/yr per Mbd). Fuel cycle HC (VOC) emissions, not including tailpipe component, are computed at 10 g/gallon (0.17 x 10^6 tons/yr per Mbd).