Do Market Failures Justify Tightening Corporate Average Fuel Economy (CAFE) Standards?

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July 6, 2005

Keywords: fuel economy standards; oil dependency; carbon emissions; rebound effect; gasoline tax.

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We are grateful to the Environmental Protection Agency and the National Highway Traffic Safety Administration for financial support, to Jeff Alson, Paul Balserak, Paul Leiby, and Keith Sargent for helpful comments and suggestions, and to Puja Jawahar and Kenneth Gillingham for research assistance.

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Abstract

This paper develops and implements analytical models to estimate the welfare effects of higher Corporate Average Fuel Economy (CAFE) standards on new passenger vehicles. The analysis incorporates a broad range of fuel- and driving-related externalities, fuel taxes, different assumptions concerning consumers' valuation of fuel saving technologies and their alternative value in enhancing other vehicle attributes, and endogenous vehicle fleet composition. To implement the analysis, we develop estimates of CAFE's impact on local pollution, nationwide congestion, and traffic accidents. We find that higher fuel economy standards can produce anything from significant welfare gains, to very little or no effect, to significant welfare losses, depending on how consumers value fuel economy technologies and their opportunity costs.

1. Introduction

The Corporate Average Fuel Economy (CAFE) program requires automobile manufacturers to meet standards for the sales-weighted average fuel economy of their passenger vehicle fleets; current standards are 27.5 mpg (miles per gallon) for cars and 20.7 mpg for light-duty trucks (SUVs, minivans and pickups).[1] Recent attempts to sharply increase the standards have been blocked in Congress, though the National Highway Traffic Safety Administration (NHTSA), which has authority to set light-truck standards, has finalized an increase in that standard to 22.2 mpg by Model Year 2007.

Proponents of tighter CAFE standards emphasize the benefits of reducing greenhouse gases and the economy's dependence on a volatile world oil market. In addition, a number of engineering studies suggest that there is a wide array of emerging technologies for which discounted, lifetime fuel savings would easily exceed costs of incorporating them in new vehicles (e.g., NRC 2002, figure 4.5). It is frequently alleged that these seemingly cost-effective technologies may not be adopted unless CAFE standards are tightened because consumers undervalue fuel economy (Greene 1998). Finally, there is concern that average fuel economy of the new passenger vehicle fleet has fallen significantly from its peak in 1987, due to the rising share of light-duty trucks which now account for just over half of new passenger vehicle sales (see Figure 1).

Gasoline accounts for 43% of US oil consumption and 20% of carbon emissions (EIA 2002, Tables 5.11 and 12.3). Broad oil and carbon taxes are therefore far more cost-effective policies than

[1] Manufacturers must pay a penalty of $55 per vehicle for every 1 mpg that their fleet average falls below the relevant standard; vehicles weighing more than 8,500 pounds (such as the Hummer H2 and Ford Excursion) are exempt.

CAFE, as they exploit options for reducing oil use and carbon emissions throughout the economy, rather than placing the entire burden on (new) passenger vehicles. Nonetheless, energy taxes are not being debated by policy stakeholders while CAFE is;[2] understanding the social welfare effects of tightening CAFE would enlighten this debate.

This paper develops and implements an analytical framework for assessing the social welfare effects of tightening CAFE standards, a framework that takes into account a number of important factors.

First, the analysis integrates CAFE's impact on a broad range of motor vehicle externalities, including carbon emissions and oil dependency, which are proportional to fuel use, as well as congestion and accidents, which increase through the "rebound effect", that is, the incentive to drive more when fuel costs per mile fall. We also model CAFE's impact on local air pollution, which is potentially affected by vehicle use, fleet composition, fugitive emissions from the petroleum industry, and the effects of fuel economy on the emission profiles of aging vehicles.

Second, we incorporate pre-existing fuel taxes that work to raise fuel prices and internalize fuel-related externalities, considering scenarios when revenues are earmarked for highways and when they form part of general government revenue.

Third, we consider scenarios meant to span the diverse range of opinions among experts about how consumers value fuel saving technologies, and the full economic costs of adopting them, allowing for possible opportunity costs from forgoing their use in enhancing other vehicle attributes such as power, comfort, safety, and payload. We examine scenarios when consumers correctly perceive fuel savings and, based on NRC (2002), when they excessively discount fuel savings over the entire vehicle life, or when they have short horizons and consider fuel savings over only three years.

Fourth, we consider implications of changes in vehicle fleet composition when the net costs of improving fuel economy, and external costs, differ across vehicle types.

We begin with a single vehicle model, where welfare effects of fuel economy standards are explicitly decomposed into terms with clear economic interpretation. The model is then extended to distinguish ten vehicle classes. This extension allows us to consider differential standards for cars and light trucks, induced changes in the vehicle sales mix, and cost savings from trading of fuel economy credits across cars and light-trucks.

We develop new estimates of parameters required to implement the model where prior empirical literature is inadequate. Emissions inspection data is used quantify lifetime vehicle emission rates and to assess the emissions/fuel economy relation. Results from a computational transport network model are extrapolated to estimate marginal congestion costs for the nation as a whole. Crash data is used to

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[2] For example, a recent high-profile report from a bipartisan commission recommended higher fuel economy standards (NCEP 2004).

estimate external accident costs for the ten vehicle classes. And we account for some previously unexamined subtleties in measuring baseline fuel economy in absence of regulation, vehicle demand elasticities, and the implications for the rebound effect of changes in the vehicle stock.

In previous literature, the usual approach has been to measure welfare effects of fuel economy regulations by estimating lifetime fuel saving benefits minus added vehicle costs (e.g., Yee 1991, Greene 1991a, Thorpe 1997, Goldberg 1998, NRC 2002, Greene and Hopson 2003, CBO 2003). These studies yield widely different results concerning not only the magnitude but also the *direction* of the welfare effect, depending on whether they allow for market failure due to consumer undervaluation of fuel economy, or rule it out by assumption. There has been very little attempt to integrate externalities into welfare assessments of CAFE. The one exception is Kleit (2004); using a disaggregated, computational model of the auto market, he estimates that a long run 3-mpg increase in the CAFE standard would reduce social welfare by $0.78 per gallon of fuel savings.

Our analysis builds on Kleit (2004) in several respects. We develop detailed estimates of external effects and behavioral responses where prior empirical literature is inadequate. Our framework encompasses a broad spectrum of scenarios about consumers' valuation of fuel saving technologies and their opportunity costs; Kleit's analysis assumed no (non-externality) market failures. The analytical framework explicitly shows the contribution of underlying parameters to welfare effects; the single vehicle model yields welfare formulas that are easy to implement and update in the light of new evidence, and estimates from the simple model are very close to those from the multi-vehicle model. We also examine the role of pre-existing fuel taxes, the effect on accidents from changing fleet composition, and we consider a rich array of policy scenarios and sensitivity analysis.[3]

We summarize the results as follows.

First, we find essentially no difference in the deterioration of emissions per mile over vehicle lifetimes for cars with different fuel economy, and for light-trucks with different fuel economy. This suggests conventional pollution is (approximately) independent of fuel economy within car and truck groups, and varies only with mileage.

Second, we estimate the marginal congestion cost, averaged across 348 US cities and rural areas, and across time of day, at 6.5 cents per mile. External accident costs per mile are estimated at 4.5 cents per mile for the average passenger vehicle; although external costs differ across vehicles, safety effects of

[3] Another issue that has been hotly debated is CAFE's impact on highway fatality rates (e.g., Crandall and Graham 1989, Khazzoom 1997, Kahane 1997, van Auken and Zellner 2002, Noland 2004). Our analysis instead quantifies the regulation's effect on external accident costs, which is quite different; external costs exclude own-driver fatality risk, and include non-fatal injuries to other road users, traffic holdups, and a portion of property damage, medical and emergency service costs, and productivity losses (see below).

changes in vehicle fleet composition contribute very little to overall welfare effects because most of the behavioral response to regulation comes from technological modifications to vehicles rather than changes in fleet composition.

Third, we show that the reduction in fuel demand induced by improved fuel economy is itself welfare-improving only if the marginal external costs of carbon emissions and oil dependency exceed the product of the existing fuel tax and the marginal social value of fuel tax revenues. When the social value of an additional dollar of revenue is a dollar, which could be a reasonable approximation even when revenues are earmarked for highways, the reduction in gasoline demand (moderately) reduces welfare because the current (federal and state) fuel tax of \$0.40 per gallon overcharges for fuel-related externalities. Our benchmark values for marginal oil dependency and carbon externalities are \$0.16 and \$0.12 per gallon respectively.

Fourth, relative welfare losses from the rebound effect can be significant (as in Kleit 2004), though the increase in aggregate mileage is diminished by the reduction in vehicle sales, which differs depending on how fuel economy technologies and their costs are valued. Although the overall increase in miles driven is pretty modest, the welfare cost may still be significant because mileage-related external costs are large relative to fuel-related external costs. Expressed on a per-gallon equivalent basis at initial on-road fuel economy, marginal external costs from congestion, accidents, and local pollution convert to \$2.53 per gallon, or nine times combined carbon and oil dependency externalities.

Fifth, there is a wide range of possibilities for the welfare change from the improvement in fuel economy itself from significant welfare gains when consumers have short horizons, to significant welfare losses when consumers correctly perceive fuel savings but value new technologies in other uses. When technologies have no opportunity costs, higher standards are non-binding in our policy scenarios (except in the short horizon case), as many emerging technologies would be employed to raise fuel economy in the absence of regulation.

Sixth, in the single vehicle model a mandated increase in fuel economy of 4 mpg above current levels reduces future welfare by \$2.5 to \$8.5 billion on an annualized basis (\$0.20 to \$0.68 per gallon of fuel reduction) when technologies have opportunity costs and consumers correctly perceive, or excessively discount, fuel savings; with no opportunity costs the policy is non-binding. When consumers have short horizons, welfare effects are positive and vary between \$4.7 and \$6.6 billion. The sign of the welfare effect in each scenario is robust to a wide range of alternative parameter assumptions.

Seventh, benchmark welfare effects from the multi-vehicle model are similar in each scenario for a general 4-mpg increase in fuel economy standards; thus fleet composition effects have little consequence for the aggregate results for this policy. Finally, raising the light-truck standard up to the current car standard again improves welfare only if consumers have short horizons; otherwise it has no effect, or produces significant welfare losses. Allowing trading of credits across cars and light trucks has a modest effect on raising welfare gains or reducing welfare losses.

There are several caveats to our analysis, discussed at the end of the paper. For example, marginal damages from carbon and oil dependency may change over time, and we do not model possible efficiency gains from induced innovation in the presence of technology spillovers. Nonetheless, given that tightening CAFE standards might have little effect, or might produce significant welfare losses, our own preference would be for alternative policies which appear to have a firmer efficiency foundation, such as broad-based oil and carbon taxes, higher fuel taxes, pay-as-you-drive auto insurance, subsidies for alternative fuel vehicles, and subsidies for R&D into carbon capture technologies.[4]

The rest of the paper is organized as follows. Section 2 develops the single- and multi-vehicle analytical models. Section 3 provides the parameter assessment. Section 4 presents the main results and sensitivity analysis. A final section offers conclusions.

2. Analytical Models

A. Assumptions in the Single-Vehicle Model

(i) Utility and Driving. We consider a one-period model where the period represents the average lifetime of a new passenger vehicle, currently 14 years (NRC 2002). At the start of the period the representative agent buys v identical vehicles, drives each of them for m miles, then scraps them at the end of the period; total miles driven is $M = vm$.[5] The agent has utility function:

(1a) $$U = u(D, T, X) - A - O - Z_M - Z_G$$

(1b) $$D = D(v, m, H, q),$$

where $u(.)$ is quasi-concave in D, and X and decreasing in T; all variables are present discounted values per capita.

$D(.)$ denotes sub-utility from vehicle travel; it is increasing and concave in all arguments.[6] H is government spending on highways; more spending may raise the benefit of driving through access to a more extensive and better-maintained road network. T is in-vehicle time, and $-u_T$ represents marginal disutility from reduced time available for other activities. q is an index of vehicle quality and is included

[4] See for example Edlin (2003), Parry and Small (2005), Leiby and Rubin (2001), Anderson and Newell (2004).

[5] It is reasonable to treat v as a choice variable for the representative agent, as it is a continuous variable at the economy-wide level.

[6] Concavity in m (as opposed to M) ensures agents buy more than one vehicle; this may represent increased risk of breakdown for vehicles with higher mileage.

to capture trade-offs between fuel economy and other vehicle attributes (e.g., power, comfort, safety, payload). X is the quantity of a numeraire consumption good.

A and O denote, respectively, the social costs of traffic accidents and external costs from the economy's dependence on a volatile world oil market (the nature of the externalities are discussed below). Z_M is environmental damages from local tailpipe emissions subject to emissions per mile regulations; based on empirical findings in Section 3 we assume lifetime emissions are proportional to vehicle miles and independent of fuel economy even though abatement equipment may deteriorate over time. Z_G is the cost of emissions that are proportional to fuel use. These include carbon emissions, which are not subject to (federal) emissions per mile regulations, and upstream local emissions leakages from the petroleum industry.[7]

We define:

$$(2) \qquad G = gM \,, \qquad p_G = \tilde{p}_G + t_G$$

g and G denote gallons of gasoline per mile (the inverse of fuel economy), and total gasoline consumption, respectively. p_G is the consumer price of gasoline equal to the pre-tax price $\tilde{p}_G$ plus a specific tax per gallon t_G.

The government imposes a maximum allowable ceiling on fuel per mile, $\bar{g}$, equivalent to a fuel economy standard. The welfare effects of this mandated standard depend on how it reduces fuel per mile relative to the free-market baseline; in practice fuel per mile may decline in future without regulation if emerging fuel saving technologies were to be adopted by the market. To allow for this it will be helpful to define two reference scenarios: the first (denoted R1) represents fuel per mile at the end of a previous period; the second (denoted R2) represents the free-market baseline during the course of the next period after the possible adoption of technologies emerging during the period. Thus:

$$(3a) \qquad \left.\begin{array}{l} g^{R2} < g^{R1} \\ g^{R2} = g^{R1} \end{array}\right\} \begin{array}{l} \text{if emerging technologies would be adopted to raise fuel economy} \\ \text{if not} \end{array}$$

$$(3b) \qquad \left.\begin{array}{l} g = \bar{g} \\ g = g^{R2} \end{array}\right\} \begin{array}{l} \text{if regulations are binding, } \bar{g} < g^{R2} \\ \text{if not} \end{array}$$

We assume that any pre-existing fuel economy standards (in the first reference scenario) are non-binding, which is a common modeling assumption (e.g., Thorpe 1997, Goldberg 1998, Greene and Hopson 2003,

[7] A, Z_G, O and Z_M (which are expressed in utils) enter utility separably; that is, damages from global warming, pollution-induced health effects etc. do not affect the demand for travel relative to other goods, which is a reasonable approximation.

CBO 2003).[8] To the extent that prior standards might be binding our analysis overstates the welfare effects of mandating higher standards (Kleit 2004).

We define:

(4) $\Gamma = \rho p_G mg$

Γ is lifetime fuel costs *as perceived by agents at the start of the period*. If $\rho = 1$ agents correctly perceive future fuel costs (as assumed in CBO 2003, Kleit 2004, Thorpe 1997, and others); we refer to this as the "far-sighted consumers" case. If $\rho < 1$ agents undervalue fuel costs, for example they may have excessive discount rates, consider fuel savings over a shorter horizon than the vehicle lifetime, or it may not pay boundedly rational consumers to inform themselves about fuel costs if they care more about other vehicle attributes (e.g., Greene et al. 2004); we refer to this as the "myopic consumers" case.

(ii) Externalities. Travel time is given by:

(5) $T = \pi M$; $\pi = \pi(\overline{M})$

where $\pi'(.) > 0$ and a bar denotes an economy-wide variable (expressed in per capita terms) perceived as exogenous by individual agents. π is driving time per mile; it increases with aggregate driving as more congested roads slow driving speeds. Agents do not take into account the impact of their mileage on reducing speeds for other drivers.

Accident costs are:

(6) $A = a_{INT}(M) + a_{EXT}(\overline{M})$

where a'_{INT}, $a'_{EXT} > 0$. a_{INT} is internalized accident costs (e.g., own-injury risks to drivers) and a_{EXT} is external costs (e.g., pedestrian injuries, property damages not perceived on a per mile basis). Accident costs depend on mileage; below we allow them to also vary with fleet composition.

Remaining external costs are:

(7) $Z_G = Z_G(\overline{G})$; $Z_M = Z_M(\overline{M})$; $O = O(\overline{G})$

where $Z'_G(.)$, $Z'_M(.)$, $O'(.) > 0$.

[8] A possible justification is that the car standard has been unaltered since 1985 and until a recent ruling the light-truck standard had been unaltered since 1995; in addition, recent rises in fuel prices reduce the likelihood that existing standards are binding. We also ignore the possibility that firms pay a fine instead of meeting fuel economy requirements, as this has not been the case for US companies.

(iii) Firms. We assume domestic, competitive firms produce gasoline, vehicles, and the numeraire consumption good with labor under constant returns. We believe these are reasonable simplifications for our purposes; Section 5 briefly comments on alternative assumptions.

Manufacturers face the following functions:

(8a) $C = C(g^{R1} - g)$, $C' = \alpha + \beta(g^{R1} - g)$

(8b) $q = q^{R1} - \gamma(g^{R1} - g)$

where $\beta > 0$ and α, $\gamma \geq 0$. In (8a) $C(.)$ is the added dollar production cost per vehicle from reducing fuel per mile below the first reference level through technology adoption (e.g., technologies to improve engine efficiency and transmission, or reduce vehicle drag and rolling resistance); marginal costs are assumed linear. In (8b), we allow for the reduction in fuel per mile to lower quality by diverting technologies that would otherwise have been employed to enhance other vehicle attributes (we consider cases both with and without quality changes).[9]

We denote the vehicle sales price by p. Entry/exit of competitive firms ensure that in equilibrium

(9) $p = p^{R1} + C$

that is, the sales price equals the sales price (or production cost) in the first reference scenario, plus any added manufacturing costs from adopting fuel saving technologies.

(iv) Government Budget Constraint. This is:

(10) $H + F = t_G G$

where F is a lump-sum transfer to households. This equation equates highway and transfer spending with fuel tax revenues. We consider cases where reductions in revenues, due to the erosion of the fuel tax base from higher fuel economy, imply either reductions in H or F.[10]

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[9] There is casual evidence that fuel saving technologies may have value in other uses. For example, emerging technologies identified as fuel saving technologies in NRC (1992), including 4 valve per cylinder engines and 4- and 5-speed automatic transmissions, were widely introduced over the last decade, yet new vehicle fleet fuel economy did not improve while average horsepower increased significantly (CBO 2002, Table 2).

Besides these opportunity costs there may be other unobserved costs that are excluded from empirical estimates of C, such as marketing, maintenance, consumer unfamiliarity, and retraining of mechanics. However, incorporating them would have essentially the same effect of assuming a higher value for γ.

[10] A further possibility is that the government would maintain fuel tax revenues by increasing the gasoline tax. This is beyond our scope, though a related analysis by Parry and Small (2005) finds that higher fuel taxes would significantly improve welfare by reducing both fuel-related and mileage-related externalities. However, it is not clear that higher fuel economy leads to higher fuel taxes: on-road fuel economy increased from 10.6 mpg in 1960 to 20.0 mpg in 2003, while federal and state tax rates *fell* in real terms by 54% (from BTS 2004, Tables 1.32 and 4.7, and adjusting nominal rates by the consumer price index).

B. Solution to the Single-Vehicle Model

(i) Household Optimization. We solve the household optimization problem backwards in two steps (this is necessary when agents misperceive lifetime fuel costs). First, for a given number of vehicles $\tilde{v}$ purchased at the start of the period, households choose miles per vehicle and the numeraire good to maximize utility (1) subject to the budget constraint $I + F - p\tilde{v} = X + \tilde{v}p_G mg$ and (5)–(7), where I denotes (fixed) labor income.[11] Second, at the start of the period they optimize over the number of vehicles and (planned) spending on the numeraire good, subject to the constraint $I + F = X + v(p + \Gamma)$, (5)–(7), and taking Γ as given.

The optimization yields:

(11a) $\{u_D D_m / v + u_T \pi - a'_{INT}\} / u_X = p_G g$

(11b) $\{u_D D_v / m + u_T \pi - a'_{INT}\} m / u_X = p_E \equiv p + \Gamma + \omega$

where $\omega(g^{R1} - g) = u_q \gamma(g^{R1} - g) / u_X$ is the utility loss (in dollars) from reduced quality per vehicle. Equation (11a) equates driving benefits per mile, net of time and internal accident costs, with per mile costs of fuel. Equation (11b) equates driving benefits per vehicle, net of time and internal accident costs, with "effective" vehicle price p_E; the latter includes the sales price, perceived lifetime fuel costs, and quality costs.

To obtain demand functions we assume changes in π and a'_{INT} are negligible (this is reasonable as proportionate changes in M are small). We also adopt constant-elasticity functional forms:

(12a) $m \approx m^{R1} \left\{ \frac{g}{g^{R1}} \right\}^{\eta_m}$

(12b) $v \approx v^{R1} \left\{ 1 + \frac{p_E - p_E^{R1}}{p^{R1}} \right\}^{\eta_v}$

$\eta_m < 0$ is the elasticity of miles driven per vehicle with respect to fuel costs and $\eta_v < 0$ is the elasticity of vehicle demand with respect to the effective price.[12]

(ii) Firm Optimization. From (11b) firms face a sales price $p = p_E - \Gamma - \omega$; they take p_E as given as they are competitive, though their choice of fuel economy alters how much consumers are willing to pay

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[11] We assume agents correctly perceive fuel costs when choosing mileage at a point in time, as this is an ongoing decision (unlike the vehicle purchase decision that requires forecasting over a 14-year period).

[12] We define changes in effective prices relative to the retail price in order to apply elasticities from the empirical literature that are defined relative to retail prices.

for vehicles p, through altering Γ and ω. With no fuel economy constraint firms choose g to maximize profits per vehicle $p-(C+p^{R1})$. Using (4) and (8), this yields:

(13) $\rho mp_G = C' + \omega' \qquad \rightarrow g^{R2} = g^{R1} - \{\rho mp_G - (\alpha + \omega')\}/\beta$

Equation (13) states that fuel per mile is reduced until the incremental lifetime fuel saving benefits perceived by consumers, $\rho mp_G = \Gamma_g$, equals the added vehicle cost, C', plus the marginal value of forgone vehicle quality, ω'.

Foregone quality is unobservable in practice. We assume that $\omega' = \gamma u_q / u_X$ is constant; that is, quality costs cause up upward parallel shift in the overall marginal costs of improving fuel economy. And we consider two extreme cases that span the entire range of possibilities for the magnitude of ω'. In a "no opportunity costs" scenario (e.g., NRC 2002), we simply set ω' = 0. In an "opportunity costs" scenario, we follow CBO (2003) and assume any failure to adopt emerging technologies for which perceived fuel saving benefits exceed added vehicle costs, is explained entirely by foregone quality.

Thus, there are four possible equilibria in the second reference scenario, illustrated in Figure 2. With far-sighted consumers, equilibrium is at point A, with opportunity costs, and point B, with no opportunity costs. Since the perceived and actual (or social) marginal benefits are the same, and equal to marginal cost, inclusive of any opportunity costs at these points, any mandated reduction in fuel per mile beyond these levels will reduce efficiency (leaving aside externalities and fuel taxes). With myopic consumers, equilibrium is at point C, with opportunity costs, and point D, with no opportunity costs. In these cases, a mandated reduction in fuel per mile can increase efficiency, because the social marginal benefit initially lies above marginal costs (inclusive of any opportunity costs). Finally, note that in the no opportunity cost cases, standards must be increased above a strictly positive threshold level before they become binding and have any effect.

(iii) Welfare Effects. When regulation is binding ($\overline{g} < g^{R2}$), the (monetized) welfare effect (denoted W) from an incremental reduction in $\overline{g}$ can be obtained by differentiating the agent's indirect utility function, accounting for changes in external costs, and in F or H to maintain government budget balance. The result can be expressed as the sum of the following three components (see Appendix):

(15a) $$-\frac{dW}{d\overline{g}} = \overbrace{(\mu t_G - E_G)\left\{-\frac{dG}{d\overline{g}}\right\}}^{gasoline\ reduction} - \overbrace{E_M\left\{-\frac{dM}{d\overline{g}}\right\}}^{mileage\ increase} + \overbrace{\{mp_G - (C' + \omega')\}v}^{fuel\ economy}$$

(15b) $E_G = (Z'_G + O')/u_X$; $E_M = \{a'_{EXT} + Z'_M - u_T M\pi'\}/u_X$; $\mu = \left\{\frac{dF}{dG} + \frac{dH}{dG}\frac{u_H}{u_X}\right\}\frac{1}{t_G}$

(15c) $\frac{dG}{d\bar{g}} = M + \bar{g}\frac{dM}{d\bar{g}} > 0$; $\frac{dM}{d\bar{g}} = v\frac{dm}{d\bar{g}} + m\frac{dv}{dp_E}\frac{dp_E}{d\bar{g}} < 0$

E_G is the combined external cost per gallon (in dollars) from carbon emissions, upstream local emissions, and oil dependency. E_M is the combined external cost per mile from accidents, local tailpipe pollution, and congestion.[13] μ is the social value per dollar of extra tax revenue. If all marginal revenue is spent on transfer payments, $dF/dG = t_G$ (from (10)) and μ = 1. If it is all spent on highways, $dH/dG = t_G$ and $\mu = u_H/u_X$; in this case μ is greater/less than unity if the value of an extra $1 of highway spending is greater/less than $1. We assume E_G, E_M, and μ are constant.[14]

The first component in (15a) is the induced welfare change in the gasoline market. It equals the change in gasoline times the product of μ and the gasoline tax, minus the per gallon external cost. If μ = 1, the reduction in gasoline increases/decreases welfare, depending on whether the gasoline tax under- or over-charges for external costs of fuel use. With fuel tax revenues earmarked for highways, the erosion of the fuel tax base involves higher/lower efficiency costs (gross of externalities) if the social value per $1 of marginal government spending is greater/less than $1. Thus, the common perception that fuel taxes are not distortionary because they pay for highways is only valid in our analysis if highway spending has no social value.

The second component in (15b) is a welfare loss equal to the increase in mileage, or "rebound effect", times the external cost per mile from mileage-related externalities. The increase in mileage equals the increase in miles per vehicle due to lower per mile costs, less a (partially) offsetting effect due to reduced vehicle demand as the effective vehicle price increases (see (12a), (14) and (15c)); note that the change in effective price will vary with the different scenarios in Figure 2.[15]

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[13] The marginal cost of congestion is the increase in travel time per mile following an incremental increase in aggregate mileage π', times per capita mileage M, times the marginal disutility of in-vehicle time, $-u_T$.

[14] These are reasonable assumptions with the possible exception of marginal oil dependency costs, which vary modestly with reductions in oil use (Leiby et al. 1997).

[15] The effective price always increases because marginal costs, including quality costs, exceed perceived marginal benefits, for non-incremental reductions in fuel per mile beyond the free market baseline (see Figure 2). In our simulations below, the reduction in vehicle sales lowers the rebound effect by between 14 and 26% across different scenarios.

The third welfare component is from the increase in fuel economy itself. It is the marginal social benefit from fuel savings, net of marginal vehicle costs, including forgone quality, times the number of vehicles. As can be seen in Figure 2, there is a welfare loss with far-sighted consumers, but a potential welfare gain with myopic consumers.

We integrate equation (15a) in a spreadsheet to obtain welfare effects of non-incremental policy changes, using (8a), (12), assumptions about opportunity costs, and parameter values discussed below.

C. Multi-Vehicle Model

We now assume the representative agent drives $i = 1 \ldots N^C$ cars and $i = N^C+1 \ldots N^T$ light trucks; we maintain the assumption of homogeneous firms, where each firm is engaged in production of all vehicles. Initial prices, fuel economy, and the marginal cost of reducing fuel use per mile, differ across vehicles, as do accident and pollution costs per mile, though not congestion costs.[16] Added vehicle production cost and quality take the same form as in (8). Vehicle demands are now given by the constant elasticity formulas:

(16) $$v_i = v_i^{R1} \prod_{j=1}^{N^T} \left\{ 1 + \frac{p_{Ej} - p_{Ej}^{R1}}{p_j^{R1}} \right\}^{\eta_{ij}}, \quad i, j = 1 \ldots N^T$$

where η_{ii} is an own price elasticity and η_{ij} $(j \neq i)$ a cross-price elasticity.

CAFE sets separate standards for the harmonic average miles per gallon across car and light-truck fleets; this is equivalent to imposing maximum fuel per mile requirements, expressed as $\bar{g}^C$ for cars and $\bar{g}^T$ for trucks. When standards are binding:

(17) $$\sum_{i=1}^{N^C} (\bar{g}^C - g_i) v_i = 0, \qquad \sum_{i=N^C+1}^{N^T} (\bar{g}^T - g_i) v_i = 0$$

Manufacturers choose fuel per mile for each vehicle, and the sales mix, to maximize profits $\sum_{i=1}^{N^T} \{p_i - (C_i + p_i^{R1})\} v_i$ subject to (11c), (16) and (17), taking p_{Ei} as given. This yields:

(18a) $$C_i' + \omega_i' - \rho p_G m_i = \delta_k, \qquad i = 1 \ldots N^C,\ k = C;\ i = N^C+1 \ldots N^T,\ k = T$$

(18b) $$p_i - (C_i + p_i^{R1}) = \delta_k (g^i - \bar{g}^k), \qquad i = 1 \ldots N^C,\ k = C;\ i = N^C+1 \ldots N^T,\ k = T$$

δ_C and δ_T are the shadow prices on the constraints for cars and trucks respectively; prior to any mandated increase in fuel economy δ_C, $\delta_T = 0$.

[16] FHWA (1997), Table V-23, puts the difference in marginal congestion costs across cars and light trucks at only 0.01 to 0.15 cents per mile; vehicles differ in length, and therefore how much road space they take up, but these differences are small relative to average on-road distance between vehicles.

(18a) states that within a vehicle class (cars or trucks) fuel economy is improved in a vehicle until the increased production and quality cost, net of perceived fuel saving benefits, is equated to the shadow price of the fuel economy constraint for that class. (18b) states that, within a vehicle class, sales prices are above, equal to, or below, production costs, according to whether fuel per mile is above, equal to, or below, the average for that class, when the standard is binding. Thus, the standard effectively taxes fuel inefficient vehicles and subsidizes fuel efficient ones. By altering the relative vehicle prices in this way, the multi-vehicle model admits another channel for improving fleet average fuel economy that is absent from the single-vehicle model.

External costs of fuel consumption are identical for cars and trucks (though per mile costs differ); thus, there is no efficiency rationale in our analysis for policies resulting in different shadow prices on fuel economy for cars and trucks.[17] If fuel economy credits could be traded across cars and light trucks this would effectively replace the separate standards with a single standard and a single shadow price; efficiency would improve in two respects. First, the marginal cost of improving fuel economy, including quality costs, and net of perceived fuel savings, would be equated across all vehicles, rather than differing between cars and trucks; second, the penalty (subsidy) for a vehicle with relatively high (low) fuel per mile would be the same for cars and trucks.

Analogous to the decomposition in (15a), the welfare change from an incremental reduction in the fuel per mile constraint $\bar{g}_k$, $k = C$, T is calculated by:

$$(19) \qquad -\frac{dW}{d\bar{g}_k} = \overbrace{(E_G - \mu t_G)\left(-\frac{dG}{d\bar{g}_k}\right)}^{gasoline\ reduction} - \overbrace{\sum_{i=1}^{N^T} E_{Mi} \frac{dM_i}{d\bar{g}_k}}^{mileage\ increase} + \overbrace{\sum_{i=1}^{N^T} \{m_i p_G - [C_i' + \omega_i']\} v_i)}^{fuel\ economy}$$

The multi vehicle model is solved in a spreadsheet that selects values for the shadow prices, uses these to compute fuel economy and vehicle sales prices from (18), and then vehicle demands from (16), and then iterates over the shadow prices until constraints in (17) are met for given fuel economy standards. We incrementally increase the fuel economy standard to its new level for one vehicle class, obtaining welfare effects by integrating over (19), and then do the same for the other vehicle class.

3. Benchmark Parameter Values

Here we discuss benchmark parameter values; in a subsequent sensitivity analyses we consider alternative values for key parameters.

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[17] When CAFE standards were initially introduced light trucks were mainly used for industrial and agricultural purposes and a lower standard for them was set to limit the burden on commerce. Today however, today most light trucks are used as passenger vehicles.

A. Basic Vehicle Data. Table 1 summarizes vehicle classifications, sales, initial prices, fuel economy, and actual lifetime fuel costs for model year 2000; this data is used to produce the first reference scenario.

Following NRC (2002), Ch. 4, we distinguish four car classes (subcompact, compact, midsize and large) and six light-truck classes (small SUV, mid SUV, large SUV, small pickup, large pickup, minivan). Cars and light trucks each account for about 50% of total passenger vehicle sales. Initial certified fuel economy averages 27.4, 20.6 and 24.0 mpg across cars, light trucks and all vehicles, respectively, or 3.65, 4.85 and 4.17 gallons per 100 miles. We assume on-road fuel economy is 85% of the certified level.[18]

Following NRC (2002) we assume all vehicles are initially driven 15,600 miles in the first year, decreasing thereafter at 4.5% per year, over the 14-year life cycle. Initial discounted lifetime fuel costs for vehicle i, $m^{R1} p_G g^{iR1}$ are therefore computed with m^{R1} = 15,600 $\Sigma_{j=1}^{14} 1/(1+r^S+.045)^{j-1}$, where r^S is the social discount rate. We assume r^s = 0.05, a typical value used in medium-term cost/benefit analysis.[19] The retail gasoline price, p_G, is assumed to be \$1.80 per gallon, though other values are considered later.[20] Actual lifetime fuel costs under these assumptions are shown in Table 1.

The ratio of perceived to actual lifetime fuel costs is given by:

$$\rho = \frac{\Sigma_{j=1}^{Y} 1/(1+r^p+.045)^{j-1}}{\Sigma_{j=i}^{14} 1/(1+r^s+.045)^{j-1}}$$

where $Y \leq 14$ is horizon over which households consider fuel savings, and r^p is the private discount rate. We consider two scenarios for the myopic consumer case, based on the two scenarios considered in NRC (2002). In the first "high discount rate" scenario consumers consider the full vehicle life, but use a discount rate of 12% (Y = 14, r^p = 0.12); in the second, they do not discount the future but consider fuel

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[18] See NRC (2002), pp. 66. Unlike certified (i.e. dynamometer-tested) fuel economy, on-road fuel economy varies with traffic conditions, temperature, trip length, frequency of cold starts, driving style, etc. Certified fuel economy is from NRC (2002), Table 4.2 (adjusted for future safety and emissions standards). As in NRC (2002), we assume no deterioration of fuel economy over vehicle lifetimes. Sales data was compiled from *Wards Automotive Handbook 2001*. The price for each vehicle class was obtained from a sales-weighted average of prices of models within that class from www.Edmunds.com. To classify vehicles according to the NRC subgroups we used a combination of the Wards descriptions and EPA classifications. Luxury vehicles, two-seaters, large vans and some other specialty vehicles like hybrids were excluded.

[19] See for example www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html.

[20] This represents the expected gasoline price averaged over the next 14 years. NRC (2002) used a price of \$1.50 per gallon, based on prices throughout the 1990s when the world oil prices were around \$15-\$28 per barrel. However, since mid-2004, oil prices have exceeded \$40 per barrel and gasoline prices have been above \$2.00 per gallon. EIA (2005) projects world oil prices to fall back somewhat in coming years; they forecast a world oil price of \$20 to \$35 per barrel out to 2015.

savings only over the first three years of the vehicle life ($Y = 3$, $r^p = 0$).[21] These cases yield values for ρ of 0.74 and 0.35 respectively.

B. Cost of Improving Fuel Economy. We calibrate the direct costs of improving fuel economy C_i to underlying data in NRC (2002).[22] This yields coefficients shown in the last two columns of Table 1; here, $g^{R1i} - g^i$ is defined in gallons per 100 miles. Marginal costs rise more rapidly for smaller vehicles with higher initial fuel economy. The benefit from a gallon reduction in (on-road) gasoline per 100 miles, evaluated at the social discount rate and first reference mileage, is \$2,329 for each vehicle; this greatly exceeds all the intercepts of all the marginal cost curves.

C. Vehicle Demand and Mileage Elasticities. We simulate an internal General Motors (GM) model of new vehicle sales to obtain a 10×10 matrix of own and cross vehicle price elasticities.[23] However the magnitude of the own-price elasticities are too large as they reflect people holding on to used vehicles longer—an effect that disappears in the long run—in addition to substitution between vehicles and reduced overall vehicle demand; the own-price elasticities are therefore adjusted as follows.

First, we simulate a dynamic model of vehicle choice developed by Harrington et al. (2003) to obtain long run estimates of the own-price elasticities for cars as a group, denoted $\hat{\eta}_{CC}$, and light trucks as a group, denoted $\hat{\eta}_{TT}$; results are $\hat{\eta}_{CC} = -0.79$ and $\hat{\eta}_{TT} = -0.85$.[24] Second, we express the own price

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[21] The first case is based on empirical studies finding that (implicit) private discount rates exceed market rates for a wide spectrum of energy saving products (e.g., Frederick et al. 2002 and, in the specific case of fuel economy, see Dreyfus and Viscusi 1995). The second case is based on the views of some in the automobile industry and is the assumption built into the US Energy Information Administration's National Energy Modeling System (Greene et al. 2004).

[22] Their data consist of costs and fuel savings from a wide range of technological options for each vehicle type, which we order by the ratio of average cost to the average percentage improvement in fuel economy. Fitting regressions of the form in (8a) to this data yields our coefficient estimates. The NRC estimates were obtained from available evidence and conversations with manufacturers, and are broadly similar to those in a number of other engineering studies (see NRC 2002, figures 4.5 and 4.6). Cost estimates are expressed as retail price equivalents with a 40% markup assumed for parts supplier, automaker and dealer. Thus, costs may be overstated, since some of the markup may reflect a transfer payment rather than a pure resource cost.

[23] The GM model estimates sales of specific vehicle models, given a set of prices for all included models, for model year 1999. We aggregate these responses to estimate changes in demand for each new vehicle class, according to the percentage change in its own price and those of the other new vehicles.

[24] The Harrington et al. model incorporates a nested logit structure of household ownership over new and old cars and light trucks where the demarcation between new and old vehicles is 3.5 years. The nesting structure consists of an upper level where the choice of how many vehicles to own is estimated and a lower level where vehicle class/vintage is estimated; vehicle miles traveled is then estimated conditional on the number of vehicles owned. Behavioral response parameters are econometrically estimated from the 1990 National Personal Transportation

elasticity for car i computed from the GM model as $\eta_{ii} = \sum_{j \neq i} \eta_{ji} v_j / v_i + (\eta_{ii} - \sum_{j \neq i} \eta_{ji} v_j / v_i)$, where i, j = 1…C. The first component reflects substitution effects among cars. The second component encompasses all other effects—reduced overall vehicle demand, substitution into trucks, *and* people holding on to vehicle i longer; to remove the last effect we scale the second component by $\hat{\eta}_{CC} / \tilde{\eta}_{CC}$, where $\tilde{\eta}_{CC}$ is the own-price elasticity for cars as a group from the GM model, equal to –2.25. Truck elasticities are similarly scaled using $\hat{\eta}_{CC} / \tilde{\eta}_{CC}$, where $\tilde{\eta}_{TT}$ = –0.97. The adjusted 10×10 matrix of own and cross vehicle price elasticities is shown in Table 2: own price vehicle elasticities vary between –1.40 and –3.20.

For the single vehicle model we assume a vehicle demand elasticity η_v of –0.36, based on the long run change in combined car and truck demand to a 1% increase in all vehicle prices that we estimated using the Harrington et al. (2003) model.[25] And we assume a miles per vehicle elasticity η_m = 0.125.[26]

D. Local Pollution Costs

(i) Tailpipe emissions and fuel economy. First, we validate our assumption that local tailpipe emissions are independent of fuel economy within car and light-truck classes.

If there were no deterioration over time of abatement equipment installed in new vehicles to satisfy a given emissions per mile standard, improving a vehicle's fuel economy would have no effect on its lifetime per mile emissions rate. However, because abatement equipment deteriorates over time, and vehicles with lower fuel economy have greater engine-out emissions (i.e. emissions into the catalytic converter), it is conceivable that tailpipe emissions will be negatively related to fuel economy in used vehicles. Indeed Harrington (1997) identified this negative relation, by mapping remote sensing data on vehicle emissions in 1990 from the Arizona Inspection and Maintenance (I/M) Program to EPA certified fuel economy data. However these results need to be revisited because current motor vehicles have more

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Survey (NPTS), and initial conditions calibrated to match the observed 2001 vehicle fleet composition. The above elasticities were obtained from increasing new car prices by 1% and running the model through 30 years, and similarly for light trucks.

[25] In contrast, aggregate vehicle demand falls by 1.2% following a 1% increase in all vehicle prices in the GM model, which is consistent with other short run estimates (e.g., McCarthy 1996, pp. 543).

[26] In time series studies the estimated elasticity of vehicle miles with respect to fuel costs is around -0.1 in the short-run, increasing to -0.2 or more over the long run (for a given vehicle stock); results from studies using cross-sectional survey data are more variable (see Greene et al. 1999). The most recent study, by Small and van Dender (2004), puts the miles per vehicle elasticity at –0.09, with a projection of –0.08 for 2005. In the Washington-START model described below the mileage elasticity is -0.14. Our chosen value represents a compromise among these values.

durable control equipment than the 1990 fleet, and even if the negative relation persists it may have lost its practical significance given the rapid decline in new vehicle emission rates since 1990.

We repeated Harrington's analysis of deterioration rates using data from the Arizona I/M program collected in 1995 and 2002 on car and truck emissions of volatile organic compounds (VOC), nitrogen oxides (NOx), and carbon monoxide (CO).[27] The 1995 dataset showed that emission rates were still significantly affected by fuel economy (though less so than in 1990); however we were unable to find much of an effect in the 2002 dataset.[28] As shown in Figure 3, projected CO, HC and NOx emissions per mile for cars with certified fuel economy of 20 and 30 mpg are virtually indistinguishable over vehicle lifetimes; the same applies within trucks.[29] Thus it seems reasonable to assume lifetime emission rates are equivalent for different cars and for different light trucks.

(ii) Per mile tailpipe emission damages. We obtained average emissions per mile over car and truck lifetimes using data in Figure 3, and above assumptions about miles driven in each year of the vehicle life. We multiply average emissions by (adjusted) damage estimates from Small and Kazimi (1995), 0.19 cents per gram for VOC, 0.69 cents per gram for NO_X, and zero for CO,[30] and aggregate over pollutants. The result is external damages of 1.1, 2.0, and 1.5 cents per mile for cars, light trucks, and all vehicles respectively.

(iii) Upstream emissions leakage. The most important pollutant emitted during the activities of petroleum production, refining, transport and storage is VOCs. In 1999, petroleum industry VOC emissions amounted to 9.8 grams per gallon;[31] using our damage estimate gives 1.9 cents per gallon.

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[27] Sample sizes were 60,000 vehicles per month over a 12-month period for 1995 and 35,000 per month for 2002 (the difference being due to new exemption rules for new vehicles). The test itself changed between these dates; however, we were able to transform 1995 test results into 2002 test results using a procedure developed by Sierra Research (2003).

[28] We used a Davidson-MacKinnon (1981) test to compare a simple model of emissions deterioration based on mileage versus one based on fuel economy. The fuel economy model performed better in 5 out of 6 vehicle/pollution groups in 1995. In 2002 the superiority of the fuel economy model is limited to car HC and CO; in other cases the mileage model does as well or better. Statistical results are available from harrington@rff.org.

[29] The graphs in Figure 3 were obtained through regressing emissions on fuel economy for vehicles of a given age, and reading off emissions from this relation at mpgs of 20 and 30.

[30] See their Table 5, "baseline assumptions". Damages are dominated by mortality effects; we scale estimates to be consistent with the value of life for traffic fatalities assumed below. Small and Kazimi's estimates are on the high side as they apply to Los Angeles (rather than the nation as a whole), where the topography tends to trap pollutants and the climate favors photochemical reactions.

[31] Calculated from EIA (2002) and EPA (1999), Appendix A-5. The emissions rate has fallen by 64% since 1980 due, at least in part, to increased regulatory stringency.

E. Global Pollution Costs. Most economic assessments of the damages to future world agriculture, forestry, coastal activities, etc. from carbon emissions put damages at well below $50 per ton of carbon (Tol et al. 2000, Pearce 2003). A few studies obtain much higher values by attaching differing distributional weights to rich and poor nations (the latter being the most at risk from climate change) and assuming zero rates of time preference (e.g., Tol 1999). The possibility of abrupt, non-linear climate change may also be understated in conventional damage assessments (Schneider 2004). We follow NRC (2002) in adopting a benchmark value of $50 per ton and consider other values later; since a gallon of gasoline contains 0.0024 tons of carbon (NRC 2002) this converts to 12 cents per gallon.

F. Congestion Costs. We are unaware of previous estimates of nationwide marginal congestion cost (MCC).[32] To obtain an estimate we begin with a model of the Washington, DC metropolitan area road network, Washington-START.[33] Fuel economy is a parameter input into the model that affects per mile driving costs. We increase this parameter incrementally and calculate the change in consumer welfare, after netting out fuel savings. This gives an estimate of net welfare change from added congestion and utility of the additional trips taken by motorists. Dividing by extra aggregate mileage we obtain an MCC of 7.7 cents per mile.

We extrapolate a nationwide MCC estimate as follows. We compute MCCs from the Washington-START model with the baseline population and travel demand scaled by between +20% and –40%, holding the road capacity fixed; results are used to estimate a relation between MCC and the mileage/pavement ratio (R), where R is normalized to unity for Washington. We then inferred values for MCC for the 75 cities for which R can be obtained from Schrank and Lomax (2002), using our MCC/R relation. These 75 cities are then classified into four bins according to their population and an average of

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[32] Schrank and Lomax (2002) estimate average congestion costs per mile for 75 US cities. However, MCCs are highly convex with respect to traffic volumes under congested conditions, so it is difficult to infer MCC from average costs, even if we had estimates for all 348 cities. Moreover, in deriving MCCs averaged across time of day, we need to account for the weaker sensitivity of peak-period driving to fuel costs than off-peak driving; the former is dominated by commuting and fuel costs are a smaller portion of combined time and money costs of driving. Furthermore, in computing MCC, account should be taken of various re-allocations of travel across peak and off-peak periods, and across roads with different degrees of congestion within a period, as the pattern of driving and congestion changes (Yang and Huang 1998); this requires a network model.

[33] In the model, households have a nested logit utility function and optimize over trips, destination, mode, time of day, and route. 40 travel zones are disaggregated with arterials and side streets within each zone aggregated into an in-bound, out-bound and circumferential link; freeway segments and bridges are also incorporated. The distribution of travel, and the speed/traffic flow curves are taken from the Metropolitan Washington Council of Governments' transportation planning model. Behavioral responses to travel costs at different times of day are calibrated to estimates in the travel demand literature. See Safirova et al. (2004) for more discussion of the model.

MCCs for each bin is then obtained: MCCs vary between 7.3 cents per mile for cities with over 3 million population to 2.2 cents per mile for cities with 100,000 to 500,000 population. We attribute one of these four MCC values to the remaining 273 cities using population figures from the Census Bureau. Finally, we aggregate MCCs over all cities using the shares of total US population within each city class, and assuming MCC for areas outside cities is zero. The result is a nationwide MCC of 6.5 cents per mile.[34]

G. External Accident Costs. We follow the methodology in Parry (2004) to estimate external accident costs per mile for the ten vehicle types.

Crash data averaged over 1998-2000 is used to assign traffic injuries to different vehicle types.[35] For single vehicle crashes we assume occupant injury risks are internal, while injuries to pedestrians and cyclists are external. In crashes involving $n > 1$ vehicles, each vehicle is responsible for $1/n$ of the pedestrian/cyclist injuries, which are external, and $1/(n-1)$ of the injuries to other vehicle occupants. However, whether other occupant injuries are external is unclear; all else the same, one extra vehicle on the road raises the accident risk for other drivers, but if people drive slower or more carefully in heavier traffic, a given accident will be less severe. We assume 50% of other occupant injuries are external.

Traffic delay, property damage and miscellaneous costs (medical costs, emergency services, and legal/court costs) are divided equally among vehicles in the crash. We assume 100% of travel delay costs, 85% of miscellaneous costs (which are mainly covered by group insurance), and 75% of property damages are external.[36] We use estimates from NHTSA (2002b), Table A-1, to value quality of life costs, property damage, travel delay, and miscellaneous costs for different injury categories. Aggregate external costs per vehicle were converted to per mile costs using estimates of annual miles driven across vehicle types.[37]

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[34] This figure is for the costs of recurrent congestion. Non-recurrent congestion due to accidents is incorporated below; congestion from roadworks and bad weather is excluded.

[35] We use the FARS (Fatality Analysis Reporting System) data for all accidents involving a fatality and the GES (General Estimates System) data for all other accidents (both are collected by the National Highway Traffic Safety Administration). The GES data provides an extrapolation of national estimates based on a representative sample of police-reported crashes; following Miller et al. (1998), pp 18, we scale up non-fatal injuries by 12% and 9% for police and survivor under-reporting respectively. Both the FARS and GES provide information on the vehicles involved in each accident and driver characteristics. Injuries are classified according to the system in police reported data: fatality (K), disabling (A), evident (B), possible (C), property damage only (O), injured severity unknown (UI), unknown if injured (U).

[36] If insurance is truly lump sum and premiums do not change in response to accidents, then all property damage is external. In practice people pay deductibles, and premiums vary, albeit moderately, with previous crash record and stated annual mileage.

[37] Mileage shares for vehicle classes were obtained from the NPTS, weighting results from the 1995 and 2001 surveys by 1/3 and 2/3 respectively. Total mileage per vehicle class was obtained by multiplying these shares by

Overall, the mean external cost across all passenger vehicles is 4.39 cents per mile (Table 3). Pedestrian injuries account for 18% of costs, other driver injuries 37%, property damage 7%, travel delay 4%, and miscellaneous costs 34%. External costs (indicated by Method 1 in Table 3) are moderately higher than average for pickups and sub-compacts, and below average for minivans, mid-size cars and small SUVs. Thus, based on this approach of simply allocating traffic injuries to vehicles involved in crashes, there appears to be little correlation between vehicle weight/size on per mile external costs.

However, a potential problem with this method is that it does not control for a wide range of non-vehicle characteristics such as driver age, region, speed, prior crash record, alcohol use, gender, road class, weather, seatbelt use, etc. For example, above average external costs for small cars might be partly explained by their ownership concentration among young, inexperienced drivers, who have greater propensity to drink and drive, while below average external costs for minivans might be explained by their ownership concentration among (responsible) drivers with children. We are not aware of a fully comprehensive assessment of marginal external costs across a large number of vehicle classes that controls for this broad array of non-vehicle characteristics. The closest is a recent econometric study by White (2004) that estimates differences in external costs across cars as a group and light-trucks as group, using a fatalities for other road users as the measure of external cost. She finds that the probability of an automobile driver or passenger being killed in a two-vehicle crash is 61% higher if the other vehicle is a light truck than if it is another car; for a pedestrian the risk is 125% higher if hit by a light truck.

As an alternative way of assessing relative external costs across vehicles that takes these recent findings into account in a crude way, we simply assume a risk factor for light trucks as a group, relative to that for cars as a group. This relative risk factor is taken to be 1.8 (i.e. external costs per mile are 80% greater for light trucks). Keeping the mileage share-weighted sum of external costs per mile across all vehicles at 4.39 cents per mile, this yields marginal external costs for all cars of 3.28 cents per mile and 5.91 cents per mile for light trucks (see the last row of Table 3, Method 2).

H. External Costs from Oil Dependency. Most estimates focus on two main components. First is the "optimum tariff" component, determined by the inverse import supply elasticity; this depends on the US share of world oil consumption and how OPEC, and other oil exporting and importing regions, might respond to a change in US import. Second is the expected cost of economic disruptions during price shocks that the private sector may not fully anticipate or be insured against. These include added payments for imports and various adjustment costs (e.g., temporarily idled capital and labor); they are estimated using postulated probability distributions for price shocks or supply disruptions, estimated oil

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economy-wide annual passenger vehicle mileage, averaged over 1998-2000, of 2,471 billion (from www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2000.pdf).

price-GDP elasticities, and assumptions about how markets internalize oil price risks. Recent estimates for these two components combined vary between \$0 and \$14 per barrel, or 0 to 33 cents per gallon;[38] NRC (2002) adopted a value of 12 cents per gallon. We use a benchmark value of 16 cents, to make some adjustment for probable increases in the long run oil price since 2002.[39]

I. Government Parameters. The gasoline tax is 40 cents per gallon.[40] Initially, we assume $\mu = 1$; that is, all marginal spending is transfers, or the social value per \$1 of highway spending is \$1. The latter may not be unreasonable: Shirley and Winston (2004) estimate annual returns from highway investments at around 5%, our assumed social discount rate. If instead the rate of return on highway spending were say 0% or 20%, then μ = \$0.95 or \$1.14.

4. Results

A. Single-Vehicle Model

(i) Benchmark Results. Table 4 displays benchmark results from the single-vehicle model for an increase in fuel economy from the currently observed (first reference) level of 24 mpg, to 28 mpg.

With far-sighted consumers and no opportunity costs (initially point B in Figure 2) there would be a very substantial market-determined increase in fuel economy up to 35.6 mpg in the second reference scenario; hence a tightening of the standard up to 28 mpg is non-binding.

With opportunity costs (second column, Table 4), fuel economy would remain at 24 mpg in the absence of regulation (point A in Figure 2). A tightening of the standard by 4 mpg reduces discounted lifetime fuel consumption by 12.4 billion gallons, or 13.4%. This induced reduction in fuel demand causes a welfare loss of \$1.26 billion, given that the fuel tax (\$0.40 per gallon) exceeds combined external costs from carbon, oil dependency, and upstream emissions leakage by \$0.10 per gallon. Miles driven

[38] See the seven studies summarized in CEC (2003), Table 3.12. Leiby et al. (1997) is a particularly comprehensive assessment.

[39] Assuming the long run oil price has increased from around \$25 (at the time of the NRC study) to \$35 per barrel would add about 4 cents.

Middle East military expenditures have been quantified at around \$50 billion per year, or \$7 per barrel of oil (www-cta.ornl.gov/data/Download23.html, Table 1.9). Although these costs might apply to an estimate of *total* external costs, they are usually excluded from marginal costs because they are regarded as a fixed cost that would not fall following a moderate reduction in US oil consumption.

A further point is that although the potential market power of OPEC is substantial (e.g., Greene 1991b), this does not in itself add to any distortion between marginal consumer benefit and marginal supply cost in the US oil market, and therefore does not directly add to marginal external costs.

[40] 18 cents at the federal level and, on average, 22 cents at the state level (from dividing state tax receipts by gasoline sales using DOC 2000, Tables 1022 and 1174).

increases by "only" 0.7%; however the resulting welfare loss is still significant at $2.52 billion. The reason is that mileage-related externalities are relatively large in magnitude so even seemingly trivial changes in vehicle miles can have non-trivial welfare effects; at initial fuel economy, mileage-related externalities convert to $2.53 per gallon. There is a further welfare loss of $4.72 billion from the improvement in fuel economy itself, given that cost-effective technologies are ruled out by assumption in this scenario. In sum, welfare losses amount to $8.50 billion, or $0.68 per gallon of fuel saved.

In the myopic consumers/high discount rate case, higher fuel economy standards are again non-binding with no opportunity costs, as there is a market driven increase in fuel economy up to 31.2 mpg. And in the opportunity costs case, higher fuel economy standards still reduce welfare, by $2.47 billion; there is a modest net welfare gain from the increase in fuel economy, but this is more than offset by welfare losses from the reduction in gasoline and increase in mileage.

However the overall welfare effect reverses sign with myopic consumers/short horizons; net welfare gains are $4.65-$6.57 billion. With no opportunity costs (initially point D in Figure 2) fuel economy would increase to 25.9 mpg without regulation. Welfare losses from reduced gasoline and increased mileage are therefore smaller than when second reference fuel economy remains at 24 mpg; these losses are $0.60 and $2.09 billion respectively. However the increase in fuel economy itself now generates a welfare gain of $7.33 billion, given that the marginal social benefit from reducing fuel per mile exceeds the marginal vehicle cost. Paradoxically, welfare gains are larger with opportunity costs (initially point C in Figure 2); this is because fuel economy in the second reference scenario remains at 24.0 miles per gallon, implying higher standards are more effective. The gain from the increase in fuel economy ($10.79 billion) easily exceeds welfare losses from the gasoline reduction and increase in mileage ($1.24 and 2.98 billion, respectively).

(ii) Sensitivity Analysis. Table 5 shows what happens to total welfare effects as we vary a number of key parameters one at a time. We vary the gasoline price between $1.50 and 2.50 per gallon, the miles per vehicle elasticity between –0.05 and –0.25, the vehicle demand elasticity between 0 and –0.8, the social discount to 0.12, the marginal value of government spending between $0.80 and $1.20, fuel related external costs between 0 and $0.80 per gallon, and the intercept of the marginal cost of improving fuel economy by + and – 50%.[41]

The main qualitative findings in the benchmark simulations are robust to all these parameter variations. These findings are that with no opportunity costs, higher fuel economy standards have no effects in the far-sighted and myopic consumer/high discount rate scenarios; they only induce welfare

[41] In this last perturbation, the marginal cost of forgone quality is adjusted in the opportunity cost scenarios to keep total marginal costs the same.

gains in the myopic consumers/short horizons case, and even then gains are fairly moderate (between $0.4 and $5.3 billion). With opportunity costs, the higher fuel economy standard produces fairly large welfare losses with far-sighted consumers (between $2.3 to $12.2 billion) and with myopic consumers/high discount rates there is usually a modest net welfare loss. Only in the case of myopic consumers/short horizons is there a robust potential for a welfare gain, varying between $0.6 and $12.8 billion.

B. Multi-Vehicle Model.

Table 6 displays results for the multi-vehicle model for a 4-mpg increase in both car and light-truck standard (for method 1 of allocating accident costs). As expected from the analytical model, in scenarios with binding regulation, the price of relatively fuel inefficient vehicles within a class (large cars large pickups and large SUVs) increase, while prices for relatively fuel-efficient vehicles (subcompacts and small SUVs) fall. However, the change in gasoline consumption, and overall welfare effects, are close to those predicted by the single vehicle model in Table 4, implying that changes in external effects from fleet composition effects matter very little for overall welfare. This reflects the relatively modest differences in external costs across vehicles when all external costs (not just accident costs) are considered, and that most of the increase in fuel economy comes from technological changes to vehicles, rather than changes in fleet composition (using method 2 to calculate accident costs instead of method 2 has very little effect on the results).

Finally, in Table 7 we raise the light-truck standard by 6.8 mpg up to the current car standard of 27.5 mpg; the upper and lower halves of the table illustrate cases with and without trading of credits across cars and trucks. Qualitative results are similar to those above; welfare gains are positive if consumers have short horizons, but zero or negative when consumers are far-sighted or have excessive discount rates. Allowing for trading of fuel economy credits reduces welfare losses/increases welfare gains, but only by a relatively modest amount. Interestingly, welfare losses from the increase in mileage are less important for this policy (and are actually positive, though small, in one case); this is because the reduction in the vehicle stock (which offsets the increase in miles per vehicle) is greater when a disproportionate burden of regulatory costs are borne by trucks (the own-price elasticity for trucks is more than twice the size of that for the entire fleet).

5. Conclusion

Based on our best assessment of parameter values, it appears to be difficult to justify tightening car and light-truck fuel economy standards on externality grounds alone (see also Kleit 2004). Current fuel taxes exceed conventional estimates for combined fuel-related (marginal) external costs, and higher fuel economy causes mileage-related external costs to increase through the rebound effect. Higher fuel economy standards can be welfare improving, but only if consumers greatly undervalue fuel savings due to their having short horizons.

There are a variety of caveats to our analysis. It is easy to imagine future scenarios with higher (marginal) costs of oil dependency: a political takeover in Saudi Arabia (the swing producer) by elements hostile to the United States; heightened risks of terrorist attacks on oil infrastructure; greater abuse of market power as world oil production becomes more concentrated in the Persian Gulf; rapid growth in vehicle ownership in China and India adding to oil market pressures. On the other hand, market penetration of hybrid and alternative fuel vehicles, and enhanced supply from conventional oil finds or breakthroughs in converting oil-bearing formations (oil shales and tar sands), may lower future concern about oil dependency. Perceived costs of greenhouse gases may change with improved knowledge about the extent of global warming and the likelihood of abrupt, non-linear climate change. The costs of the rebound effect may increase if marginal congestion costs continue to rise, or fall as fuel costs diminish relative to driving time costs. All these uncertainties underscore the need for frequent updating of the analysis.

Allowing for increasing returns and strategic behavior among manufacturers could alter CAFE's impact on vehicle prices and sales, and would introduce a wedge between vehicle price and marginal production cost. It is unclear whether this would have a major impact however, given that welfare effects depend primarily on changes in fuel economy, gasoline, and miles driven, rather than changes in vehicle sales.

We ignore imperfections in the market for fuel economy innovations, caused by spillovers; nearly all empirical studies suggest social returns to R&D substantially exceed private returns, due to incomplete appropriability (e.g., Mansfield et al. 1977, Hall 1995). To the extent tightening CAFE would spur new innovation, without crowding out R&D elsewhere in the economy, it may induce a significant source of welfare gain that is excluded from our calculations.

Finally, we do not model the potential for CAFE to affect external accident costs through manufacturers reducing vehicle weight or size. However, the magnitude any resulting welfare effect is unclear: for example, a recent econometric assessment by Noland (2004) finds little relation between average fleet fuel economy and highway fatalities in recent years.

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Appendix A: Analytical Derivations

Deriving Equation (15)

Using (1), (4)-(9), and assuming binding regulation $g = \overline{g}$, the representative agent's indirect utility function, *V*(.), where fuel costs are correctly estimated, is defined by:

$$\text{(A1)} \quad V(\pi, \overline{g}, F, H, a_{EXT}, O, Z_M, Z_G) = MAX \quad u(D(v, m, H, q(g^{R1} - g)), \pi M, X)$$
$$- a_{INT} - a_{EXT} - O - Z_M - Z_G + \lambda\left\{I + F - X - v(p^{R1} + C(g^{R1} - \overline{g}) + p_G m\overline{g})\right\}$$

Partially differentiating (A1) gives:

$$\text{(A2)} \quad V_\pi = u_T M, \quad V_{\overline{g}} = \{\omega' u_X + \lambda v(C' - p_G m)\}v, \quad V_F = \lambda, \quad V_H = u_H,$$
$$V_{a_{EXT}} = V_O = V_{Z_M} = V_{Z_G} = -1$$

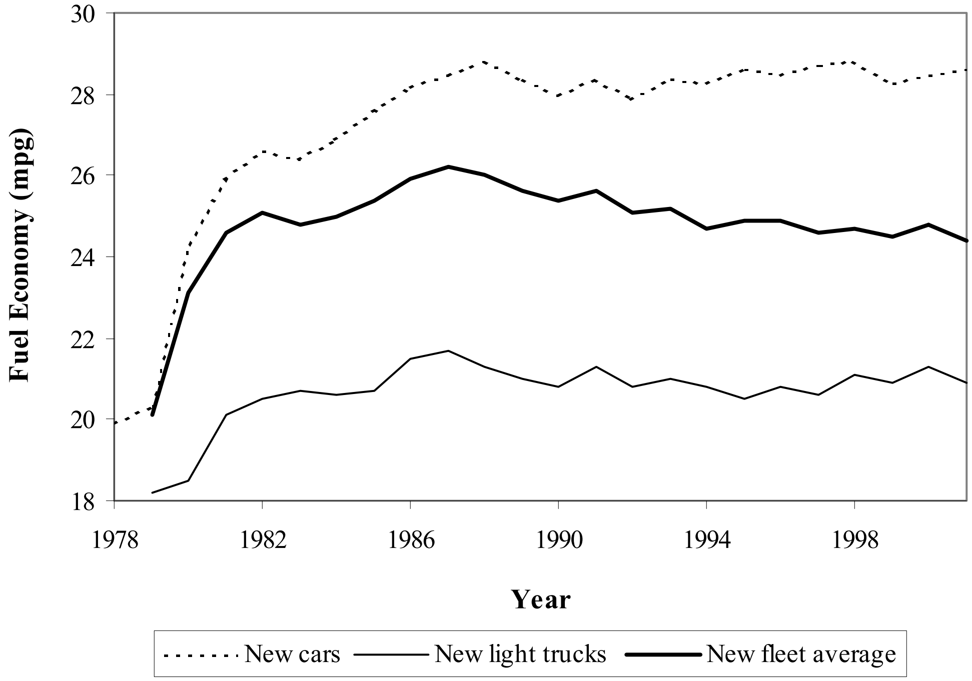
where we have used $\omega' u_X = u_Q m$. Totally differentiating the indirect utility function in (A1) with respect to $\overline{g}$, using (5)-(7) and (10) gives:

$$\text{(A3)} \quad \frac{dV}{d\overline{g}} = \left\{V_{Z_G} Z'_G + V_O O' + \left(V_F \frac{dF}{d(t_G G)} + V_H \frac{dH}{d(t_G G)}\right)t_G\right\}\frac{dG}{d\overline{g}}$$
$$+ \{V_\pi \pi' + V_{a_{EXT}} a'_{EXT} + V_{Z_M} Z'_M\}\frac{dM}{d\overline{g}} + V_{\overline{g}}$$

Equation (15) can be obtained from substituting (A2) into (A3), dividing by $\lambda = u_X$ to convert to money units, and using (15b).

Equation (15c) follows from (1c), (2), (12a), and (12b).

Figure 1. Fuel Economy Averages for Model Years 1978-2001



Source: NHTSA (2002a).

Figure 2. Equilibrium in the Second Reference Scenario

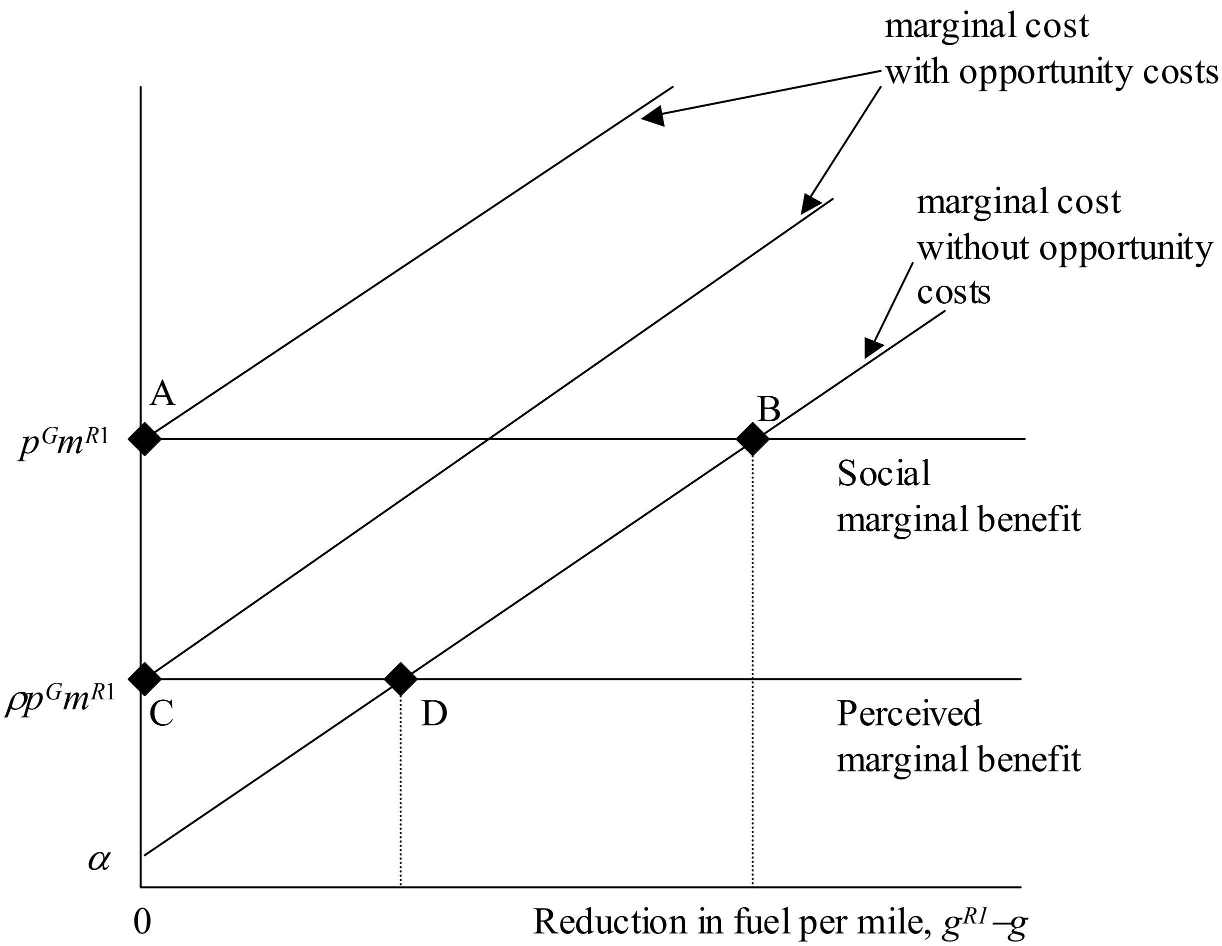
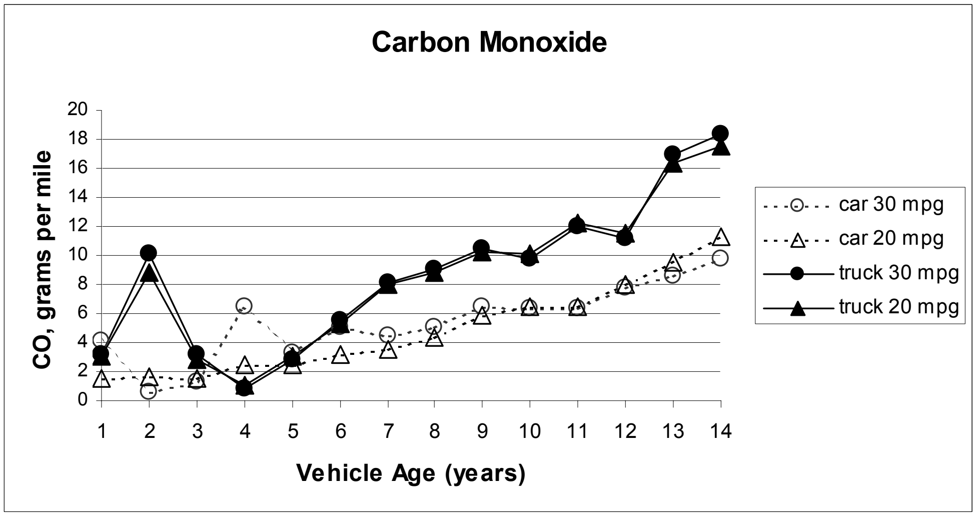
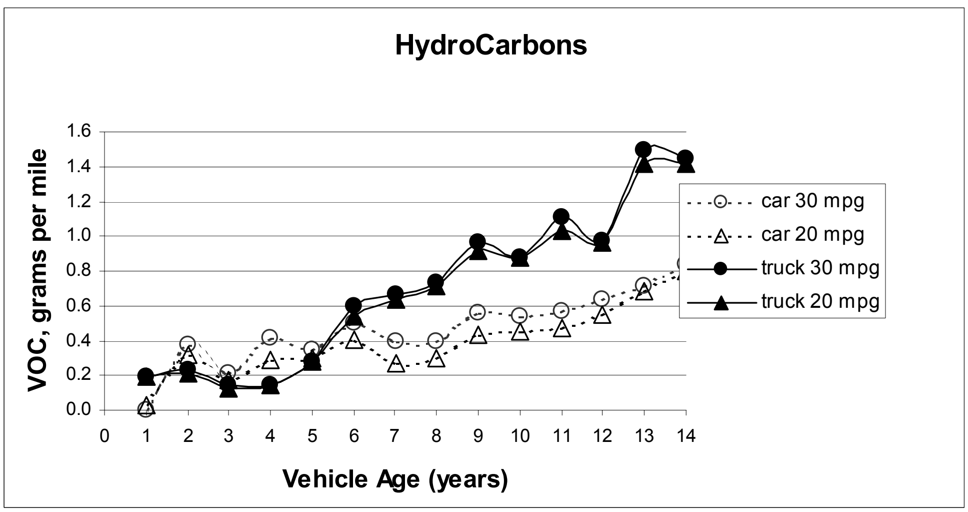


Figure 3. Fuel Economy and Emission Deterioration Rates





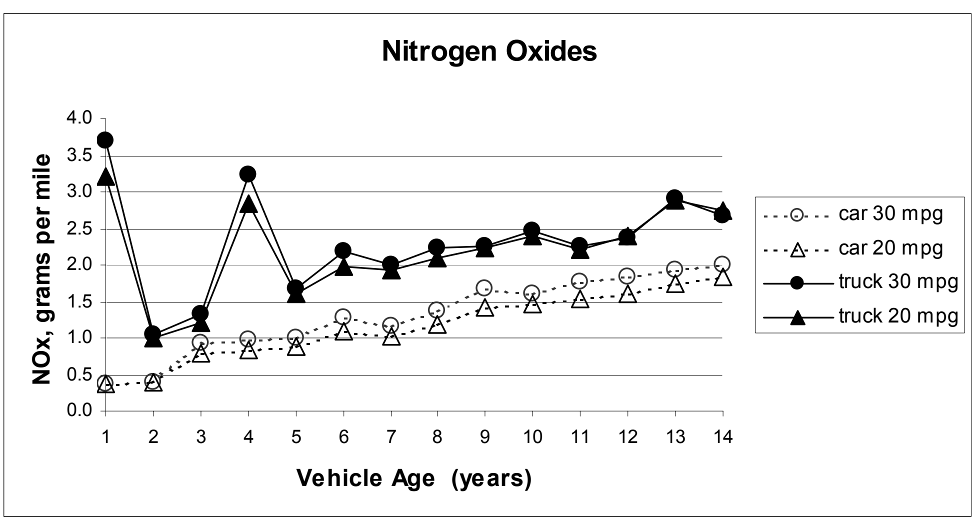


Figure 4. Sensitivity of Multiple-Vehicle Results

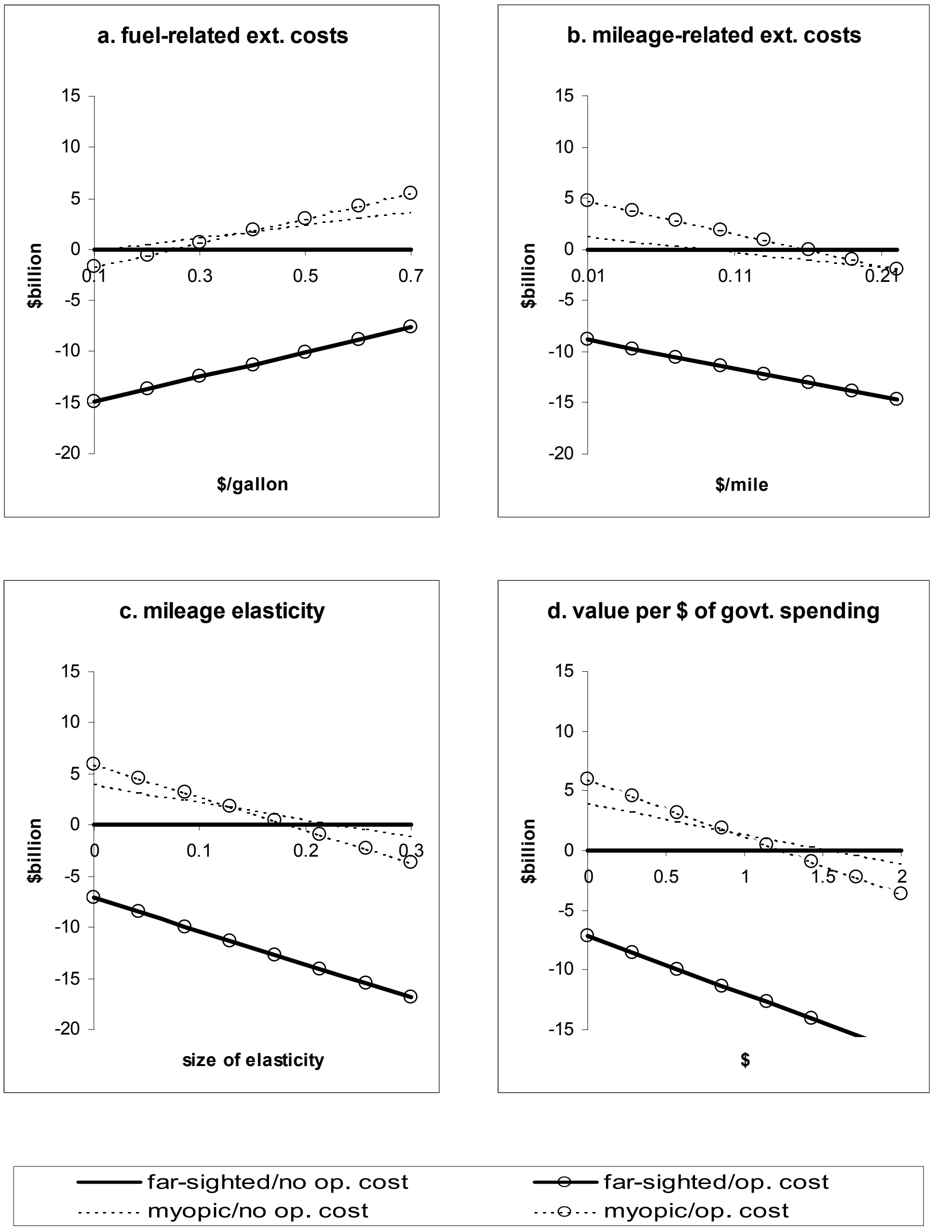


Table 1. Year 2000 Vehicle Data
(Representing the First Reference Scenario)

Vehicle class	Sales (thousands)	Initial price, $	Initial certified fuel economy		Actual lifetime fuel	fuel economy cost parameters	
			mpg	gal/100 miles	costs, $	α^i	β^i
cars							
subcompact	756	15,280	30.2	3.3	9,070	368	2,892
compact	2,650	15,647	29.1	3.4	9,412	310	2,789
midsize	3,205	21,907	26.2	3.8	10,454	81	2,638
large	748	25,266	23.9	4.2	11,460	641	1,569
total cars	7,359	19,314	27.4	3.6	9,989	250	2,610
light trucks							
small SUV	617	18,571	23.3	4.3	11,755	336	1,559
mid SUV	1,672	27,557	20.3	4.9	13,493	85	1,390
large SUV	834	34,051	16.6	6.0	16,500	174	818
small pickup	1,026	17,551	22.2	4.5	12,338	102	1,705
large pickup	2,121	23,362	22.4	4.5	12,228	201	936
minivan	1,200	24,490	17.9	5.6	15,302	243	1,563
total trucks	7,470	24,481	20.6	4.9	13,292	176	1,282
total cars and truck	14,829	21,917	24.0	4.2	11,418	213	1,941

Sources: NRC (2002) and authors' own calculations based on *Wards Automative Handbook 2001* and *Edmunds.com*.

Table 2. Vehicle Demand Elasticites

	sub-compact	compact	mid size	large	small SUV	mid SUV	large SUV	small pickup	large pickup	minivan
subcompact	**-2.18**	1.17	0.35	0.00	0.02	0.02	0.00	0.07	0.00	0.01
compact	0.27	**-2.07**	0.58	0.01	0.02	0.02	0.00	0.03	0.01	0.02
mid Size	0.12	0.80	**-1.88**	0.36	0.03	0.10	0.00	0.03	0.02	0.06
large	0.02	0.12	1.98	**-2.24**	0.00	0.10	0.00	0.01	0.02	0.10
small SUV	0.04	0.32	0.11	0.00	**-3.20**	0.11	0.00	0.08	0.02	0.02
mid SUV	0.04	0.24	0.45	0.07	0.17	**-2.58**	0.24	0.13	0.23	0.27
large SUV	0.01	0.03	0.16	0.06	0.02	1.09	**-1.88**	0.02	0.39	0.43
small pickup	0.04	0.14	0.12	0.00	0.04	0.09	0.00	**-2.55**	0.38	0.03
large pickup	0.01	0.04	0.07	0.01	0.02	0.08	0.05	0.32	**-1.40**	0.03
minivan	0.03	0.07	0.16	0.07	0.01	0.14	0.04	0.01	0.04	**-2.41**

Sources: Own estimation using GM and Harrington et al. (2003) models.

Table 3. External Accident Costs Across Vehicles
(cents per mile)

Cost component	cars				light trucks						
	sub-comp.	comp.	mid size	large	small SUV	mid SUV	large SUV	small pickup	large pickup	minivan	average
Quality of life costs											
Ped. & cycl. deaths	0.80	0.60	0.42	0.66	0.40	0.42	0.30	0.70	0.72	0.40	**0.56**
Ped. & cycl. injuries	0.40	0.25	0.19	0.24	0.14	0.30	0.07	0.17	0.16	0.13	**0.21**
Other vehicle deaths	0.71	0.68	0.55	0.84	0.74	0.90	0.53	1.15	1.71	0.56	**0.81**
Other vehicle injuries	1.23	0.98	0.71	0.94	0.60	0.88	0.42	0.98	0.96	0.56	**0.84**
Property damage	0.51	0.39	0.26	0.30	0.20	0.26	0.13	0.31	0.24	0.20	**0.29**
Traffic holdups	0.29	0.22	0.15	0.17	0.11	0.15	0.07	0.17	0.14	0.12	**0.17**
Other economic costs											
med., em. serv., legal, etc.	1.85	1.36	0.89	1.06	0.78	0.84	0.47	1.28	1.01	0.67	**1.07**
wages/household prod.	0.67	0.52	0.38	0.49	0.31	0.47	0.21	0.49	0.47	0.29	**0.44**
Total (cents/mile)											
Method 1	**6.46**	**5.00**	**3.56**	**4.71**	**3.27**	**4.23**	**2.21**	**5.25**	**5.41**	**2.93**	**4.39**
Method 2	**3.28**	**3.28**	**3.28**	**3.28**	**5.91**	**5.91**	**5.91**	**5.91**	**5.91**	**5.91**	**4.39**

Source: Own estimates compiled using crash data from the Fatality Analysis Reporting System and the General Estimates System; injury cost valuations from NHTSA (2002b); and mileage data from the National Personal Transportation Survey. Method 2 re-allocated external costs across cars and light trucks as a group in proportion to fatality risks to other road users estimated in White (2004).

Table 4. Benchmark Results for Single-Vehicle Model
(effect of 4 mpg increase in fuel economy standard)

	Far-sighted consumer		Myopic consumers high discount rate		Myopic consumers short horizons	
	No opp. costs	opp. costs	No opp. costs	opp. costs	No opp. costs	opp. costs
Certified fuel economy in second reference scenario						
gallons per 100 miles	2.8	4.2	3.2	4.2	3.9	4.2
miles per gallon	35.6	24.0	31.2	24.0	25.9	24.0
Change in gasoline from second ref. scenario						
billion gallons (discounted)	0	-12.4	0	-12.4	-5.9	-12.3
%	0	-13.4	0	-13.3	-6.8	-13.2
Change in total VMT (with reduced vehicle sales)						
billion (discounted)	0	20.3	0	21.8	16.8	24.1
%	0	1.1	0	1.1	0.9	1.3
Change in vehicle sales						
thousand	0	-127.5	0	-116.0	-17.3	-98.6
%	0	-0.9	0	-0.8	-0.1	-0.7
Components of welfare change, $billion (discounted)						
total	0	-8.50	0	-2.47	4.65	6.57
gasoline reduction	0	-1.26	0	-1.25	-0.60	-1.24
mileage increase	0	-2.52	0	-2.70	-2.09	-2.98
fuel economy	0	-4.72	0	1.48	7.33	10.79
Welfare change per gallon of fuel reduction, $	0	-0.68	0	-0.20	0.78	0.54

Table 5. Sensitivity Analysis for the Single-Vehicle Model
(welfare effect in $billion of 4 mpg increase in fuel economy standard, $billion)

	Far-sighted consumers		Myopic consumers high discount rate		Myopic consumers short horizons	
	No opp. costs	opp. costs	No opp. costs	opp. costs	No opp. costs	opp. costs
Benchmark results	0	-8.5	0	-2.5	3.2	6.6
Gasoline price						
$1.50 per gallon	0	-8.7	0	-3.6	4.6	2.7
$2.50 per gallon	0	-8.1	0	0.2	0.6	12.8
Miles per vehicle elasticity						
-0.05	0	-6.4	0	-0.3	6.1	8.9
-0.25	0	-12.0	0	-6.2	2.8	1.5
Demand for vehicles elasticity						
0	0	-10.5	0	-4.3	4.3	5.0
-0.8	0	-6.1	0	-0.3	5.1	8.4
Social discount rate						
0.12	0	-7.7	0	-3.2	4.3	3.6
Marginal value per $ of government spending						
0.80	0	-7.5	0	-1.5	5.3	7.6
1.20	0	-9.5	0	-3.5	4.3	5.6
Fuel-related external costs, $/gallon						
0	0	-12.2	0	-6.1	2.7	2.9
0.80	0	-2.3	0	3.7	7.8	12.7
Intercept of marginal fuel economy cost function						
reduced 50%	0	-8.5	0	-2.5	3.5	6.6
increased 50%	0	-8.5	0	-2.5	5.5	6.6

Table 6. Results from the Multi-Vehicle Model
(effect of 4 mpg increase in fuel economy standard)

	Far-sighted consumers		Myopic consumers high discount rate		Myopic consumers short horizons	
	No opp. costs	opp. costs	No opp. costs	opp. costs	No opp. costs	opp. costs
Change in certified miles per gallon						
subcompact	0	4.2	0	4.2	2.2	4.2
compact	0	4.0	0	4.0	2.1	4.0
midsize	0	3.6	0	3.6	1.9	3.6
large	0	5.2	0	5.2	2.5	5.2
small SUV	0	3.9	0	3.9	1.9	3.9
mid SUV	0	3.6	0	3.6	1.8	3.6
large SUV	0	4.4	0	4.4	2.3	4.4
small pickup	0	3.4	0	3.5	1.7	3.5
large pickup	0	4.3	0	4.3	2.2	4.3
minivan	0	3.6	0	3.6	1.8	3.6
Change in vehicle sales price, $						
subcompact	0	-76	0	-77	-93	-77
compact	0	66	0	66	-37	66
midsize	0	414	0	414	119	414
large	0	727	0	727	352	727
small SUV	0	-114	0	-115	-122	-115
mid SUV	0	272	0	272	46	272
large SUV	0	1005	0	1006	326	1005
small pickup	0	-55	0	-56	-89	-55
large pickup	0	736	0	737	220	737
minivan	0	26	0	26	-58	26
Change in vehicle sales, %						
subcompact	0	2.25	0	1.60	1.00	1.89
compact	0	0.14	0	0.15	0.54	0.15
midsize	0	-2.06	0	-1.54	-0.67	-1.77
large	0	-2.40	0	-1.87	-1.76	-2.12
small SUV	0	2.47	0	1.72	1.72	2.05
mid SUV	0	-0.12	0	-0.08	0.04	-0.10
large SUV	0	-2.66	0	-2.01	-1.05	-2.31
small pickup	0	2.34	0	1.65	1.36	1.95
large pickup	0	-3.98	0	-2.90	-1.18	-3.38
minivan	0	0.62	0	0.48	0.68	0.55
Change in gasoline, %	0.0	-13.7	0.0	-13.6	-7.2	-13.6
Components of welfare change, $billion (discounted)						
total	0	-8.6	0	-2.9	3.5	7.0
gasoline reduction	0	-1.3	0	-1.3	-0.7	-1.3
mileage increase	0	-2.6	0	-3.1	-2.2	-2.9
fuel economy	0	-4.7	0	1.6	6.5	11.2
Welfare change per gallon of fuel reduction, $	0	-0.65	0	-0.22	0.51	0.54

Table 7. Raising Light-Truck Standard to Car Standard

	Far-sighted consumers		Myopic consumers high discount rate		Myopic consumers short horizons	
	No opp. costs	opp. costs	No opp. costs	opp. costs	No opp. costs	opp. costs
No trading of fuel economy credits						
Change in gasoline, %	0	-14.3	0	-13.9	-4.5	-14.0
Components of welfare change, $million (discounted)						
total	0	-7.4	0	-2.5	2.5	7.2
gasoline reduction	0	-1.4	0	-1.3	-0.4	-1.4
mileage increase	0	0.3	0	-0.9	-1.2	-0.4
fuel economy	0	-6.3	0	-0.3	4.1	9.0
Welfare change per gallon of fuel reduction, $	0	-0.54	0	-0.19	0.58	0.53
With trading of fuel economy credits						
Change in gasoline, billion gallons (discounted)	0	-13.9	0	-13.6	-7.0	-13.7
Components of welfare change, $million (discounted)						
total	0	-6.3	0	-1.4	3.9	8.1
gasoline reduction	0	-1.3	0	-1.3	-0.7	-1.3
mileage increase	0	-0.8	0	-1.8	-1.4	-1.4
fuel economy	0	-4.2	0	1.7	6.0	10.8
Welfare change per gallon of fuel reduction, $	0	-0.47	0	-0.11	0.59	0.62