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Automobile Externalities and Policies

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RESOURCES
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Abstract

This paper reviews theoretical and empirical literature on the measurement of the major automobile externalities, namely local pollution, global pollution, oil dependence, traffic congestion and traffic accidents. It then dicusses the rationale for traditional policies to address these externalities, including fuel taxes, fuel economy standards, emissions standards and related policies. Finally, it discusses emerging, more finely-tuned policies, such as congestion pricing and pay-as-you-drive insurance, that have become feasible with advances in electronic metering technology.

Key Words: pollution, congestion, accidents, fuel tax, fuel economy standard, congestion pricing

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1. Introduction

Of all consumer products, few are taxed more heavily or regulated more extensively than automobiles. In the United States various taxes on vehicle ownership average about 18% (Harrington and McConnell, 2004), and state plus federal gasoline taxes average about $0.40 per gallon, or about 20% of 2004 retail prices. These tax rates dwarf those on almost any other consumer product (tobacco products are an exception), though they are still very low by international standards; gasoline taxes in the Netherlands, Germany, and United Kingdom exceed $3 per gallon (Figure 1). New vehicles are also subject to regulations governing local emissions, safety, and fuel economy, and in many states, mandatory purchase of liability insurance.

At the same time, few consumer products require a gigantic public infrastructure to be useful, an infrastructure on which Americans spend over $100 billion per year on maintenance and new construction (BTS 2004, Table 3-29a). Motor vehicles also cause over 40,000 accidental deaths and almost 3 million injuries each year (BTS 2004, Tables 2.1 and 2.2); no other consumer good approaches this figure. Queuing costs associated with using automobiles are also uniquely large: travel delays now cost the nation around $70 billion a year in lost time (Schrank and Lomax 2005). Furthermore, along with electricity generation, automobiles are a leading source of both greenhouse gas emissions and local air pollutants. And gasoline consumption is responsible for nearly half of the nation's dependence on oil, which is a major national security concern.

In short, the range and potential magnitude of externalities associated with automobile use are exceptional, and it is not surprising that they have attracted unprecedented attention from the regulator and taxman. What we may wonder is whether the current collection of policies could be improved upon, and perhaps even overhauled in favor of new, and more precisely targeted pricing instruments. For several reasons, it is a particularly good time for a thorough re-assessment of federal automobile policies.

First, there are heightened concerns about energy security with the recent tripling of world oil prices and continued instability in the Middle East. Second, there is growing pressure on the federal government to curb greenhouse gas emissions, in light of solidifying consensus

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among scientists that global warming is occurring, various state level initiatives to control carbon emissions, and the birth of carbon emissions trading in the European Union. Third, because of rising urban land costs and intense siting opposition, it is impossible to build enough road capacity to keep up with expanding vehicle use, with relentlessly increasing road congestion the inevitable result. Fourth, due to the steady erosion of real fuel tax revenues per vehicle mile of travel, there is a growing transportation funding gap, increasingly met at the state and local level by referenda tying, for example, sales tax increases to specific transportation projects. Finally, due to advances in electronic metering technology it is now feasible, at very low cost, to charge motorists on a per mile basis according to the marginal external costs of their driving. In fact in the United Kingdom, which has Western Europe's worst congestion and highest fuel taxes, the government is considering replacing fuel taxes with a nationwide system of per mile tolls on passenger vehicles that would vary across region and time of day according to the congestion on the road where the driving occurs.

The confluence of all these factors suggests that automobile policies in the United States could be on the verge of a dramatic shake-up. With this policy backdrop, estimates of external costs of motor vehicles have more than academic interest. The first part of this paper discusses literature on external costs, focusing mainly on local air pollution, global air pollution, oil dependency, congestion, and accidents. The second part discusses traditional policies, primarily fuel taxes and fuel economy standards, but also emissions standards and alternative fuel policies. And a third section discusses emerging pricing policies, including congestion pricing and pay-as-you-drive auto insurance. To keep our discussion focused we must omit a number of important but somewhat tangential issues, including automobile policies in Europe and developing countries, policies for heavy-duty trucks, infrastructure policy and the appropriate balance between highways and mass transit, and the interface between automobiles and urban development.

2. Automobile Externalities

Empirical literature on the external costs of passenger vehicles has been expanding rapidly since around 1990. Other discussions for the United States include Delucchi (2000), Lee (1993), US OTA (1994), Peirson et al. (1995), Porter (1999), Litman (2003), Rothengatter (2000), Parry and Small (2005), and various papers in Greene et al. (1997); for Europe see ECMT (1998) and Quinet (2004). Given the availability of these other reviews, our discussion is confined to distilling the main findings and remaining controversies in the literature.

2.1 Local Air Pollution

Our discussion focuses on gasoline-powered vehicles as they account for 95% of light-duty vehicle sales.[1] Gasoline-powered vehicles emit carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HC), otherwise referred to as volatile organic compounds (VOCs).

[1] This figure includes the 4% of flexible fuel vehicles that could operate on ethanol but typically use gasoline (see EIA 2005, Table 43). Diesel vehicles, which directly emit particulate matter, have in the past had difficulty in satisfying new-vehicle emissions standards; they account for just 4% of vehicle sales. Diesels are far more common in Europe, where they typically receive favorable tax treatment (see Figure 1).

CO reduces the flow of oxygen in the bloodstream and causes problems ranging from difficulty of breathing and inability to exercise to more serious cardiovascular effects (e.g., Morris and Naumova 1998, Peters et al. 2000). HC and NOx react in the atmosphere, in the presence of heat and sunlight, to produce ozone (the main component of urban smog); ozone impacts on pulmonary function in children, asthmatics, and exercising adults, as well as reducing visibility and agricultural productivity. But the most serious health effects are from total suspended particulates, either coarse particles (PM10) or fine particles (PM2.5), formed indirectly by chemical reactions in the atmosphere from emissions of sulfur dioxide, NOx, and HC; the fine particles are most problematic, as they are small enough to reach lung tissue. A number of studies find that exposure to particulates causes higher mortality rates (e.g., Dockery et al. 1993, Özkaynak and Thurston 1987, Schwartz 1994).

Nationwide vehicle emissions of all these pollutants have fallen dramatically since the Clean Air Act was enacted in 1970, despite relentless growth in vehicle-miles-traveled (see Figure 2 and below). According to EPA's MOBILE model, which contains emissions factors according to the type and vintage of vehicles in the on-road fleet, annual emissions are between 42% and 74% lower now than in 1970 (PM2.5 has declined 59% since measurement began in 1990). This is primarily a result of progressively more stringent emissions standards imposed on new passenger vehicles (see Section 3), as well as the gradual retirement of the oldest, most polluting vehicles on the road. The share of vehicle emissions in emissions from all stationary and mobile sources has also declined (EPA 2004); for example, vehicles accounted for almost 50% of total VOC emissions in 1970 but only 28% in 2003.

Perhaps counter-intuitively, recent evidence suggests that local emissions over the vehicle life are not much affected by the initial fuel economy of the vehicle (Fischer et al. 2005). This is because emissions standards, which must be met for each vehicle regardless of fuel economy, are defined in terms of grams per mile, rather than grams per gallon, and state-of-the-art technologies for meeting emissions standards are more durable over the vehicle life. Hence we define marginal external costs from pollution on a per-mile rather than per-gallon basis.

A few studies have estimated the marginal external costs for passenger vehicles; most find that damages are dominated by mortality effects, especially those from particulate emissions. To obtain an actual dollar value of these impacts requires several steps. First, changes in emissions must be translated into changes in ambient concentrations, which depend on climate, topography, wind patterns, and the like. Then the potentially exposed population must be estimated and epidemiological evidence used to establish the link between air quality and health risks, including information on the risks for different population sub-groups (seniors and children are most at risk); aggregate health effects are usually assumed proportional to ambient concentrations (Small and Kazimi 1995, pp. 15–16). All this information leads to an estimate of changes in the number of annual fatalities and acute health events caused by changes in air pollution. The final step is to monetize these outcomes using measures of the value of life and non-fatal illness.[2]

[2] An alternative, though less common, approach to estimating pollution costs is to measure how much people are willing to pay for pollution reductions based on differences in property values between regions with different air quality, holding household and other property characteristics constant (e.g., Chay and Greenstone 2005).

A widely cited study by Small and Kazimi (1995) estimates marginal air pollution costs from gasoline-powered vehicles, relying on many detailed studies of ozone formation, exposure analysis, and economic studies of willingness-to-pay (WTP) to reduce health risk.[3] Their projection for year 2000 was 2.3 cents per mile (see their Table 8 and updating to $2005), with approximate range of 1–8 cents per mile depending on different assumptions about health effects and the value of life. About half of the cost is from NOx emissions, primarily due to their role in the formation of particulates (CO effects are excluded as they are thought to be small). Although Small and Kazimi's estimates are for the Los Angeles area where meteorological conditions are especially favorable for pollution formation, the results are broadly consistent with those for other urban areas in a comprehensive analysis by McCubbin and Delucchi (1999). US Federal Highway Administration (2000) reviews several studies and concludes with a value of 2.2 cents per mile, with range 1.6–18.6 cents per mile (updated to $2005).

These nationwide average estimates mask considerable heterogeneity in per mile pollution costs not only across space but also driving conditions. For example, there is a U-shaped relation between emission rates per mile and vehicle speeds (NAS 1995); pollution increases with trip frequency for a given mileage since emission rates are higher for cold starts; and evaporative emissions (i.e. non-exhaust emissions that "leak out" from the vehicle in various ways) are greater on hot days.

In summary, while there is uncertainty surrounding marginal pollution damages, they are not insignificant in magnitude: Small and Kazimi's best estimate of 2.3 cents/mile is approximately 20% of average per-mile fuel costs.[4] And the upper range of their sensitivity analysis yields figures significantly higher. Nonetheless, as tighter emissions standards are phased in over coming years (see Section 3.3 below) and as the on-road vehicle fleet is gradually replaced, we expect local pollution costs to decline.

2.2 Global Air Pollution

Light-duty vehicles account for 20% of nationwide emissions of carbon dioxide, the leading greenhouse gas (Figure 3).

A number of studies have attempted the daunting challenge of monetizing the potential future damages from human-induced global warming (see reviews by Pearce 2005 and Tol 2005). Here we focus on a particularly thoughtful assessment by Nordhaus and Boyer (2000); Table 1 summarizes their total damage estimates, in terms of GDP losses for thirteen regions, for

[3] Three methods have been used to estimate WTP. Revealed preference studies look at compensating wage differentials for jobs with different levels of health risk (e.g., Viscusi, 1993, Viscusi and Aldy, 2003). Stated preference studies typically rely on contingent valuation whereby survey respondents provide information about hypothetical tradeoffs they are willing to make to reduce health risks (e.g., Mitchell and Carson 1989, Krupnick et al. 2002). A simpler but less rigorous method is to value illness by medical expenses and forgone wages incurred (e.g., ERS 2004). See Krupnick (2004) for a discussion of the pros and cons of each approach, and alternatives to WTP such as QALYS (quality-adjusted life years).

[4] Assuming fuel economy and gasoline prices of approximately 20 mpg and $2.40/gallon, respectively.

a warming of 2.5°C, which occurs around 2100 in their reference case analysis.[5] Aggregating over regions and the seven damage categories in the table, total damages amount to 1.50% of projected world GDP in 2100, or 1.88% if regional damages are weighted by current population rather than projected GDP.

More than half of the estimated total damages are from the willingness to pay to avoid the risk of catastrophic or abrupt climate changes, such as a melting of the West Antarctic Ice Sheet, or changes in the Gulf stream or thermohaline circulation system that currently warm Europe. Scientific understanding of such risks, let alone their monetary valuation by economists, is still in its infancy. Given there is presently no objective way of quantifying these risks, Nordhaus and Boyer obtained a highly subjective estimate using a survey of opinion among experts about the likelihood, at different levels of warming, of a catastrophe that would wipe out 25% of world GDP indefinitely, along with assumptions about society's degree of risk aversion.

Most of the other damage components are surprisingly modest in aggregate, and in some cases effects are beneficial, though this masks some adverse distributional impacts; for example, India and middle-income countries are most vulnerable to agricultural impacts and Africa to health effects. Agricultural impacts for different regions have been estimated from agronomic models relating crop yields to climate variables, with more recent studies allowing for farm-level adaptation to future climate change (e.g., altering crop mix, planting and harvesting dates). Health effects refer to the possible spread of tropical disease (e.g., malaria) to sub-tropical and temperate regions; Nordhaus and Boyer crudely valued them using data on the incidence of various diseases across regions with different climates, along with disease-specific estimates of disability adjusted life years (DALYs) lost.

As for other damage components, Nordhaus and Boyer value sea level rise by extrapolating US estimates of the costs of protecting valuable coastal areas, and the value of potentially inundated land, to other regions using an index of coastal area to total land area. Damages to immobile settlements (low-lying cities like Venice or countries like Bangladesh) or to ecosystems (e.g., species loss) were assessed using assumptions about the capital value of these assets (around 5–25% of regional output), and how much society might be willing to pay each year to preserve this value. Impacts on non-market time were obtained by extrapolating US estimates of how temperature affects the value of outdoor leisure activities. Finally, available evidence suggests that impacts on other non-farm market sectors that are climate sensitive (e.g., forestry, fishing, energy, construction) are modest.

Converting these total global damage estimates into a marginal damage from today's carbon emissions requires three further sets of assumptions. First is the functional form relating

[5] This is the long run warming projected for a doubling of atmospheric greenhouse gas concentrations over pre-industrial levels, and is roughly consistent with mid-range predictions from the International Panel on Climate Change (Nordhaus and Boyer 2000, Figure 3.7). Needless to say, these projections are subject to much uncertainty: for example, the impact of warming on cloud formation, and whether the resulting impact will be to compound or mitigate warming, is highly unsettled (IPCC 2001). Even the widely cited increase in average global surface temperature since 1970 of 0.5°C is subject to some uncertainty; for example, there is dispute over how much the temperature record should be adjusted for the urban heat island effect (that is, warming from heat absorption in new roads and buildings in expanding urban areas).

each damage component to different amounts of temperature change; typically, these are assumed convex. Second is how today's emissions affect the future path of warming over time, which depends on the expected atmospheric lifespan of carbon dioxide (around a century or more), and how long it takes global temperatures to adjust to their long run equilibrium following a change in atmospheric forcing (typically several decades, due to gradual heat diffusion processes in the oceans). Third is the social discount rate, equal to the pure rate of time preference for discounting utility, plus the product of the expected growth in per capita consumption and the elasticity of the marginal utility of consumption. The pure rate of time preference is contentious; based on market interest rates Nordhaus and Boyer assume it is currently 3% and declining gradually over time (their assumed social discount rate is 4–5%). Others have argued, on philosophical grounds, for using a lower, or even zero, rate of time preference in this context (see certain chapters in Portney and Weyant 1999).

Overall, Nordhaus and Boyer (1999) estimate marginal damages are around $15 per ton of carbon (in $2005), though rising over time. Other reviews of the literature, for example Pearce (2005) and a meta-analysis by Tol (2005), suggests marginal damages of below $50 per ton.[6] Damages of $15–$50 per ton of carbon are equivalent to 4–12 cents per gallon of gasoline. This surprisingly small number is due to the relatively low carbon content of gasoline; in contrast, these damages are equivalent to around $11–38 per ton of coal, or 40–140% of the 2004 coal price paid by electric utilities.[7] Along with greater possibilities for carbon fuel substitution, this explains why energy models (e.g., EIA 1998, Table 2) project that proportionate emissions reductions in electricity generation under an economy-wide carbon tax will be several times the proportionate reductions in transportation emissions.

Nonetheless, as Nordhaus and Boyer repeatedly emphasize, many of the potentially critical impacts of climate change have only been quantified in a very primitive way at best, and there is a worrying lack of impact studies for regions other than the United States that are more vulnerable to climate change. Combined with scientific uncertainties, disputes over discount rates, distributional issues, the difficulty of forecasting adaptive technologies decades from now, and of course the risk of catastrophic climate change, it is not surprising that damage estimates remain highly contentious.[8]

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[6] Pearce adjusts marginal damages upwards to account for two additional factors. First is (mean-preserving) uncertainty over future discount rates, which reduces the expected value of the discount-*factor* applied to future damages (Newell and Pizer 2003a). Second is the incorporation of differing social welfare weights (with plausible values) applied to rich and poor nations.

[7] On average a ton of coal and a gallon of gasoline contain 0.746 and 0.0024 tons of carbon (see http://bioenergy.ornl.gov/papers/misc/energy_conv.html). Coal prices are from www.eia.doe.gov.

[8] Compare, for example, Schneider (2004) with simulations by Link and Tol (2004) and Nicholls et al. (2005) suggesting that certain "catastrophes" are not as catastrophic as commonly supposed.

2.3 Oil Dependency

US oil imports increased from 27% of domestic consumption in 1985 to 56% in 2003, and are projected to grow to 68% by 2025 (EIA 2005, Figure 95);[9] gasoline is the single most important source of oil dependency, accounting for 44% of total petroleum products (EIA 2005, Figure 99). Growing dependence on foreign suppliers is not a problem in and of itself, if it is less costly to meet additional oil needs through overseas purchases rather than producing extra oil at home. Concerns about oil dependency revolve around market power issues, the economy's vulnerability to energy price shocks, and the compromising of US national security and foreign policy interests.

2.3.1 Externality Measurement. Economists have focused on two main components of the marginal external costs of oil dependence.

First is the "optimum tariff", familiar from trade theory, due to monopsony power from US importers as a group in the world oil market. Individual importers do not account for their effect on infinitesimally bidding up the world oil price, thereby raising costs for all other domestic importers, and enacting a transfer from the domestic economy to foreign suppliers; given the large volume of imports in the United States, this "externality" can be significant. Obligations under the World Trade Organization likely preclude any internalization of the externality through an oil import tariff; thus, in principle it is legitimate to include it in computing an optimal tax on oil consumption.[10]

The optimum tariff is given by the inverse elasticity rule, or the world oil price divided by the price elasticity of US imports, evaluated at the optimum import level (Leiby et al. 1997, pp. 26). This elasticity depends on the share of US imports in world oil consumption (about a quarter), and assumptions about how OPEC, and other oil exporting and importing regions, would respond to a change in US oil imports over the long term. Leiby et al. (1997) pp. 63 puts the US import elasticity at around 5-20, depending on different assumptions about long run world demand and supply elasticities. At current oil prices of $60 per barrel, this would imply a marginal external cost of around $3–10 per barrel (7.2 to 28.6 cents per gallon of gasoline).[11]

The second source of externality comes from expected macroeconomic disruption costs caused by short-term oil price volatility about a given long-term trend. We would expect there to

[9] Currently just under half of imports come from OPEC countries, of which half come from the Persian Gulf; however dependence on Persian Gulf oil is expected to increase in the future as around 60% of the world's known oil reserves are located there, compared with around 2% in the United States (see www.eia.doe.gov/emeu/international/reserves.html).

[10] This assumes (in contrast to our discussion of climate damages) that we are viewing welfare from a US, rather than global, perspective. It also depends on the assumption that changes in domestic oil demand are met, at the margin, by changes in imports; however, this is reasonable given that the oil import supply curve is flat relative to the domestic oil supply curve.

[11] Note that the optimal tariff does not directly address the possibly large losses in global welfare from non-competitive pricing by OPEC producers (e.g., Greene and Ahmad 2005). This is because non-competitive pricing by them does not drive a wedge between the domestic US oil demand curve and import supply curve; thus it does not drive a wedge between the social and private cost per extra barrel of imported oil to the United States.

be positive net costs to price volatility because of adjustment costs incurred when prices rise or fall (Hamilton 1988). These reflect costs of temporarily idled labor or capital as various industries (e.g., airlines, petrochemicals, fertilizers) contract in response to price shocks, costs of retraining labor or refurbishing plants, inefficiencies associated with sunk investment decisions that are no longer optimal at ex post prices etc.

There is an established negative correlation between oil price volatility and GDP, suggesting the presence of such adjustment costs.[12] However, to what extent these expected adjustment costs might be taken into account by the private sector is much disputed. According to one view, the private sector should mostly account for the risks of future price shocks in futures markets, inventory strategy, the allocation of capital and labor across energy-intensive and non-energy-intensive industries, etc. (e.g., Bohi and Toman 1996). But another view is that markets do not adequately insure against energy price risks. For example, consumers may undervalue future fuel saving costs when choosing among vehicles with different fuel economy (see below); market rigidities such as fixed wage contracts may inhibit efficient resource re-allocations in response to price changes; and the pass-through of added input costs from higher energy prices may compound distortions from non-competitive pricing (e.g., Rotenberg and Woodford 1996).

A particularly comprehensive assessment by Leiby et al. (1997) put the marginal external cost from the risk of oil price shocks at \$0–8.3 per barrel (for 1993, updated to \$2003). They assume that the elasticity of GNP with respect to oil prices is between –0.025 and –0.060[13] and that the private sector internalizes 25–100% of the risk of price shocks under different hypothesized probability distributions for future oil supply disruptions. Combining this estimate with the above optimum tariff yields an overall marginal external cost of around \$3–18 per barrel, or 6.8–40.1 cents per gallon of gasoline (other recent reviews, by NRC 2002 and CEC 2003, reach broadly similar conclusions).

However it is unclear how much confidence we can have, even within this fairly wide range of estimates. The projected future oil price trajectory, and the distribution of short-term prices about the trend, is sensitive to a number of uncertain factors. These include growth in vehicle ownership in China and India, the extent of oil capacity expansions in OPEC countries, enhanced supply from conventional oil finds, and possible breakthroughs in converting oil-bearing formations, such as the enormous oil shale reserves in the western United States and the Canadian tar sands. Moreover, the risk of terrorist attacks on oil supply infrastructure, or policy

[12] Without adjustment costs, the costs of price increases, indicated by the loss of consumer surplus under the oil import demand curve, should be approximately offset by the gains in consumer surplus from price reductions (at least if demand is inelastic in the short term). Most of the empirical research has focused on documenting the asymmetry rather than exploring underlying causes of it (see reviews by Brown and Yücel 2002 and Jones et al. 2004). However recent studies by Hamilton and Herrera (2004) and Balke et al. (2002) reject earlier hypotheses that destabilizing monetary policy occurring at the same time as price shocks explains the observed GDP/oil price correlation.

[13] Recent studies are closer to the latter figure, even though the oil intensity of GDP, and the responsiveness of natural gas prices to oil prices, has declined over time (see Jones et al. 2004).

change in Saudi Arabia (the swing oil producer), cannot be objectively incorporated into the assumed distribution of future price shocks.

2.3.2. Broader Costs of Oil Dependency. In principle, some portion of Middle East military expenditures constitutes part of the total external cost of oil dependency. However, it is difficult to pin down a cost estimate because the Department of Defense does not divide its budget into regional defense sectors, and even if it did it is difficult to disentangle spending for defense of Persian Gulf oil supplies from spending on other objectives, such as promoting regional stability, democracy and development.[14] However, analysts usually exclude military spending from computations of the *marginal* external costs of oil consumption, as they are typically viewed as a fixed cost rather than a cost that would vary in proportion to (moderate) changes in US oil imports.

A further concern about oil dependence is that revenue flows to non-democratic governments, or possibly terrorist groups, may undermine US foreign policy and national security interests. For example, oil revenues may help to fund insurgents in Iraq; or they may embolden Russia to limit democratic freedoms and Iran to pursue nuclear weapons capability, as the revenue makes these countries less vulnerable to the threat of western sanctions. These geo-political costs would be especially challenging to quantify; however, it should be remembered that the United States only has a very limited ability to reduce these costs through domestic conservation measures to lower the world price of oil.[15]

2.4 Traffic Congestion

Between 1980 and 2003 total vehicle miles traveled (VMT) in urban areas in the United States increased by 111%, against an increase in urban lane-miles of only 51% (BTS 2004, Tables 1-6 and 1-33), with reduced average speeds on roadways, especially during rush hours, the inevitable result. Annual congestion delays experienced by the average peak-period driver increased from 16 to 47 hours during this period while at a national level traffic congestion caused 3.7 billion hours of delay by 2003 and wasted 2.3 billion gallons of motor fuel; congestion now costs the nation an estimated $63 billion compared with $12.5 billion twenty years ago (in 2003$).[16]

[14] Prior to the second Iraq war, oil-related military expenditures were put at anything from $1 to $60 billion per year, or $0.1 to $8.2 per barrel of oil consumption (see Delucchi and Murphy 1996 and www-cta.ornl.gov/data/Download23.html, Table 1.9).

[15] For example, based on the above range for the oil import supply elasticity, a 10% reduction in US oil imports would reduce world oil prices by 0.5–2%, or $0.3–1.2 per barrel at an oil price of $60 per barrel. This counts for something, but is tiny when set against the recent tripling of oil prices.

[16] All these estimates are from Schrank and Lomax (2005), based on a panel of 89 urban areas. Hours of delay are measured by comparing observed travel times and what travel times would be under free flow conditions. Year-to year changes are primarily computed from changes in the ratios of reported traffic per unit of time to lane mile capacity for various road classes, applied to a base-case estimate of congestion in each urban area.

Not all observers are alarmed by these trends;[17] however, traffic congestion is still an uncompensated externality though (along with traffic accidents) somewhat unusual in that the perpetrators and the victims are the same group. When choosing whether to enter a congested roadway, a motorist weighs the benefit of the trip versus the cost, including the private time cost, but not their effect on adding to congestion and lowering travel speeds for other road users. Quantifying the resulting externality requires using engineering models of roadway crowding to generate the average and marginal social costs of travel, and then combining these with a travel demand curve (Walters 1961).

The principal measure of crowding is vehicle density or vehicles per lane mile that, in aggregate, is the result of the autonomous travel decisions of all motorists choosing, within limits, their speed and following distance to the next vehicle. Figure 4 illustrates the relation between vehicle density and average speed, “headway”, and vehicle flow, for sections of the Washington DC Beltway.[18] Speed declines from 65 to 10 miles per hour as vehicle density rises from 30 to 115 vehicles per lane mile. Headway, which is the average time between vehicles, is very flat at 1.4 to 1.5 seconds between about 35 and 80 vehicles per mile, suggesting that as density increases, speed declines to keep headway constant, at a level very close to that taught in driver training (approximately one car length per 10 mph of speed). At very high densities headway creeps up; driving is now stop-and-go and is no longer describable by a simple spacing heuristic.

While average vehicle speed is the most important performance measure for the individual motorist, a better measure of roadway productivity is vehicle flow, which equals speed times density. In Figure 4, vehicle flow peaks at about 2,200 VMT per lane-mile per hour when density is about 40 vehicles per mile and average speed is about 50 mph. The speed-flow relation, shown in Figure 5, becomes backward bending—a condition called “hypercongestion”—at the peak flow, so any given flow is consistent with two speeds. For example, a flow of 1,500 VMT per lane-mile per hour is consistent with speeds of both 17 and 65 mph; both these situations are equally productive in terms of vehicle throughput but the former, which is most likely at the peak of the rush hour, involves much greater time costs.

Walters (1961) used the speed-flow curve to plot vehicle flow against the average cost per vehicle mile, which is the sum of vehicle operating costs and the product of time per mile (the reciprocal of speed) and the value of time, usually assumed to be around 50% of the wage (Small 1992b, pp. 36-46). Inevitably, as shown in Figure 6, the average cost curve is backward-bending above the peak flow and therefore subject to the usual pathologies of multiple and unstable equilibria. As Button (2004) notes, however, the hypercongested portion of this curve is

[17] For example Downs (2004) argues that congestion is simply the price we pay for living in urban areas and insisting on traveling when everyone else is traveling. Gordon and Richardson (1994) emphasize compensating behavior, such as households moving closer to work and employers relocating to the suburbs and rural areas; in fact the average commute time, 26 minutes in 2000, is only a few minutes greater than in 1960, and part of this increase is due to a definitional change (US FHWA 1994 and US Bureau of the Census 2000).

[18] This figure was obtained from fitting aerial survey data (TPB 1999) to the Van Aerde speed-density-flow model (Rakha and Crowther 2002). Analysis by Van Aerde and Rakha (1995) and Rakha and Crowther (2002) of expressways in Toronto give similar results to those for Washington discussed below.

usually ignored in speed-flow analysis and the upward-sloping portion can be differentiated to produce the marginal social cost curve shown in Figure 6; near capacity, the marginal social cost becomes very steep, increasing from 3 to nearly 60 cents per mile as flow increases from 1,200 to 2,000 vehicles per hour. Equilibrium would be where the demand for travel intersects the average cost, at which point the gap between the marginal and average cost is the marginal external cost; clearly, the marginal external cost is large relative to private cost borne by the individual motorist as the peak flow is approached.

A number of studies estimate congestion costs for individual roads or cities, but few attempt an average over a nation. One exception, based on speed-flow curves, is US FHWA (1997, 2000) who weight marginal external costs for representative urban and rural roads, at different times of day, by the respective mileage shares; their middle estimate of "averaged" marginal external cost is 5 cents per passenger vehicle mile. However this figure should be viewed with caution for several reasons.

First, if this figure is to be used for estimating optimized fuel prices it should be adjusted to account for the much weaker sensitivity of peak-period driving (which is dominated by commuting) to fuel prices compared with off-peak or rural driving; hence Parry and Small (2005) used a value of 3.5 cents for the congestion benefit per mile reduced through higher fuel taxes. Second, the estimate captures recurrent travel delays but not holdups due to roadwork, inclement weather or traffic accidents (however our discussion of accident costs below accounts for congestion effects).

Third is that using a speed-flow approach for the whole road segment does not account for congestion at intersections or other bottlenecks. And fourth, the estimate ignores the troublesome issue of hypercongestion by aggregating over the whole peak period, rather than dividing it up into short periods of time; marginal external costs are not well defined under hypercongestion. The last two points are closely related. Hypercongestion occurs in response to a temporary spike in demand for road use, which causes the inflow of vehicles to exceed the outflow; in other words, there is a bottleneck, and this clears over time as demand falls from its peak level (Small and Chu, 2003). Thus the bottleneck model of congestion, developed by Vickrey (1969) and extended by Arnott et al. (1993, 1994) and Arnott and Kraus (1995), provides an alternative framework for understanding the determinants of congestion, though it is difficult to implement empirically when drivers differ in their willingness to re-schedule trips.[19]

2.5 Traffic Accidents

Total annual fatalities on American roads have hovered around 40,000 since 1960; however, there has been a dramatic decline in fatality rates, from 5.1 per 100 million miles of travel in 1960 to 1.5 in 2003 (BTS 2004, Tables 2–17). This declining trend reflects a number of

[19] The bottleneck framework also clarified that the costs of congestion are broader than just the pure delay costs as they also include the costs of compensating behavior to avoid congestion, including re-scheduling and driving early to reduce the risk of missing appointments given uncertainty over traffic conditions. To some extent however, these types of costs may be implicit in revealed preference estimates of people's willingness to pay to avoid congested roads. More broadly, motorists also avoid congestion through housing and employment re-location though, through the envelope theorem, these demand substitution effects do not affect social welfare in the absence of other distortions.

factors, including greater seatbelt use, improved vehicle technology, reduced drunk driving, and reduced pedestrian deaths as fewer people are inclined to walk.[20]

2.5.1. Social Costs of Traffic Accidents. A number of studies have estimated the total social costs of traffic accidents (e.g., Miller 1993); Table 2 puts together an estimate (for all motor vehicles) for year 2000 based on US NTHSA (2002), Tables 3 and A-1. Total costs are quite substantial at $433.5 billion or 4.3% of GDP; this is equivalent to an average social cost of 15.8 cents per vehicle mile.

Accidents involving fatalities account for one-third of total costs in Table 2; accidents with non-fatal injuries, classified according to the Maximum Abbreviated Injury Scale (MAIS) and property damage only, account for the other two-thirds.[21] For each injury classification, Table 2 shows recent estimates of various social costs allocated to each injury, based on averaging across all accidents involving that injury. These include quality-adjusted life years (QALYs), property damage, travel delay, medical costs, lost productivity, etc.; total costs per injury vary from $2,532 for property damage only crashes to $3.4 million per fatality.[22]

2.5.2. Marginal Accident Externality. While most transportation economists may agree, in principle, on how the total social costs of traffic accidents can be measured, assessing marginal costs is far more troublesome (e.g., Small and Verhoef 2005, Ch. 3).[23] A standard assumption is that the injury risk associated with an individual's own driving will be internalized; the main difficulty lies in assessing whether that driving imposes an externality on other road users.

[20] According to US NTHSA (2002), Table 21, lives lost due to non-use of seatbelts fell from 13,301 in 1975 to 9,238 in 2000. Airbags were estimated to save 2,488 lives in 2003, compared with 536 in 1995, child restraints 446 lives in 2003 compared with 408 in 1995, and fatalities in accidents involving alcohol fell from 23,167 in 1985 to 17,013 in 2003 (BTS 2004, Tables 2-25 and 2-30). Pedestrian death rates fell from 1.01 to 0.17 for each 100 miles of vehicle travel between 1960 and 2003. Data on non-fatal injuries is available from 1990, and show a similar trend to that for fatalities; non-fatal injuries per mile declined 33.7% between 1990 and 2003 while fatalities per mile declined 28.6% (BTS 2004, Table 2.17).

[21] Data on highway fatalities is far more reliable than for non-fatalities. The Fatality Analysis Reporting System (FARS) provides data on all crashes that involve a fatality. In contrast, the General Estimates System (GES) provides data for fatal and non-fatal injuries based on extrapolating from a sample of police-reported crashes; moreover, the injury classification is designed for use by police officers who may not even see or speak to victims, let alone obtain a proper medical diagnosis. Another data source, the Crash Worthiness Data System (CDS), provides more accurate injury information, but for a limited set of accidents that excludes crashes where no vehicles are towed. Cost estimates underlying Table 2 are based on studies that map the two data sources, making some adjustment for underreporting.

[22] For details on methods for measuring all these cost components see, for example, US NHTSA (2002) and Miller (1993, 1997). An alternative to using QALYs is measuring people's willingness to pay for reductions in injury risks, typically measured by wage premiums paid for risky jobs. Recent meta-analyses by Mrozek and Taylor (2002) put the value of a statistical life (VSL) at $1.57–2.5 million (1998 dollars), while another meta-analysis by Viscusi and Aldy (2003) puts the VSL at $5.5–7.6 million (2000 dollars). For comparison, the VSL can be implied from Table 2 by combining the QALY and the market and non-market productivity effects, which gives $3.2 million.

[23] Theoretical foundations for measuring accident externalities were developed by Vickrey (1968), Newberry (1988), Jones-Lee (1990), and Jansson (1994).

All else the same, extra mileage by one motorist raises the likelihood that other vehicles will be involved in a collision, as other vehicle have less road space. However, if people compensate by driving slower or more carefully with extra vehicles on the road, the average severity of a given accident will be reduced. In theory, the severity-adjusted risk elasticity for other drivers with respect to additional traffic might even be negative, implying a positive rather than negative externality! Empirical evidence on this critical issue is limited and conflicting.[24] Given this ambiguity, some recent studies (e.g., Mayeres et al. 1996, US FHWA 1997) adopt central cases where the externality imposed on other drivers is assumed to be zero.

Aside from the inter-driver issue, studies typically include pedestrian and cyclist injuries in computing marginal external costs (these account for about 13% of fatalities attributed to passenger vehicles). A portion of property damage (at least for single-vehicle accidents which account for about half of vehicle occupant injuries) are also external given that premiums are primarily levied on a lump sum rather than variable (per mile) basis; for the same reason, a portion of medical cost is also external. Productivity effects are internal for own-driver injury risks but not for pedestrians. Recent studies using this general approach put the marginal external costs for the United States at around 2 to 7 cents per mile (US FHWA 1997, Miller et al. 1998, Parry 2004). This range is about 13–44% of the average social cost per vehicle mile, which is broadly consistent with European studies (e.g., Lindberg 2001, Mayeres et al. 1996).

2.5.3. Safety across Vehicle Types. A further important, though unsettled, issue is the relation between vehicle size/weight and safety; this matters both for policies that cause downweighting of some vehicles and/or a change in the fleet composition, particularly between cars and light trucks.

In general we might expect lighter vehicles to be less safe for their occupants (as less of the energy in a crash is absorbed by the vehicle and more is transferred to its occupants) but more safe for other road users. However, one complication is that drivers of lighter vehicles may feel more at risk and drive more carefully, resulting in a lower crash frequency. Injury risk also depends on fleet composition; all else the same, light trucks (sport utility vehicles, minivans, and pickups) do more damage to other car occupants and pedestrians than car drivers do, as trucks have stiffer frames (and therefore transfer more energy to other vehicles and individuals) and are taller implying a higher likelihood of hitting the upper body or head of other road users.

Most of the empirical literature on this issue has focused on the relation between vehicle size/weight and total highway fatalities or injuries (e.g., Crandall and Graham 1989, Khazzoom 1997, Kahane 1997, Coate and VanderHoff 2001, Noland 2004). But for our purposes, we are

[24] There are no estimates of the elasticity of severity-adjusted accident risk with respect to traffic volume that use a comprehensive notion of accident cost. Some studies focus on the risk elasticity unadjusted for accident severity; according to Lindberg (2001) pp. 406–407 the unadjusted elasticity is zero for inter-urban roads and urban links, though positive at intersections. Edlin and Karaca-Mandic (2003), using panel data on state-average insurance premiums and claims, find that an additional driver can substantially increase insurance costs for other drivers, particularly in urban areas. However, insurance costs are far from a comprehensive measure as they mainly reflect only property damage that, according to the last column of Table 2, account for only 14% of the total social costs. Edlin and Karaca-Mandic also find that fatality rates increase with traffic density in urban areas but the opposite in non-urban areas, though their results are not statistically significant.

interested in how (marginal) external costs differ across vehicle types; external costs are quite different from total injuries as they exclude own-driver injury risks, but include property damage, travel delay, and other costs listed in Table 2.

Surprisingly, studies that allocate injuries from crash data to different vehicle types involved in crashes, and quantify costs using components in Table 2, find only modest differences in external costs per mile driven between cars and light trucks (US FHWA 1997, Miller et al. 1998, Parry 2004). However a potential problem with these studies is that they only control for, at most, a very limited number of non-vehicle characteristics, such as driver age and region; ideally, one would also control for speed, negligence, gender, road class, weather, seatbelt use, etc. Although they do not provide a comprehensive measure of external costs per mile, econometric studies by White (2004) and Gayer (2004) that control for a much broader range of non-vehicle characteristics, find that injury risks to other road users are substantially higher for light trucks than for cars. For example White finds that the probability of a vehicle occupant being killed in a two-vehicle crash is 61% higher if the other vehicle is a light truck than if it is a car.

2.6 Summary of external costs

Table 3 provides a summary of "best available" estimates of external costs based on the above discussion. Given the popular focus on the need to reduce US gasoline consumption because of energy security and climate change it is striking that these externalities are small in magnitude relative to externalities that are proportional to vehicle miles. Combined external costs from traffic congestion, accidents, and local pollution are 8.8 cents per mile, or $1.76 per gallon at current on-road fuel economy of 20 miles per gallon;[25] this is nearly an order of magnitude greater than combined costs from carbon emissions and oil dependency (7 and 12 cents per gallon respectively).

Of course we should be open-minded about the magnitude of the latter two external costs in particular, given the preliminary nature of the available evidence, and the difficulty of quantifying various dimensions of climate and energy security risks. Despite this, in our view the "best available" estimates summarized in Table 3 are about the appropriate ones to use in current policy analysis, until future research findings (e.g., concerning the risk of abrupt climate change), provides evidence to adopt other values.

In fact estimates need to be updated over time, even in the absence of new evidence. Marginal damages from climate change rise over time with the extent of warming and the size of the global economy affected; in Nordhaus and Boyer (2000) marginal damages rise to around $40 per ton in 2050 and $80 in 2100 (in $2000). Similarly, marginal congestion costs are likely to increase in the absence of policy change, with continued growth in demand for vehicle travel relative to capacity. On the other hand, external costs per mile from local pollution will continue to diminish as new-vehicle emissions standards are ratcheted up. External accident costs per mile are also likely to decline with continued advance of safety technologies, a diminishing share of

[25] From www.epa.gov/otaq/fetrends.htm. Certified (i.e. dynamometer-tested) fuel economy (for the purposes of complying with fuel economy regulations) overstates on-road fuel economy, which varies with traffic conditions, temperature, trip length, frequency of cold starts, driving style, etc., by an estimated 15% (NRC 2002).

young drivers on the road as the population ages, and increasing effectiveness of policies to control drunk driving, not least more widespread use of in-vehicle breathalyzer interlock devices. As mentioned above, there are many reasons why marginal external costs of oil dependence may rise in the future, but there are also some possibly counteracting factors.

2.7 Other Externalities

An array of additional externalities are often attributed to motor vehicles, though they tend to be small in magnitude relative to the above external costs, apply primarily to heavy- rather than light-duty vehicles, or result from other policy failures rather than sub-optimal automobile policy.

2.7.1 Noise. Unwanted automobile noise includes engine acceleration, tire/road contact, braking, etc. Noise costs have been quantified by estimating the effect of proximity to roads, and traffic volumes, on residential property values holding other variables constant (however it is difficult to control for natural and intended noise mitigation barriers, such as hills, sound-proof walls, double glazed windows). For example, Delucchi and Shi-Lang (1998) estimate costs between 0 and 0.4 cents per vehicle mile across different road classes, while US FHWA (1997), Table V-22, put external costs at 0.06 cents per mile for passenger vehicles.

2.7.2 Highway Maintenance Costs. Analysts have estimated the effect of axle loads and traffic volumes on pavement damage for different vehicle classes, controlling for other factors (e.g., pavement age, climate). The key finding is that a vehicle causes road wear at a rate that is a sharply increasing function of the weight per axle, so that virtually all damage is attributed to heavy-duty trucks (e.g., Small et al. 1989, Newbery 1988). For example, US FHWA (1997), Table V-9, put external costs per mile at 0.06-0.08 cents per mile for passenger vehicles, and 1.59 and 2.78 cents per mile for the average single unit and combination truck respectively.

2.7.3 Urban sprawl. Many authors have argued that the low cost of motor vehicle use encourages urban sprawl (e.g., Brueckner 2000, Glaeser and Kahn 2003, Glaeser and Kohlhase 2003); in turn this may cause additional traffic congestion as well as lost natural habitat and aesthetic benefits from open space. However, there is little consensus on either the magnitude of increased external costs, or the relation between vehicle miles and development (e.g., McConnell and Walls 2005, Crane 1999). Moreover, if sprawl is excessive in specific regions this is primarily due to the failure of land-use policies, particularly development fees and zoning restrictions, to fully account for the external and infrastructure costs of new development.

2.7.4 Parking Subsidies. Many individuals park for free when they work or shop; Litman (2003) puts the costs from these parking subsidies at a substantial 3–10 cents per vehicle mile. Again though there remains dispute over whether free parking should be attributed as an external cost of automobile use as it results from other policy distortions, notably the exemption of the value of free parking from income and payroll taxes that apply to ordinary wage compensation.

2.7.5 Other environmental externalities. Improper disposal of vehicles and vehicle parts (e.g., tires, batteries, oil) can result in environmental and health hazards; however Lee (1993) put these costs at only 0.0015 cents per vehicle mile, and they have probably declined with more stringent regulations governing disposal and recycling. Damages from upstream emissions leakage from the petroleum industry are also relatively small, around 2 cents per gallon according to NRC (2002).

3. Traditional Policies

This section discusses what have, historically, been the two most important fuel conservation policies, namely fuel taxes and fuel economy standards, as well as emissions per mile standards and alternative fuel policies.

3.1 Fuel Taxes

Gasoline taxes currently average about 40 cents per gallon. On a per mile basis, real fuel tax rates have declined by about 40% since 1960; about half of this is due to the failure of nominal rates to keep pace with inflation and the other half to improvements in fuel economy during the 1970s and 1980s.[26]

3.1.1 Behavioral Responses. Numerous studies have estimated the own-price elasticity of gasoline demand for the United States and other countries. Most studies regress gasoline consumption on price, income, and other variables (e.g., vehicle ownership and characteristics), using time series data, sometimes with a lag structure imposed, or cross-section data. A decade or so ago, reviews pointed to a long run gasoline demand elasticity of around –0.7 to –1.0 (Dahl and Sterner 1991, Table 2, Goodwin 1992, Table 1, Espey 1996, Table 4). Later US studies that better control for fuel economy regulations, correlation among explanatory variables, or correlation among vehicle age, use and fuel economy, suggest a less elastic response. Another factor may be the declining share of fuel costs in total travel costs as wages, and hence the value of travel time, rise over time. US DOE (1996) proposed a value for the long run fuel price elasticity of –0.38, though other recent reviews by Goodwin et al. (2004) and Glaister and Graham (2002) put the elasticity at –0.7 and –0.6 respectively.

Studies of the response of vehicle miles traveled to fuel costs typically estimate elasticities of around –0.1 to –0.3.[27] A recent study by Small and VanDender (2005), that exploits an especially long time series of state level data, suggests a value at the lower end of this range, or possibly lower, is currently applicable. Comparing estimates of fuel and mileage elasticities suggests that around 20–60% of the gasoline demand elasticity reflects changes in vehicle miles driven. The other 40–80% reflects long run changes in average fleet fuel economy, such as consumers using smaller vehicles more intensively or manufacturers making technological modifications to raise engine efficiency, reduce weight, etc.

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[26] Aggregate nominal tax rates are from www.vtpi.org/tdm/fueltrends.xls and converted into real terms using the GDP implicit price deflator. The federal tax is currently 18.4 cents per gallon; state taxes vary from 7.5 cents (Georgia) to 30.0 cents per gallon (Rhode Island) with a revenue-weighted average of about 22 cents per gallon (US DOC 2003, Table 730).

[27] For example, Goodwin (1992), Table 2, Greene et al. (1999), pp. 6–10, Johansson and Schipper (1997), Schimek (1996), Goodwin et al. (2004), Glaister and Graham (2002).

3.1.2 Externality Rationale for Fuel Taxes. The (second-best) Pigouvian tax on gasoline, t_G^P, to address the major externalities discussed above, is given by the following formula (Parry and Small 2005):

$$(3.1) \quad t_G^P = E_F + \beta f E_M$$

where E_F is fuel-related externalities (carbon and oil dependence), E_M is mileage-related externalities (congestion, accidents, local pollution), f is miles per gallon of the on-road passenger vehicle fleet (this converts costs per mile into costs per gallon), and β is the fraction of the (long run) gasoline demand elasticity due to reduced mileage, as opposed to improved fuel economy. Thus a critical—though frequently overlooked—point is that the smaller the tax-induced reduction in fuel use that comes from reduced driving, the smaller the mileage-related externality benefits per gallon of fuel conservation, and correspondingly, the smaller is the Pigouvian tax.[28]

Suppose the fuel economy/fuel price relation takes the following form:

$$(3.2) \quad f = f^0 \left\{ \frac{p_G + t_G}{p_G + t_G^0} \right\}^{(1-\beta)\eta_{GG}}$$

where p_G is the pre-tax price of gasoline and η_{GG} is the (constant) own-price gasoline demand elasticity. Taking $\beta = 0.4$, $\eta_{GG} = -0.55$, and $p_G = \$1.60$, using (3.1) and (3.2) and the parameter values from Table 3, and assuming $f^0 = 20$, we would compute the Pigouvian tax at 96 cents per gallon. This is about 2.5 times the current tax, though it is still well below tax rates in most industrial nations (Figure 1). Note that our combined value for the two fuel-related externalities, 19 cents per gallon, is *below* the current tax; higher fuel taxes are efficiency improving only because they also reduce mileage-related externalities.

3.1.3 Fiscal Rationale for Fuel Taxes. Aside from externalities, governments also tax individual products like gasoline, alcohol, and tobacco, to raise revenue to finance public spending, thereby reducing the need to raise revenue from other sources, such as income taxes. Therefore, assessing the efficient level of taxation also requires considering fuel taxes as part of the broader fiscal system.

There is a theoretical literature on the appropriate balance between excise taxes and labor income taxes for a given government revenue requirement. It shows that optimal product taxes exceed levels warranted on externality grounds for products that are relatively weak substitutes for leisure, the more so the more inelastic the demand for the product (e.g., Sandmo 1975, Bovenberg and Goulder 2002). Consistent with this framework, Parry and Small (2005) derive the following formula for the optimal second-best gasoline tax from a model that integrates

[28] In the extreme case where all of the gasoline response comes from improved fuel economy and none from reduced driving, the Pigouvian tax is independent of mileage-related external costs ($t_G^P = E_F$).

automobile externalities into a general equilibrium model with pre-existing labor taxes (representing a combination of income, payroll and sales taxes) and a government budget requirement:[29]

$$(3.3a)\quad t_G^* = \overbrace{\frac{t_G^P}{1+MEB_L}}^{\substack{\textit{Adjusted}\\ \textit{Pigovian tax}}} + \overbrace{\frac{(1-\eta_{GL}^c)\varepsilon_{LL}^c}{\eta_{GG}}\,\frac{t_L(p_G+t_G)}{1-t_L}}^{\substack{\textit{Ramsey}\\ \textit{tax}}}$$

$$(3.3b)\quad MEB_L = \frac{\dfrac{t_L}{1-t_L}\varepsilon_{LL}}{1-\dfrac{t_L}{1-t_L}\varepsilon_{LL}}$$

Here η_{GL} is the elasticity of gasoline with respect to the price of leisure (obtained from applying the Slutsky symmetry property to the effect on leisure from gasoline prices), η_{LL} is the labor supply elasticity (representing a combination of hours worked and participation elasticities, averaged across male and female workers), t_L is a proportional tax on labor income, and c denotes a compensated elasticity. MEB_L denotes the marginal excess burden of labor taxation, that is, the efficiency cost of increasing the tax wedge between the gross wage (or value marginal product of labor) and net wage (or marginal opportunity cost of forgone non-market time) per dollar of extra labor tax revenue. The marginal excess burden can be expressed as a function of the labor supply elasticity and tax rate as in (3.3b). The formula in (3.3a) makes two adjustments to the Pigouvian tax.

First is a downward adjustment reflecting the higher efficiency costs of product taxes relative to labor taxes, leaving aside externalities and assuming the product is an average leisure substitute (e.g., Bovenberg and Goulder 2002); product taxes distort the household consumption bundle as well as the consumption/leisure trade-off while labor taxes distort only the latter margin. However, estimates of MEB_L (as defined in this particular case by the uncompensated labor supply elasticity) are not that large: in Parry and Small (2005) $MEB_L = 0.11$, implying a scaling back of the Pigouvian tax by around 10%.

[29] We exclude interactions with the tax-distorted capital market from the above discussion; Bovenberg and Goulder (1997) find that they are relatively unimportant in the context of gasoline taxes, as gasoline is essentially a consumption rather than investment good.

Kaplow (2005) suggests that fiscal interactions become irrelevant to the setting of optimal environmental taxes when distributional effects are taken into account. However his argument applies only to goods that are average leisure substitutes which, we argue below, is not the case for gasoline. Moreover, as shown by Williams (2005), his result is not due to the incorporation of distributional effects but rather from the assumption that external costs always reduce the marginal value of work time relative to leisure time; under this specification, reducing externalities has a positive feedback effect on labor supply. This assumption is plausible only for a limited number of externalities, such as work-related traffic congestion. Parry and Small (2005) account for these feedback effects in their optimal gasoline tax formula but they are empirically small, so we ignore them here.

The second adjustment is the Ramsey tax component. This term would be zero if gasoline were an average substitute for leisure, in which case $\eta^c_{GL} = \varepsilon^c_{LL}$ (Parry and Small 2005); however, to the extent gasoline is a weaker substitute for leisure than consumption as a whole $\eta^c_{GL} < \varepsilon^c_{LL}$ and the Ramsey tax component is positive. In Parry and Small, where household utility is weakly separable in consumption goods and leisure, $\eta^c_{GL} = \varepsilon^c_{LL}\eta_{ME}$ where η_{ME} is the expenditure elasticity of miles driven, which is 0.6 in their benchmark case. A more recent econometric analysis by West and Williams (2004a) avoids this separability restriction by estimating an Almost Ideal Demand System over gasoline, other consumption, and leisure, with household data; their results suggest $\eta^c_{GL} / \varepsilon^c_{LL}$ is around 0.3 or less. Based on this discussion, and using Parry and Small (2005) Figure 1, we can infer a value for the Ramsey tax of around 25–50 cents per gallon.[30]

There are three noteworthy caveats to this result. First, extra gasoline tax revenue might be earmarked for highway spending; however, at the optimal taxes discussed above gasoline tax revenues would far outweigh highway needs, so at the margin (which is what counts in the optimal tax formula) revenues would still go to the general government. Second, in addition to distorting the labor market income taxes also distort the choice between ordinary household spending and spending that is exempt or deductible from income taxes, such as owner-occupied housing and employer-provided medical insurance (e.g., Feldstein 1999). Accounting for this additional distortion may significantly raise the optimal environmental tax, due to higher efficiency gains from recycling revenues in income tax reductions (Parry and Bento (2000). Third, Becker and Mulligan (2003) find empirical evidence that in the past new revenue sources have more likely financed higher general government spending rather than reductions in other taxes. This underscores the need for accompanying any major increase in fuel or environmental taxes with legislation to cut other taxes, as has been the practice in recent environmental tax shifts in other countries (Hoerner and Bosquet 2001).

Summing up so far, an increase in the gasoline tax to at least $1 per gallon, and perhaps much more, seems to be warranted on externality and fiscal grounds. But this critically assumes that (a) there are no superior policy instruments (b) there are no distributional concerns and (c) there are no political obstacles to raising taxes. We comment briefly on (b) and (c) below, and discuss superior pricing policies in Section 4.

3.1.4 Distributional Effects. Since the huge bulk of gasoline is consumed directly by households, rather than used as an intermediate good in production, studies of gasoline tax incidence have focused on the budget shares for gasoline of different household income groups.

[30] It makes intuitive sense that the proportionate increase in gasoline consumption in response to a compensated increase in the net wage is much smaller than the proportionate increase in labor supply, or consumption as a whole (i.e. $\eta^c_{GL} << \varepsilon^c_{LL}$). Around one-third of passenger vehicle mileage is commuting to work which should change in rough proportion to labor force participation rates (from US DOC 2003, Tables 1090 and 1093); the remaining two-thirds of trips are mainly leisure-related and should, at best, be unaffected by a compensated increase in the net wage, and most likely will fall.

The main finding is that gasoline taxes are regressive because lower income groups have higher budget shares, but the degree of regressivity is much weaker when a lifetime, rather than annual, measure of income is used (e.g., Poterba 1989, 1991, CBO 1990, Casperson and Metcalf 1994). However, notwithstanding concerns about the reliability of lifetime income measures (e.g., Barthold 1994, Chernick and Reschosky 1997), the literature on gasoline tax incidence remains limited in two important respects.

First, earlier studies overstate the absolute burden of gasoline taxes by not considering the potential for recycling of revenues in other tax reductions. West and Williams (2004b) find that using revenues from a $1 increase in the gasoline tax to reduce labor taxes has little effect on the relative burden to income ratios across households. However if revenues are returned in equal lump-sum transfers which, for incidence analysis, is roughly equivalent to raising personal income tax thresholds, the tax increase becomes progressive overall with the lowest quintile gaining on net while other income groups suffer net losses.[31]

Second, no study to date has integrated externality benefits into an incidence analysis of fuel taxes. Again this would lower the net burden to households, and reverse its sign in many cases, given that marginal externality benefits from reducing congestion and accidents to the average road user appear to be well above the current fuel tax. In fact, lower income groups may actually benefit disproportionately, given that mileage and the value of travel time appear to increase by less than in proportion to income (e.g., Wardman 2001).

3.1.5 Political Economy of Fuel Taxes. Political opposition to higher fuel taxes in the United States appears to be formidable. In 1993 the Clinton Administration managed to raise the fuel tax by only 4 cents per gallon despite a major effort, and the federal tax has fallen by around 20% in real terms since then; both candidates in the 2004 Presidential election opposed higher gasoline taxes.

Why is it so difficult to raise fuel taxes in the United States, when governments of other industrial countries impose tax rates that are several times as high (Figure 1)? Most likely, the explanation lies with powerful producer groups in the United States, namely auto manufacturers and oil companies, as well as the greater vulnerability of households to fuel prices; annual gasoline consumption per capita is around 470 gallons in the United States, with its low population density and limited transit availability, compared with only 90 gallons in western Europe.[32] Consistent with this, Hammar et al. (2002) find that high gasoline consumption Granger-causes low gasoline prices based on 22 OECD nations during 1978–2000.

In short, although distributional concerns may not provide a counter argument to higher gasoline taxes, political obstacles may do so. This underscores the need to look for more novel approaches for reducing externalities that are both more efficient and more practical.

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[31] West and Williams take into account the greater behavioral response of low-income groups to fuel taxes compared with high-income groups, though this has little effect on the relative burden to income ratios. Note that raising personal income tax thresholds still has a beneficial effect on labor supply through encouraging labor force participation, which accounts for around two-thirds of economy-wide labor supply elasticities.

[32] From www.eia.doe.gov/emeu/international/contents.html.

3.2 Fuel Economy Standards

Another traditional policy is the Corporate Average Fuel Economy (CAFE) program, established in the wake of the 1973 oil crisis, which requires automobile manufacturers to meet standards for the sales-weighted average fuel economy of their passenger vehicle fleets. The light-truck standard is currently being increased from 20.7 miles per gallon in 2004 to 22.2 miles per gallon by 2007, while the standard for cars, currently 27.5 miles per gallon, has not been raised since 1990.[33]

In fact Small and van Dender (2005) estimate that, although the CAFE program significantly boosted fuel economy during the 1980s, it may not have been very binding by 2000, and this is prior to the recent escalation in fuel prices. Moreover, due to the rising share of light-duty trucks, which now account for half of new vehicle sales, fuel economy averaged across all new passenger vehicles is still below its peak level achieved in 1987 (see Figure 7).

Proponents of higher fuel economy standards usually point to their benefits in terms of reducing greenhouse gas emissions and oil dependence; however an additional rationale is sometimes advanced in the academic literature, namely that they might also address a market failure due to consumer undervaluation of fuel economy (e.g., Gerard and Lave 2004). We take up both of these issues in turn.

3.2.1 Externality Rationale for Tightening CAFE. Counterintuitively, higher fuel economy standards appear to have a negative overall effect on (net) automobile externalities (Austin and Dinan 2005, Fischer et al. 2005, Kleit 2004, Portney et al. 2003). They induce an inward shift of the gasoline demand curve and therefore reduce the oil dependency and carbon externalities; however, from basic public finance (e.g., Harberger 1974, Fischer et al. 2005), the induced change in social welfare is the quantity reduction times $E_G - t_G$, that is the marginal external cost *net* of the gasoline tax. If we use the values from Table 3 the combined external costs from carbon and oil dependency are only 19 cents per gallon that is *below* the current fuel tax. In this case drivers are already being overcharged for the full social costs of fuel use, and the further reduction in gasoline demand due to tighter fuel economy regulation will *reduce* efficiency.

Might the distortionary impact of fuel taxes be mitigated if (marginal) revenues pay for highways, rather than going to the general government budget? For this case Fischer et al. (2005) show that the welfare change per gallon reduction in fuel is $E_G - t_G(1+r^H)/(1+r^S)$, where r^H is the rate of return to highway spending and r^S is the social discount rate. The greater is r^H, the *greater* the welfare loss from the reduction in gasoline, since the reduction in tax revenues crowds out highly valued public spending. A plausible range for r^H might be 0–0.2 (see the review in Shirley and Winston 2004), while a typical value for r^S used in cost/benefit analysis is

[33] 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 from CAFE. A lower standard for light-trucks was originally permitted to limit the compliance burden for industrial interests, though this argument lost its relevance with the rapid growth in use of light trucks for passenger vehicles.

0.05. With these values $t_G(1+r^H)/(1+r^S)$ is 38–46 cents per gallon, still well above our assumed value for E_G.

Leaving aside all the controversies over external costs, this is a striking result. Paradoxically, externalities can justify fuel conservation through fuel taxes, but apparently not through fuel economy standards. As already noted, higher fuel taxes are efficiency improving because they also reduce mileage-related externalities. Higher fuel economy standards do not; in fact they actually have the opposite effect by lowering fuel costs per mile.

A value for this "rebound effect" can be inferred from estimates of mileage/fuel cost elasticity, denoted η_{MG}, which were discussed above. For each gallon of gasoline saved under higher fuel economy, mileage-related external costs will increase by $-E_M f\eta_{MG}/(1+\eta_{MG})$.[34] Assuming f = 20, the value for E_M from Table 3 and, from the most recent evidence, $\eta_{MG} = -0.1$, the welfare loss from increased driving is 19.5 cents per gallon, enough to offset the entire carbon and oil dependency benefits! This calculation emphasizes the importance of accounting for effects of CAFE on all externalities when assessing its welfare effect though, as already noted, the welfare loss from the rebound effect may diminish over time as the share of fuel costs in total driving costs declines with real wage growth.

3.2.2 Information Market Failures. Even if the efficiency case for higher fuel economy standards on externality grounds is shaky, might they be justified by an informational market failure?

As documented by NRC (2002), and other engineering studies reviewed therein, there is a wide range of existing and emerging fuel saving technologies (e.g., to improve engine efficiency and transmission) that could be incorporated into new passenger vehicles, and for which the discounted lifetime fuel savings would exceed the added costs to manufacturers from incorporating them. This raises the question as to why, if these technologies more than pay for themselves, automakers are not, or may not, incorporate them.

One possibility is that consumers may substantially undervalue the discounted savings from fuel economy improvements because they have short horizons, high discount rates, or they simply care little about fuel economy relative to other vehicle attributes. According to Greene et al. (2004), many auto industry experts believe consumers reckon only the first three years of fuel savings over an average vehicle life of 14 years; this is roughly the assumption built into the National Energy Modeling System used for forecasting by the Department of Energy. However there is not a solid econometric basis for this assumption.

There is an empirical literature finding that consumer discount rates exceed market rates for a wide spectrum of energy saving technologies (Frederick et al. 2002). One of these studies, by Dreyfus and Viscusi (1995), was applied specifically to automobiles, and estimated that the implicit consumer discount rate for gasoline costs is 11–17% over the vehicle life, well above the

[34] For each gallon initially saved through higher fuel economy, $-\eta_{MG}$ gallons will be offset though added driving; thus, per gallon of fuel saved net of this effect, mileage will increase by $-f\eta_{MG}/(1+\eta_{MG})$.

social discount rate assumed above. But Dreyfus and Viscusi also note that average interest rates on car loans were 13–15% during their sample period, suggesting that high discount rates reflected far-sighted but credit constrained consumers, rather than myopic consumers. It would be particularly useful to re-estimate implicit discount rates with more recent data, given that car loan interest rates have been exceptionally low in recent years. Moreover, the recent penetration of hybrid vehicles, which are otherwise identical to their gasoline counterparts, should facilitate estimation of consumer willingness to pay for more fuel-efficient vehicles, given other vehicle characteristics.

An alternative explanation for automakers failing to adopt seemingly cost-effective technologies is that engineering studies may have understated their true economic cost by ignoring the opportunity cost of forgoing their use in enhancing other vehicle attributes (power, acceleration, safety, comfort, payload, etc.). There is some casual evidence for this; for example, emerging technologies identified as fuel saving technologies by 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 and acceleration increased significantly (Austin and Dinan 2005, pp. 568). Besides these opportunity costs there may be other unobserved costs that are excluded from engineering studies, such as marketing, maintenance, consumer unfamiliarity, and retraining of mechanics.

And a final possibility, particularly given current fuel prices, is that there will in fact be widespread adoption of emerging fuel saving technologies in coming years, in which case higher fuel economy regulations might have little or no effect. Many of the economic studies of higher fuel economy regulations assume, in the free market baseline, that all cost-effective technologies will be adopted (e.g., Kleit 2004, Austin and Dinan 2005, Thorpe 1997). Thus, binding fuel economy regulation is welfare-reducing by assumption as it forces the adoption of technologies for which fuel saving benefits fall short of added vehicle production costs.

For example, leaving aside externality effects, Kleit (2004), Table 7, estimates the annual costs of a binding 3 miles per gallon increase in fuel economy at $0.8–2.1 billion, while Austin and Dinan (2005), Table 3, estimate that reducing long gasoline demand by 10% through higher fuel economy standards would cost $3.0–3.6 billion per annum. Both studies also estimate substantially lower costs under higher fuel taxes for a given reduction in gasoline use, as the tax optimally exploits reductions in vehicle use as well as improvements in fuel economy (see also West and Williams 2005, who integrate fiscal considerations into this policy comparison). Fischer et al. (2005) model the welfare effects of higher CAFE standards allowing both for externalities and possible inefficiency due to consumer undervaluation of fuel economy. They find that even if consumers discount fuel savings excessively over vehicle life, higher fuel economy standards either have little effect or reduce welfare. Only when consumers consider just three years of fuel savings do higher fuel economy standards induce positive welfare gains overall.

These findings seem to put the burden of proof on proponents of tightening CAFE to demonstrate that consumers do in fact, greatly undervalue fuel economy. Failing that, we are left with either rationalizing standards in other ways—by using a broader notion of climate and energy security costs than in the externality literature—or by considering alternative policy options.

3.2.3 Accidents and CAFE. Opponents of higher fuel economy standards frequently argue that they will force people into smaller, less safe vehicles although the evidence on this is mixed.[35] However, as already mentioned, what matters for social welfare is the change in the external costs of traffic accidents, rather than the change in fatality rates.

Tighter fuel economy regulation may affect external accident costs through (a) changes in vehicle fleet composition, as manufacturers respond by increasing their sales share of relatively fuel efficient vehicles, and (b) technological modifications to existing vehicles to increase fuel economy. Fischer et al. (2005) find that the first effect has little impact on the overall welfare effect of tighter CAFE standards, despite allowing for higher external accident costs per mile for light-trucks; this is because most of the increase in fuel economy comes from vehicle modifications rather than changes in manufacturer sales mix (e.g., Kleit 2004). To our knowledge, no study has assessed the effect of fuel saving technology adoptions on a comprehensive measure of accident externalities.

3.3 Emissions Standards and Related Policies

The principal policy instrument used to control passenger vehicle emissions is the set of new-vehicle grams per mile exhaust standards for HC, NOx, and CO, introduced in the 1970 Clean Air Act (CAA). Amendments to the CAA in 1990 established more stringent "Tier One" standards beginning with the 1994 model year; these were superseded by the "Tier Two" standards, which are currently being phased in. As indicated in Table 4, by model year 2007 new vehicle emission rates will be a small fraction, just 0.8–5.0%, of pre-1970 rates.[36] In addition Tier Two harmonizes, for the first time, the car and light-duty truck standards so no longer will it be the case that SUVs produce more local pollution per mile than cars.

The reductions in new car emission rates were due to a number of important technological advances. Prior to 1980, oxidizing catalytic converters were used to control HC and CO emissions but NOx controls on vehicles were rather primitive. Beginning in 1981, the three-way catalyst, which controlled all exhaust emissions, became standard; these catalysts use computer-controlled air-to-fuel sensors and mechanisms to allow feedback from the sensors to the carburetor or fuel-injection system to adjust the air/fuel ratio. More advanced computer-based on-board diagnostic systems have also contributed to improved emissions performance.

The standards apply to new cars but manufacturers are required to certify, based on established test procedures, that vehicles will meet the standards after 50,000 miles of use.[37] It was not long after the first emissions standards were put in place, however, before regulators

[35] See for example Crandall and Graham (1989), Khazzoom (1997), Kahane (1997), and Noland (2004).

[36] Due to its unique air quality problems, California can set its own standards, and these have generally been stricter than the federal standards; all other states must adopt either the federal or the California standards.

[37] Beginning with the 1994 requirements in the 1990 CAA Amendments, an additional 100,000-mile certification has been required.

realized that many cars and trucks were failing to meet the standards—i.e., that so-called "in-use" emissions were, in some cases, quite high. Thus, the 1977 Amendments to the Clean Air Act mandated the use of inspection and maintenance (I&M) programs in areas with long-term air quality problems. The 1990 Amendments further tightened I&M requirements and standardized program features. In I&M programs, usually all vehicles, or vehicles over a certain age, are required to submit to periodic emissions inspections. Owners of vehicles that fail the inspection are required to have repairs made so that their vehicles pass.

Emissions standards and I&M programs target the vehicle, but fuels have also been increasingly regulated in recent years. Lead was phased out of gasoline beginning in 1974, providing direct benefits in the form of lead reductions but also facilitating the use of catalytic converters to control other emissions.[38] The 1990 CAA Amendments required oxygenated fuels be used in certain areas of the country during the winter months. This requirement has recently been replaced with an ethanol mandate (see below). Another fuels requirement in the 1990 Amendments was the summer-time reformulated gasoline program. It mandates that the Reid Vapor Pressure (RVP) of gasoline be no greater than 7.8 psi (pounds per square inch) during the summer months (June 1 to September 15) in ozone nonattainment areas and no greater than 9.0 psi throughout the 48 contiguous states. This requirement is one of the ways in which regulations have addressed evaporative HC emissions which, as exhaust emissions have declined, have become an increasingly important part of total emissions.

EPA has conducted a detailed retrospective analysis of the costs and benefits of the Clean Air Act over the 1970–1990 time period, as well as a prospective analysis of costs and benefits for the 1990–2010 period.[39] For the retrospective analysis, the costs of controlling motor vehicle emissions were estimated by calculating the purchase price and operating and maintenance cost premiums associated with vehicles equipped with pollution abatement controls over the costs for vehicles not equipped with such controls. According to EPA, total annualized costs have fallen over time; in 1990 dollars, costs were $8.8 billion in 1975 and $5.5 billion in 1990 (EPA, 2003). For the prospective study, EPA included estimates of the costs of the new car standards, I&M costs, fuel-related costs (both reformulated gasoline and oxygenated fuels), and low-emissions vehicle requirements in the CAA Amendments. The estimates (in 1990$) for 2000 and 2010 are $9.1 billion and $12.3 billion, respectively. Estimated benefits exceed costs in both studies but benefit figures are only provided for air quality improvements as a whole and not those attributable to motor vehicles. However for the earlier time period at least, benefits from PM and lead reductions are a significant part of total benefits, thus it seems clear that estimated benefits of vehicle policies exceeded costs.

Despite estimates of positive net benefits from air quality improvements, the rapid rise in annual miles traveled per vehicle and vehicles owned per household over the past 30 years have worked against the reductions in emissions rates and likely increased the overall costs of the program. Figure 8 shows total registered vehicles in the United States and annual vehicle-miles-

[38] Newell and Rogers (2005) estimate that benefits of the lead program (e.g., reduced retardation in children with high lead-blood levels) easily exceed estimated costs (see Table 4 of their study).

[39] See www.epa.gov/oar/sect812.

traveled (VMT) per vehicle from 1970 to 2002. Even on a per vehicle basis, VMT has risen over time, particularly since 1980. When combined with consistently rising vehicle ownership—by 2002, there was more than one vehicle per licensed driver—total VMT has risen sharply. Total annual VMT was 1.2 million miles in 1970; by 2002, that number had jumped more than 150% to 2.9 million.

Since efficient policy instruments would target all methods of controlling emissions, including reducing VMT, it is clear that the command-and-control methods that have focused almost exclusively on emissions rates are second best. The new car standards, I&M programs, fuels standards, and the like have had to work harder to achieve the reductions in emissions that have been reached to offset rising VMT.

3.4 Alternative Fuel Policies

Beginning with the (now infamous) Synfuels program in the late 1970s, and continuing through to the 2005 Energy Policy Act, the federal government has spent billions of dollars on inducements to develop reliable, low-cost alternative fuels to conventional gasoline to reduce the nation's dependence on oil.

The centerpiece of the Bush Administration's effort is a $1.2 billion R&D program to develop hydrogen fuel cell vehicles, which have an electric motor with the fuel cell producing electricity from a reaction between hydrogen and oxygen. But it could be several decades, if ever, before fuel cell vehicles become a standard source of power on the highway, due to formidable technological obstacles that need to be resolved (e.g., NAS 2004). One is that producing hydrogen is currently several times more costly than producing gasoline per unit of energy and some of the potential feedstocks (i.e., natural gas and coal) produce carbon emissions that partially offset the carbon savings from reduced gasoline use (this does apply to hydrogen extraction from water). Another is the cost of transitioning away from the current fuel distribution network to one based on hydrogen. But probably the biggest challenges are the high cost of fuel cells, along with the problem of safe on-board storage, given that hydrogen takes up far more space than other fuels, even when compressed. Given the lack of an alternative fuel that might one day entirely eliminate our dependence on gasoline, continued exploration into hydrogen's potential makes sense in our view (see also Sperling and Ogden 2004), though a portfolio of other research opportunities (e.g., oil shale conversion, carbon capture and storage) should be encouraged as well.

Ethanol, currently produced from corn, is another alternative to conventional gasoline favored by policymakers. The 2005 Energy Policy Act mandates that refineries purchase a minimum amount of ethanol each year, which would about double ethanol use to 8 billion gallons in 2012 (EIA 2005, Figure 1); although this would only be 5% of projected gasoline demand (EIA 2005, Figure 99), the hope is that this will stimulate investments into cellulose-based ethanol production. Blending gasoline with ethanol, or using it as a complete substitute for gasoline, reduces oil dependency, carbon emissions, and possibly local pollution.[40] The new

[40] Ethanol may reduce tailpipe emissions by helping to prevent fuel from combusting prematurely in the engine. And the carbon cycle for corn-based ethanol is "closed loop" meaning that carbon emissions absorbed during corn growth balance emissions released during harvesting, conversion to ethanol, and fuel combustion, though some emissions result from the use of energy during fermentation and distillation processes.

mandate comes on top of an array of existing incentives including a federal tax subsidy equivalent to 51 cents per gallon of pure ethanol, various state level incentives, CAFE credits for vehicles that can run on either gasoline or ethanol, and farm program subsidies for corn growers. Other alternative fuel vehicles—for example, that run on methanol, compressed natural gas, electricity only, or hybrids such as the Toyota Prius—are also favored by the tax and regulatory system (see Box 1).

We are unaware of a comprehensive welfare analysis of these alternative vehicle policies, at least one that fully accounts for impacts on the broad range of passenger vehicle externalities, as well as interactions among existing policies and fuel taxes. Nonetheless studies (at least those prior to the very recent market penetration of hybrids) suggest these policies have only modest potential for denting gasoline demand, or put another way, their incremental costs per gallon of gasoline saved rises sharply (e.g., Krupnick and Walls 1992, Krupnick et al. 1993, Walls 1996, Kazimi 1997, Leiby and Rubin 2001). This is not surprising given that (aside possibly from hybrids) these vehicles are more expensive than their gasoline counterparts even accounting for lower lifetime fuel costs, and have shorter driving ranges; moreover, unlike gasoline taxes, these policies do not discourage driving or encourage fuel economy improvements in gasoline vehicles.

4. Emerging Pricing Policies

We now turn towards more novel approaches for pricing automobile externalities that have become feasible with recent development in electronic metering technology.

4.1 Congestion Tolls

Traditionally, the main response to highway congestion has been to add road capacity; however this option is becoming increasingly difficult with rising urban land costs, opposition from neighborhood and environmental groups, and the erosion of real fuel tax revenue per VMT (e.g., Goldman and Wachs 2003). Interestingly, advanced vehicle sensing technologies, which are already being incorporated in high-end vehicles, may add to future road capacity without requiring more pavement. Eventually, embedded detectors in highways may permit vehicles to travel together in "platoons" of about twenty vehicles separated by headways of one to two feet under computer control; this could quadruple freeway lane capacity (Horowitz and Varaiya 2000), though not in urban areas with frequent entry and exit points. Moreover, capacity expansion does not internalize congestion externalities; it reduces their significance, though even this is mitigated to the extent that building new roads encourages more driving.[41]

Fuel taxes, which raise the cost of all driving regardless of where the driving occurs or what time of day, are also an extremely blunt instrument for reducing traffic congestion, which varies enormously across urban and rural roads and between peak and off-peak driving times. In

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[41] The extent of this "latent" demand effect remains contentious; increases in highway spending precede increases in VMT (e.g., Fulton et al. 2000), although this could indicate accurate transportation planning. Cervero and Hansen (2002) find that, although the elasticity of road construction to VMT is positive (0.30) it is less than the elasticity of VMT with respect to road construction (0.55).

the United Kingdom, which currently has Western Europe's worst traffic congestion despite having the highest fuel taxes, the national government is considering scrapping fuel taxes and replacing them with a system of per-mile charges that would vary from around £0.02 (4 cents) per mile in rural areas to £1.30 ($2.30) per mile in inner-city areas. This proposal follows the success of a cordon-pricing scheme introduced in central London in 2003 (Litman 2004a, Blow et al. 2003).

Unlike a gasoline tax, per mile charges that vary in real time with the prevailing amount of congestion would encourage people to drive a little earlier or later to avoid the peak of the rush hour, as well as encouraging people to use less congested routes. These charges could be collected electronically via payments against in-vehicle transponders as vehicles pass electronic meters. Alternatively, with on-board global positioning systems that are increasingly incorporated in new vehicles, individuals could be mailed a bill based on an electronic record of where and when they have driven.

As early as Pigou (1920), analysts suggested that the congestion externality could be internalized by pricing road travel at the difference between marginal and average social cost and this basic insight is robust to more complicated settings, such as trip rescheduling (Arnott et al. 1993), heterogeneous users (Arnott et al. 1994), and pricing entire transport networks (Yang and Huang 1998). However, as regards the latter point, if pricing is applied piecemeal, a large amount of the welfare gains from more comprehensive pricing may be sacrificed, not least due to traffic diversion onto other unpriced, but still congested, links in the network (e.g., Arnott et al. 1994, Small and Yan 2001, Verhoef 2005).

Despite its potential attractions congestion pricing has been slow to get off the ground. In the United States there have been only three notable applications, namely the high-occupancy toll (HOT) lanes on Route 91 in Southern California, I-15 in San Diego and I-10 in Houston, which are open to users paying a fee or meeting a vehicle occupancy requirement (e.g., Sullivan and Harake 1998).[42] In fact, pricing experiments are usually sold to the public as a way of providing motorists with an option for "premium" service rather than as a way of allocating road access; widespread, fine-tuned, road pricing still faces substantial barriers to implementation.

First, the steep marginal social cost curve, combined with the variability in traffic demands over the day, ensures that first-best tolls would be highly variable over time and space, making it difficult, at least initially, for drivers to optimize over routes and travel time; in practice, charging schemes may be relatively simple with significant departures from first-best tolls. Second, although electronic toll collection (ETC) may cost far less than worker-operated toll booths, as well as alleviating bottlenecks at collection points, it still raises privacy concerns, even though ETC systems can be designed to avoid central collection of travel information. Moreover, market penetration of transponders is surprisingly low, less than 50% in most US toll road systems (ETTM 2002), which limits the potential for reducing congestion at collection

[42] Up until recently, the only other notable examples of road pricing were the cordon tolling implemented in Singapore in the mid-1970s, which was effective in limiting downtown traffic (e.g., Holland and Watson 1978, Hau 1992), and the less effective cordon toll rings implemented in several Norwegian cities in the 1980s (e.g., Larsen 1988, Hau 1992).

points. Third is that, at least prior to use of congestion toll revenues, a large number of motorists will be made worse off (i.e., toll payments exceed their value of travel time savings); this makes some observes pessimistic that congestion pricing will ever be widely implemented in the United States (e.g., Giuliano 1992, pp. 335).

One possibility for overcoming political opposition is judicious use of congestion toll revenues to create a broader coalition of winners from the policy change; for example, Small (1993) and Goodwin (1994) recommend a mix of spending on transport alternatives, road improvements, and reductions in other taxes. Another is to proceed incrementally, beginning with pricing reforms for which there is least opposition, before implementing more comprehensive charging. For example, converting existing high occupancy vehicle (HOV) lanes into HOT lanes can make many drivers of single-occupant vehicles better off, as they have more choices, while keeping the lane free flowing for multi-occupant vehicles. Poole and Orski (2002) then recommend, as a further intermediate step, investing in new toll-lane capacity where necessary to link up the HOT lanes into a network of premium lanes covering the entire urban area.

4.2 Charging for Accident Risk

Here we focus on pricing policies to internalize accident risks into the choice of how much to drive.[43] In theory the ideal policy would be an electronically collected tax per vehicle mile that varied with marginal external costs across drivers, vehicle and region. Notwithstanding privacy concerns, such a finely-tuned tax is overly optimistic at present, given the lack of a solid comprehensive measure of marginal external cost for the nation as a whole, let alone how it varies with driver, vehicle and regional characteristics. Still, even a uniform tax on vehicle miles of travel would be more cost-effective at reducing accidents than the equivalent fuel tax given that all, rather than just a portion, of the behavioral response to it comes from reduced driving (e.g., Parry 2005).

In fact a form of charging by the mile for accident risk may emerge on its own through the market and, unlike a new driving tax, the average motorist would be no worse off under this scheme, making it especially attractive on grounds of political feasibility. This is pay-as-you-drive (PAYD) insurance under which a person's annual insurance payment would vary in direct proportion to annual miles driven, scaled by the driver's (and possibly vehicle's) relative risk factor, as determined by insurance companies; the charge for the average motorist would be around 6 cents per mile (Litman 2004b). PAYD would provide incentives to limit driving, unlike

[43] Other government policies also affect external costs, including those that affect driver care per mile driven, as well as vehicle safety. Of the former the most prominent is policies to deter drunk driving including minimum legal drinking ages and fines, jail sentences, license suspensions for drunk driver convictions, and most recently, mandated installation of in-vehicle breathalyzer interlock technologies (about 40% of highway deaths currently involve alcohol use). Studies suggest that expected penalties per drunk driver trip are far below optimum levels, due to the extremely low probability of being caught (e.g., Kenkel 1993, Levitt and Porter 2001a). Other studies have estimated lives saved from mandated safety technologies (e.g., seatbelts, airbags, child restraints, energy absorbing steering assemblies), with some accounting for added risks to other road users as people in safer vehicles drive more aggressively, and these have been compared with the increased costs of vehicle manufacture (e.g., Levitt and Porter 2001b, Kahane 2004, Peltzman 1975). However it is difficult to evaluate the welfare effects of safety mandates (as opposed to the technology itself) because the extent of technology adoption that would have occurred without the policy is not observed (unlike environmental benefits, safety benefits are, at least in part, internal).

the current insurance system where annual premiums depend only very weakly on mileage, and these incentives would be greatest for the drivers with highest risk factor (e.g., people with prior crash records). Preliminary analyses suggest large welfare gains from policies to promote PAYD (e.g., Edlin 2003), though a significant portion is the ancillary gain from mitigating traffic congestion externalities, which would be reduced if peak-period pricing were to be introduced.[44]

Drivers with below average mileage (who are the majority given that the mileage distribution across drivers is skewed to the left) have an incentive to opt for PAYD as it would lower their annual payments; premiums would rise for those remaining under the present system, which in turn would encourage additional switching at the margin. However, this transition to PAYD may be suboptimal without government incentives (e.g., tax incentives to sign up for PAYD) due to an apparently significant inter-insurance company externality (Edlin and Karaca-Mandic 2003), as well as the incomplete internalization of all mileage-related externality benefits. The insurance externality arises because reduced driving by clients at one insurance company lowers claims by drivers at other insurance companies.[45]

5. Conclusion

The externality rationale for higher fuel taxes, or more stringent fuel economy standards, may well have come and gone. Electronic road pricing, which technological advances have now made feasible, offers the only real hope of reversing the tide of ever rising traffic congestion, and a transition to pay-as-you-drive insurance would provide a more effective and practical way to improve highway safety. Local pollution is less of a concern as it is steadily being solved through technological refinements to meet progressively more stringent new-vehicle emissions standards.

That leaves climate change and energy security, but even for these cases there are far superior policy alternatives. Clearly, it makes no economic sense to focus exclusively on regulating automobiles when the huge bulk of the low-cost sources for carbon abatement are in other sectors, particularly electricity generation. In our view federal policymakers should reduce emissions through a tax on the carbon content of all fossil fuels, not just gasoline, where the tax is moderately scaled at first, but rising steadily over time.[46] Similarly, energy security calls for a

[44] Another benefit of PAYD is that it would reduce the problem of uninsured drivers by lowering the cost of owning low-mileage vehicles. This issue has not yet received attention in the limited empirical literature on PAYD.

[45] PAYD schemes are just beginning to emerge at the state level. In Oregon, insurance companies have been offered a state tax credit of $100 per motorist for the first 10,000 motorists who sign up for PAYD. The Texas legislature has passed legislation authorizing auto insurance companies to offer per-mile insurance, and state governments in Maryland and Connecticut are considering similar measures.

[46] A tax credit should also be provided for carbon capture and sequestration, for example at power plants, or in the forestry sector. There appears to be an overwhelming economic case for a carbon tax over a system of freely allocated carbon permits. Carbon permits are far more costly than taxes as they forgo large efficiency gains from recycling revenues in other tax reductions. They also have adverse distributional effects as the scarcity rents they create raise firm equity values and transfer income from energy consumers in general to stockholders (who are concentrated in high-income groups). Moreover, in the presence of uncertainty, they have higher expected abatement costs than the equivalent tax and inevitable volatility in permit prices may deter long-term energy saving

broad tax on all oil uses, including aviation fuel, diesel fuel, home heating oil, and petrochemicals, rather than just the 45% of oil used for gasoline.

But even if these cost-effective taxes on energy use were implemented they would not, by themselves, take us very far in alleviating energy security and climate concerns for the foreseeable future. What really matters is whether we are able, over the next generation or two, to transition to advanced technologies that drastically reduce fossil fuel requirements, or at least permit their use without emissions release into the atmosphere. The benefits from such technologies are enormous when one thinks about the potential for growth in fossil fuel use with current technology in China, India and other populous industrializing nations.[47] To what extent this transition materializes depends on technological possibilities and factors that motivate firms, governments, and research institutions to explore technological opportunities, particularly the level of fuel prices—including energy taxes—and government policy toward R&D.

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investments. See Parry et al. (1999), Dinan and Rogers (2002), and Newell and Pizer (2003b) on these issues respectively, and Nordhaus (2005) for a broader discussion.

[47] For example, in China and India, which together have eight times the population of the United States, vehicle ownership is currently below ten per 1000 people, compared with 780 in the United States (World Bank 2000).

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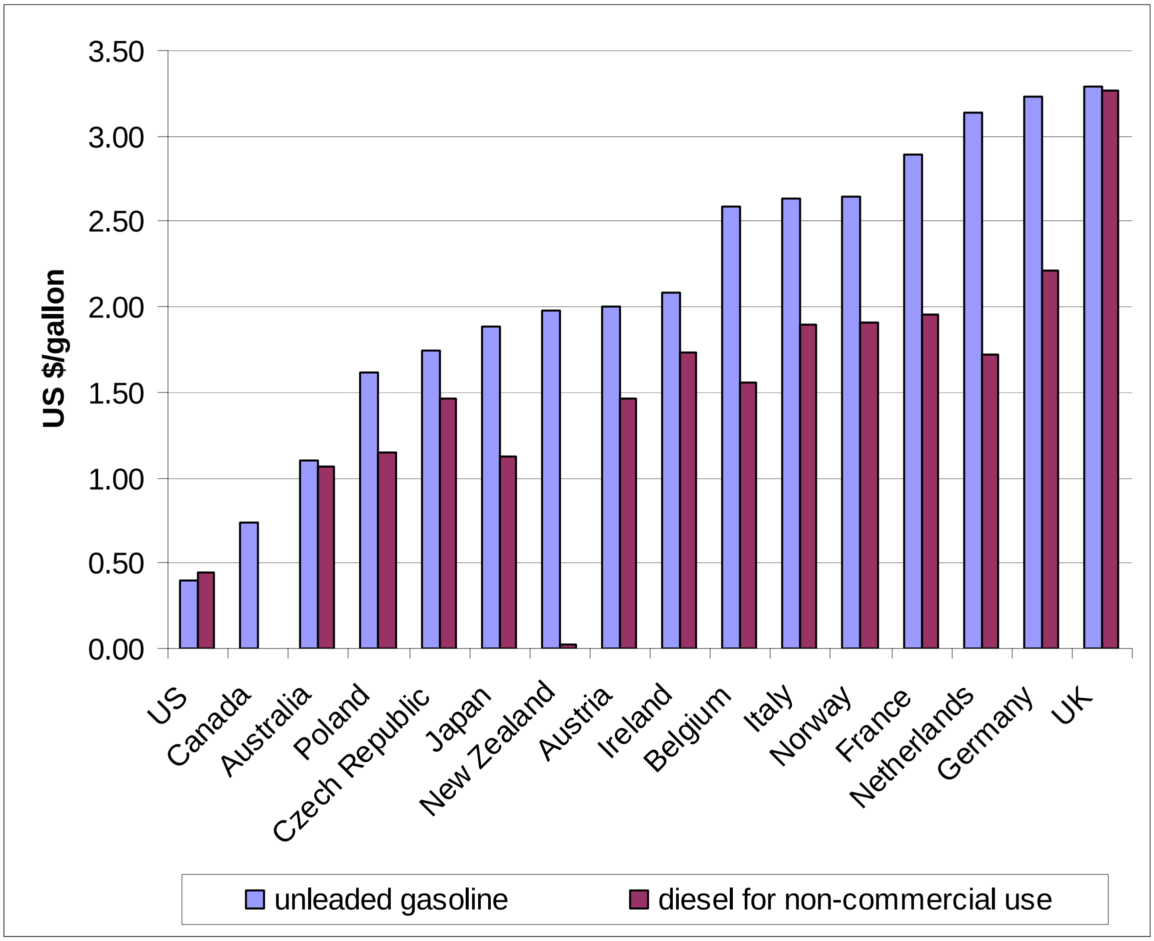
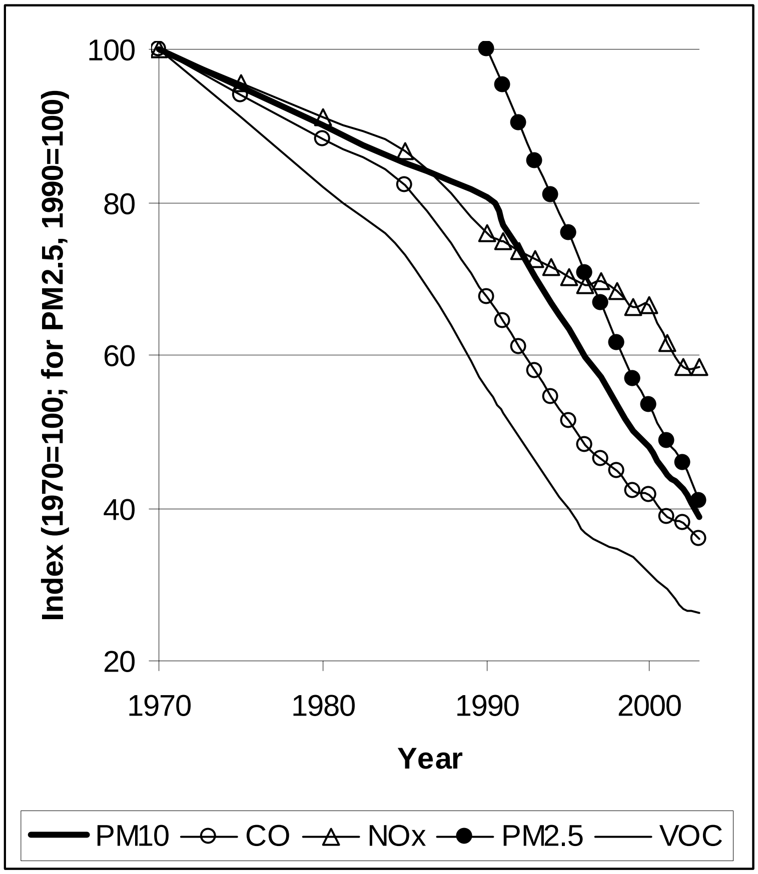
Figures, Tables, and Boxes

Figure 1. Fuel Taxes for Selected Countries, 2004



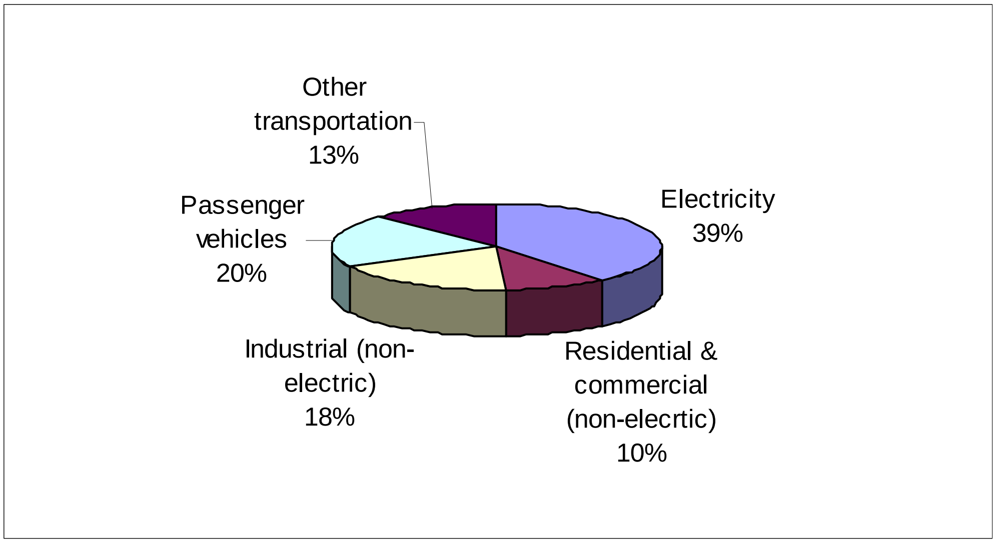
Source: OECD (2005).

Figure 2. Emissions from Highway Vehicles Relative to Base Year



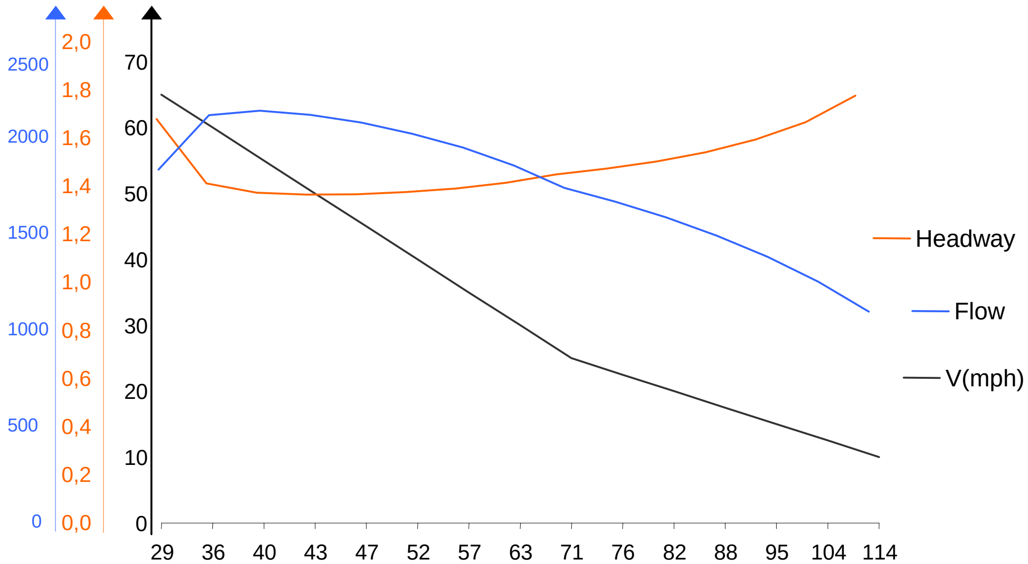
Source: EPA (2004).

Figure 3. Carbon Emissions by Sector, 2004



Source: [www.eia.doe.gov.](http://www.eia.doe.gov)

Figure 4. Vehicle Speed, Flow, and Headway as Functions of Traffic Density



Sources: Authors' estimates based on TPB (1999) and Rakha and Crowther (2002).

Figure 5. Vehicle Speed-Flow Curve for the Washington Area Beltway

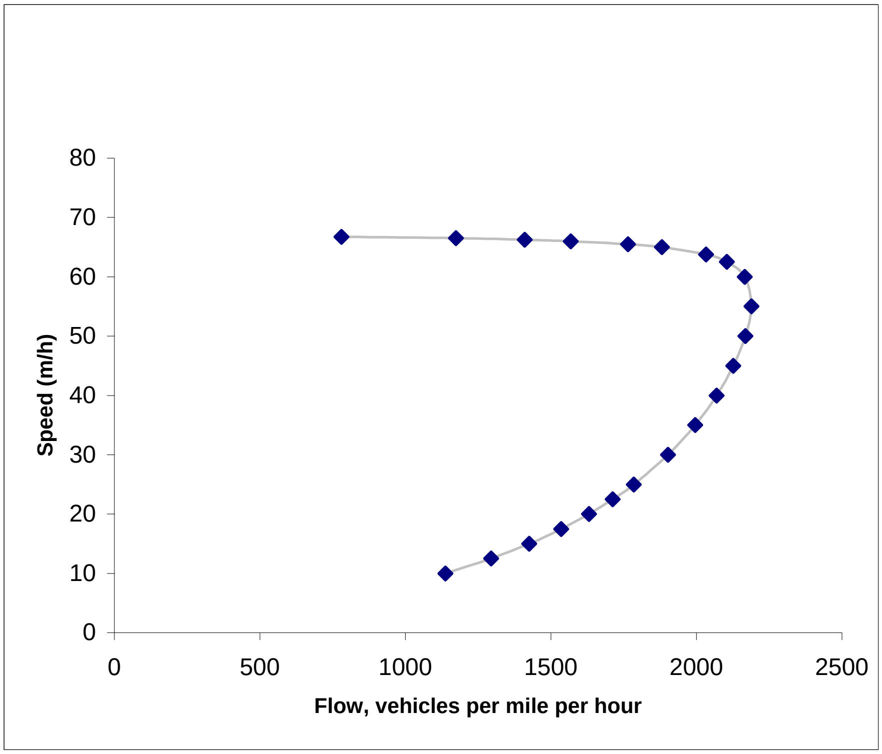


Figure 6. Average and Marginal Social Cost

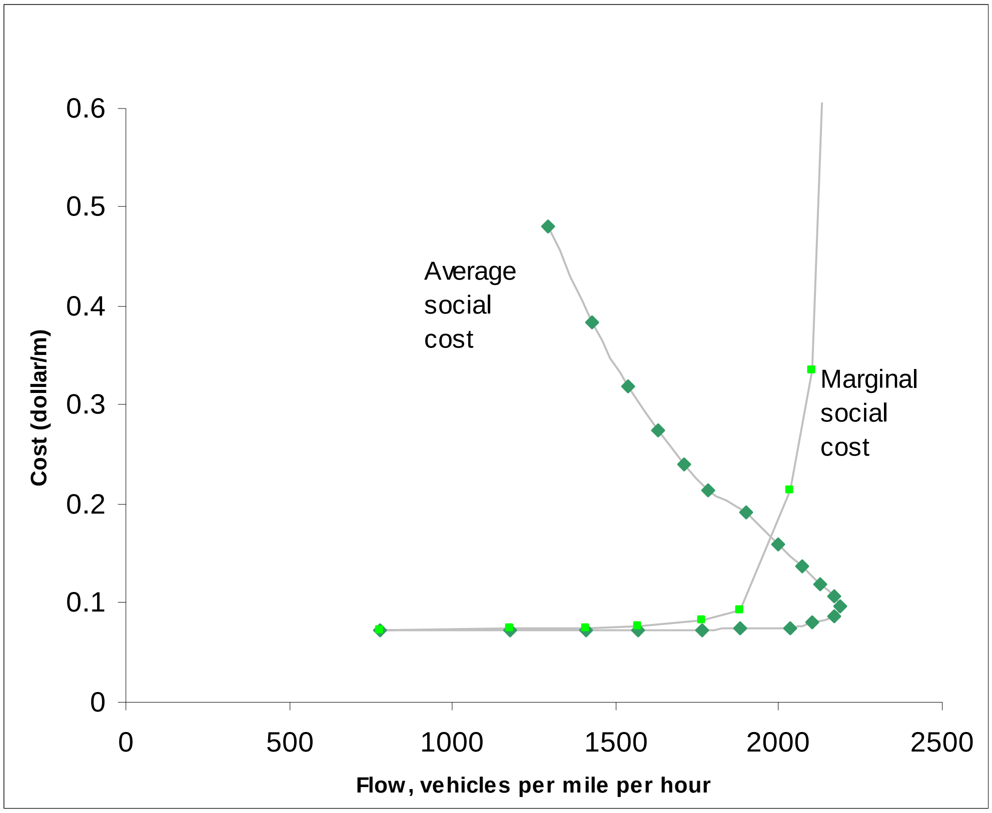
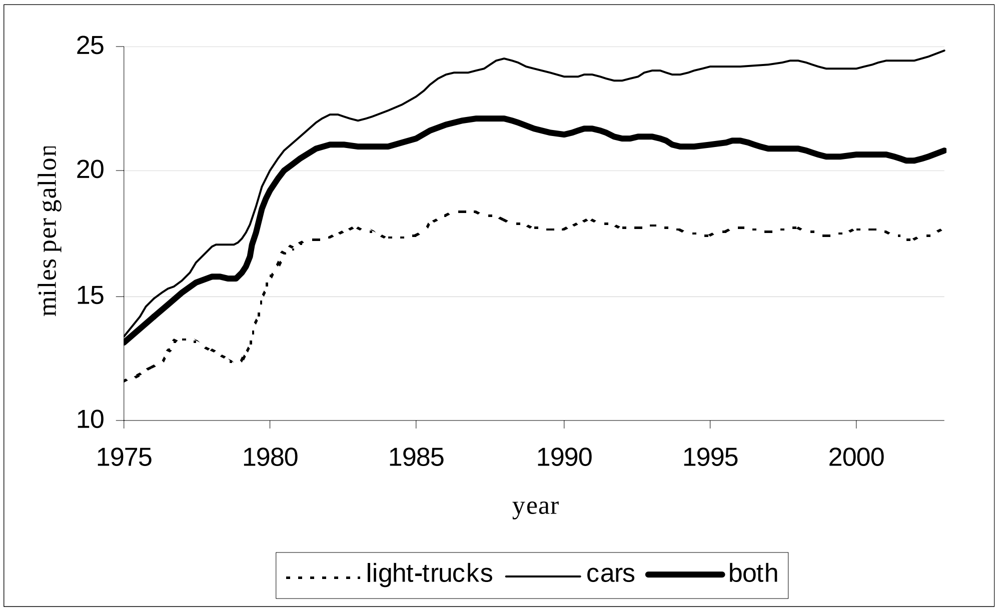
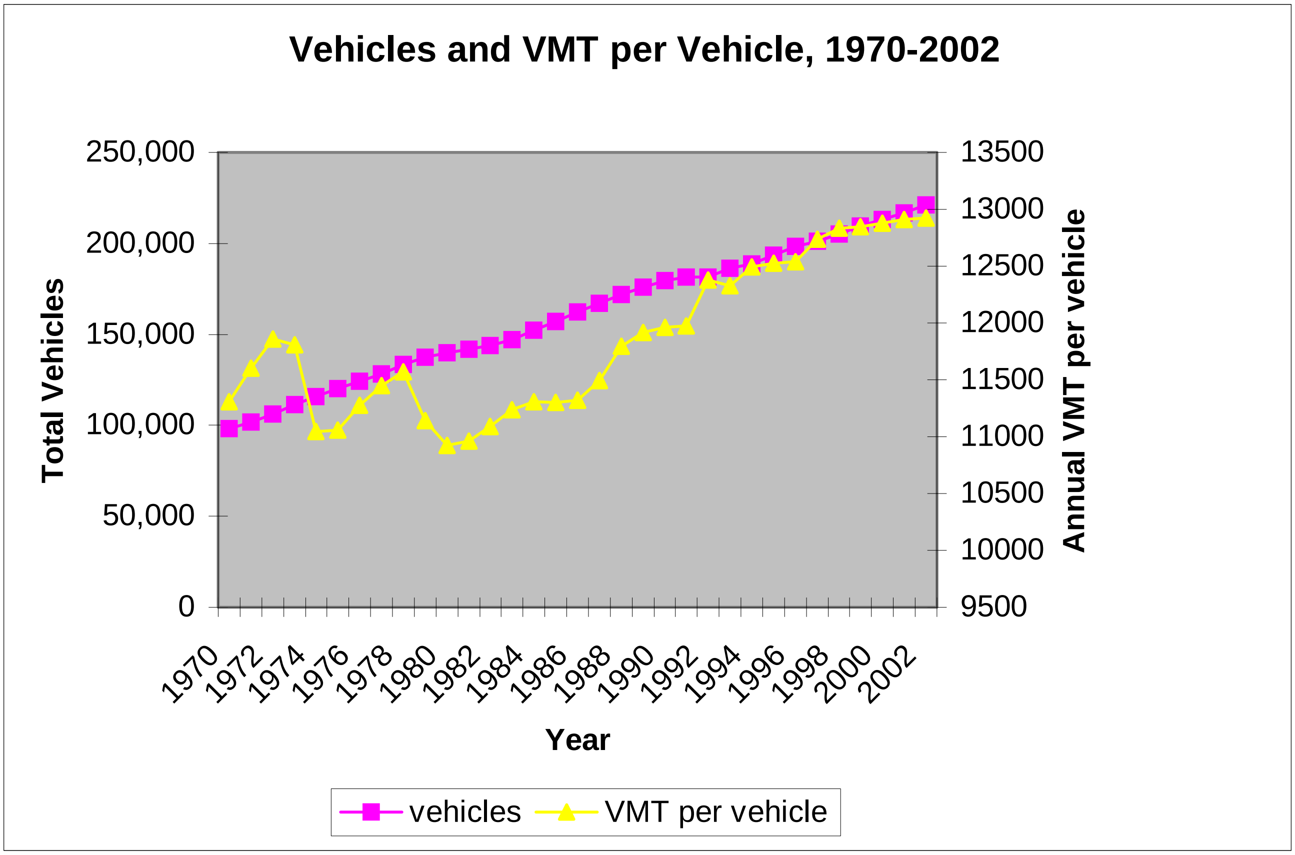


Figure 7. Fuel Economy of New Passenger Vehicles



Source: US NHTSA (2005). Data shows certified rather than on-road fuel economy.

Figure 8.



Source: US Department of Energy (2004).

TABLE 1
ESTIMATED DAMAGE TO DIFFERENT SECTORS AND REGIONS FROM 2.5°C WARMING IN 2100
(% OF MARKET GDP)

	TOTAL [2.5°C]	Agriculture	Other vulnerable market	Coastel	Health	Non-market time use	Settlements	Catastrophic Impact [2.5°C]	Catastrophic Impact [6°C]
United States	0.45	0.06	0	0.11	0.02	-0.28	0.10	0.44	2.97
China	0.22	-0.37	0.13	0.07	0.09	-0.26	0.05	0.52	3.51
Japan	0.50	-0.46	0	0.56	0.02	-0.31	0.25	0.45	3.04
OECD Europe	2.83	0.49	0	0.60	0.02	-0.43	0.25	1.91	13.00
Russia	-0.65	-0.69	-0.37	0.09	0.02	-0.75	0.05	0.99	6.74
India	4.93	1.08	0.40	0.09	0.69	0.30	0.10	2.27	15.41
Other High Income	-0.39	-0.95	-0.31	0.16	0.02	-0.35	0.10	0.94	6.39
High Income OPEC	1.95	0.00	0.91	0.06	0.23	0.24	0.05	0.46	3.14
Eastern Europe	0.71	0.46	0.00	0.01	0.02	-0.36	0.10	0.47	3.23
Middle Income	2.44	1.13	0.41	0.04	0.32	-0.04	0.10	0.47	3.21
Lower-middle Income	1.81	0.04	0.29	0.09	0.32	-0.04	0.10	1.01	6.86
Africa	3.91	0.05	0.09	0.02	3.00	0.25	0.10	0.39	2.68
Low Income	2.64	0.04	0.46	0.09	0.66	0.20	0.10	1.09	7.44
Global									
Output-weighted	1.50	0.13	0.05	0.32	0.10	-0.29	0.17	1.02	6.94
Population-weighted	1.88	0.17	0.23	0.12	0.56	-0.03	0.10	1.05	7.12

Source: Nordhaus and Boyer 2000, Table 4.10.

TABLE 2
TOTAL SOCIAL COSTS OF TRAFFIC ACCIDENTS IN THE UNITED STATES, 2000

	Property damage only	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	Fatal	All injuries
Number of injuries	23,631,696	2,548,458	4,659,585	436,007	125,903	36,509	9,463	41,821	31,489,442
Total cost per injury, $	2,532	1,962	15,017	157,956	314,205	731,580	2,402,996	3,366,387	13,766
quality adjusted life years	0	0	4,455	91,137	128,107	383,446	1,306,836	2,389,179	6,444
property damage	1,484	1,019	3,844	3,954	6,799	9,833	9,446	10,273	1,875
travel delay	803	773	777	846	940	999	9,148	9,148	812
medical	0	1	2,380	15,625	46,495	131,306	332,457	22,095	1,036
emergency services	31	22	97	212	368	830	852	833	46
market productivity	0	0	1,749	25,017	71,454	106,439	438,705	595,358	1,937
household productivity	47	33	572	7,322	21,075	28,009	149,308	191,541	640
insurance administration	116	80	741	6,909	18,893	32,335	68,197	37,120	482
workplace cost	51	34	252	1,953	4,266	4,698	8,191	8,702	142
legal cost	0	0	150	4,981	15,808	33,685	79,856	102,138	353
Total injury costs, $billion	59.8	5.0	70.0	68.9	39.6	26.7	22.7	140.8	433.5

Source : US NHTSA (2002), Tables 3 and A-1.

TABLE 3
SUMMARY OF EXTERNAL COSTS

	cent/gal.[a]	cents/mile[a]
Central values for marginal external costs		
Fuel-related costs		
Greenhouse warming	7.0	0.4
Oil dependency	12.0	0.6
sum	19.0	1.0
Mileage-related costs		
Local pollution	46.0	2.3
Congestion, cents/mile	70.0	3.5
Accidents	60.0	3.0
sum	176.0	8.8

Notes
[a]Costs converted assuming on-road fuel economy of 20 miles per gallon.

TABLE 4
US PASSENGER CAR EMISSIONS STANDARDS, GRAMS PER MILE

Model year	HC	CO	NOx
Pre-control vehicle	10.6	84.0	4.1
1970-71	4.1	34.0	--
1972	3.4	39.0	--
1973-74	3.4	39.0	3.0
1975-76	1.5	15.0	3.1
1977-79	1.5	15.0	2.0
1980	0.41	7.0	2.0
1981-93	0.41	3.4	1.0
1994-03	0.41 (0.25)[a]	3.4	0.4
2004-07[b]	0.09[a]	4.2	0.07

Notes
[a]The figure in parentheses for 1994-03 and the 2004-07 figure listed for HC are non-methane hydrocarbon (NMHC) emissions standards.
[b]Tier 2 standards beginning with the 2004 model year are different from previous standards; the NOx standard is a fleetwide average and the standards listed in the table for NMHC and C are based on the fleet mix used in the Notice of Final Rulemaking to meet the fleetwide NOx standard (NAS 2001).

Source: NAS (2001).

BOX 1
SUMMARY OF POLICIES PROMOTING ALTERNATIVE FUELS AND VEHICLES

Ethanol Tax Credits
Ethanol blenders/retailers receive a 51 cents per gallon federal tax credit per gallon of pure ethanol; this implies, for example, a tax credit of 5 cents per gallon for E10 or "gasohol" (10% ethanol, 90% gasoline) and 43 cents per gallon for E85 (85% ethanol, 15% gasoline). A few states have a further tax exemption though these are modest (typically between 1 and 3 cents per gallon of pure ethanol).

Corn Subsidy
Corn growers in Midwestern states receive federal payments through farm support programs. Averaging over federal payments for corn for 1996–2003, multiplying by the share of corn used for ethanol (7–14% over the period), and dividing by gallons of ethanol production yields an average subsidy of 23 cents per gallon per gallon of alcohol. However "deficiency payments", which typically account for around two-fifths of total federal payments have been decoupled; that is, they still distort the number of farms producing corn, but not corn output per farm. Thus, the effective subsidy is perhaps around 18 cents per gallon.

Tax Credits for AFV Purchase
The 2005 Energy Policy Act extended earlier tax credits for alternative fuel vehicle (AFV) purchase; the credit for fuel cell, hybrid, and dedicated natural gas, propane, and hydrogen vehicles now equals 50% of the incremental cost of the vehicle over conventional vehicles, plus an additional 30% of the incremental cost for vehicles with near-zero emissions. Purchasers of light-duty fuel cell vehicles receive a base tax credit of $8,000, which drops to $4,000 in 2010.
Many states have also established tax credits. For example, Colorado gives a credit on state income taxes equal to a percentage of the price differential between AFVs and comparable gasoline vehicles where the percentage is highest (85%) for zero-emission vehicles; Georgia, Illinois, Louisiana, and Rhode Island have similar programs. New York provides a sales tax exemption up to $3,000 while Arizona provides vehicle license tax relief for AFVs.

CAFE Credits
Manufacturers receive credits for selling AFVs in the calculation of fleet-wide average fuel economy for purposes of meeting CAFE requirements. For example, a flexible-fuel vehicle (FFV) that can operate on either 100% gasoline or E85 that gets 20 mpg is treated as though it went 20 miles on only 0.15 gallon of fuel; thus it is assumed to average 133 mpg for CAFE purposes, which counts against below average fuel economy attained by other vehicles in the manufacturer's fleet. The CAFE credit applies even though there is no guarantee that FFVs are operated on the ethanol blend rather than gasoline. Because of the technological hurdles that had to be overcome to produce FFVs, this program has only started to have an impact in recent years; as of 2003, 2 million E-85 vehicles covering 21 different models had been sold. Despite these incentives, there are still only 556 ethanol-refueling stations nationwide.

Vehicle fleet mandates
The 1990 Clean Air Act initially required an increasing percentage of new fleet vehicle purchases in 23 of the dirtiest cities be AFVs, though the program was changed to a voluntary one in 1995. This Act also established a California pilot program for "ultra-low emission vehicles," which other states could elect to adopt as well. Under the 1992 Energy Policy Act 75% of federal light-duty vehicle fleets had to be AFVs. The 2005 Energy Policy Act requires that the FFVs in federal fleets be operated on the alternative fuel.

Sources: www.eere.energy.gov/afdc, www.eere.energy.gov/afdc/altfuel/ethanol.html, www.ncsl.org/programs/energy/ethinc.htm, www.eere.energy.gov/afdc/infrastructure/station_counts.html, www.ewg.org:16080/farm, www.ers.usda.gov/db/feedgrains, and EIA (2005), Figure 100.