DISCUSSION PAPER

June 2006; revised January 2007 ■ RFF DP 06-26

# Automobile Externalities and Policies

Ian W. H. Parry, Margaret Walls, and

Winston Harrington

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

# Automobile Externalities and Policies

Ian W. H. Parry

Margaret Walls

and

Winston Harrington

**Abstract**

This paper discusses the nature, and magnitude, of externalities associated with automobile use, including local and global pollution, oil dependence, traffic congestion and traffic accidents. It then discusses current federal policies affecting these externalities, including fuel taxes, fuel-economy and emissions standards, and alternative fuel policies, summarizing, insofar as possible, the welfare effects of those policies. Finally, we discuss emerging pricing policies, including congestion tolls, and insurance reform, and we summarize what appears to be the appropriate combination of policies to address automobile externalities.

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

**JEL Classification Numbers:** Q54, R48, H23

## Contents

***1. Introduction*** **........ 1**

***2. Automobile Externalities*** **........ 2**
*2.1 Local Air Pollution* ........ 2
*2.2 Global Air Pollution* ........ 4
*2.3 Oil Dependency* ........ 5
*2.4 Traffic Congestion* ........ 7
*2.5 Traffic Accidents* ........ 8
*2.6 Other Externalities* ........ 10
*2.7 Summary* ........ 11

***3. Traditional Policies*** **........ 11**
*3.1 Fuel Taxes* ........ 11
*3.2 Fuel-Economy Standards* ........ 14
*3.3 Emissions Standards and Related Policies* ........ 16
*3.4 Alternative Fuel Policies* ........ 17

***4. Emerging Pricing Policies*** **........ 18**
*4.1 Congestion Tolls* ........ 18
*4.2 Charging for Accident Risk* ........ 20

***5. Conclusion*** **........ 21**

***References*** **........ 22**

***Figures and Tables*** **........ 32**

# Automobile Externalities and Policies

Ian W.H. Parry*
Margaret Walls
and
Winston Harrington

## *1. Introduction*

Of all consumer products, few are taxed more heavily or regulated more extensively than automobiles. In the United States, ownership taxes over the life of a vehicle average about 18% of the sales price, and combined state and federal gasoline taxes average 40 cents per gallon, or about 20% of pre-tax fuel prices (Winston Harrington and Virginia McConnell, 2004). New vehicles also are subject to regulations governing local air pollution, safety, and fuel economy, and in many states, mandatory purchase of liability insurance.

At the same time, few consumer products require such a gigantic public infrastructure in order to be useful, one that costs more than $100 billion per year in road and bridge maintenance and new construction (BTS 2004, Table 3-29a). And automobile use also has many undesirable side effects. About 40,000 people die on highways each year (U.S. NHTSA 2002, Table 3); urban road congestion causes 3.7 billion hours of delay a year (David Shrank and Timothy Lomax 2005); automobiles are a leading source of greenhouse gases and local air pollutants; and gasoline accounts for nearly half of the nation's dependence on oil.

For these reasons, it is not surprising that automobiles and the fuels they use have attracted attention from government. What we may wonder is whether the current collection of policies makes sense or whether it could be improved upon, or even overhauled completely. Several recent trends make it a particularly good time for re-assessing federal automobile policies. First, there are heightened concerns about energy security with the recent tripling of world oil prices and alarming instability in the Middle East. Second, there is growing pressure on the federal government to curb greenhouse gases, with solidifying scientific evidence on global warming, various regional abatement initiatives, and the birth of carbon trading in Europe. Third, because of rising urban land costs and intense siting opposition, road capacity enhancements lag far behind relentlessly expanding vehicle use, with increasing gridlock the inevitable result. Fourth, due to declining real fuel-tax revenue per vehicle mile, there is a growing transportation funding gap, increasingly met at the regional level by referenda tying various tax increases to specific highway projects. Finally, with advances in electronic-metering technology it is now, for the first time, feasible to charge motorists on a per-mile basis according to the marginal external costs of their driving.

---

* Corresponding author. Resources for the Future, 1616 P Street NW, Washington DC, 20036. Phone (202) 328-5151; email parry@rff.org; web www.rff.org/parry.cfm. This paper was prepared for the *Journal of Economic Literature*.

From an efficiency perspective, the first issue in analyzing automobile policies is to identify the specific externalities that they are designed to address. Some of these externalities, such as those from greenhouse gases, vary with fuel combustion, while others, such as congestion, vary with the extent, location, and timing of travel. In section 2 below, we describe each of the major externalities, explain what margins of behavior they operate along, and summarize evidence on their magnitude. The rest of the paper focuses on the implications of these externalities for the appropriate design of federal policy, with emphasis on some practical difficulties in policy reform. Section 3 discusses the major federal policies currently affecting these externalities including fuel taxes, fuel-economy standards, new-vehicle emissions standards, and alternative fuel policies; section 4 describes emerging pricing policies that target congestion and accident externalities more directly. Section 5 briefly summarizes what appears to be the appropriate combination of policies.[1]

## *2. Automobile Externalities*

A number of other studies provide a general discussion of automobile externalities including Bruno de Borger and Stef Proost (2001), Mark Delucchi (2000), David Greene, Donald Jones and Delucchi (1997), Douglas Lee (1993), Todd Litman (2003), David Newbery (2005a), Ian Parry and Kenneth Small (2005), John Peirson, Ian Skinner and Roger Vickerman (1995), Richard Porter (1999), Emile Quinet (2004), Werner Rothengatter (2000), and U.S. FHWA (1997); here we distill some of the main findings.

### *2.1 Local Air Pollution*

Gasoline vehicles emit carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HC) (sometimes called volatile organic compounds).[2] CO reduces oxygen in the bloodstream causing breathing difficulty and cardiovascular effects, while HC and NOx react in sunlight to form ozone (the main component of smog), which affects pulmonary function in children and asthmatics, and reduces visibility. More important, NOx and HC also react to form particulate matter; fine particles (PM2.5) are small enough to reach lung tissue and studies have documented a causal relation between particulate exposure and mortality (Douglas Dockery, C. Arden Pope, Xiping Xu et al. 1993; Joel Schwartz 1994).

The generation of these pollutants can be reduced by curbing vehicle miles traveled (VMT), improving average vehicle fuel economy or through other technologies to lower exhaust emissions per gallon of fuel combustion. A gasoline tax alone is inadequate, as it does not encourage the last of these behavioral responses. Therefore, since the 1970 Clean Air Act, new passenger vehicles have been subject to grams-per-mile standards for CO, NOx, and HC. Initially these standards were slightly more stringent for cars than for light-trucks (sport utility

[1] A number of broader issues are beyond our scope, including automobile policies outside the United States, policies for heavy-duty trucks, how to improve highway-spending mechanisms to ensure that individual projects are economically efficient, and the interface between automobiles and urban development.

[2] Gasoline vehicles account for about 95% of new passenger vehicle sales; this includes the 4% of flexible-fuel vehicles that could operate on ethanol but typically use gasoline (EIA 2005). Diesel vehicles are far more common in Europe, where they often receive favorable tax treatment.

vehicles or SUVs, pickup trucks, and minivans), though standards have been harmonized since the mid-1990s so it is no longer the case that light-trucks produce more emissions per mile than cars.

The gram-per-mile standards allow manufacturers flexibility in meeting them through abatement or fuel-saving technologies and ensure that all new vehicles emit at the same per-mile rate, regardless of fuel economy. In the past, as vehicles aged, their emissions-control systems tended to deteriorate, so that in older vehicles the natural relationship between fuel economy and emissions rates per mile reasserted itself (Winston Harrington 1997). However, given the durability of state-of-the-art abatement technologies currently being used, emissions over the life of a vehicle have become largely decoupled from initial fuel economy (Carolyn Fischer, Harrington, and Parry 2006); this means that tailpipe emissions now vary primarily with VMT rather than total fuel consumption.

Despite high growth in VMT over the past 30 years, nationwide vehicle emissions of all local pollutants have fallen dramatically. This drop can be attributed to progressively more stringent new-vehicle emissions standards over time, along with retirement of the oldest, most polluting vehicles (Figure 1). The share of vehicle emissions in total stationary and mobile emissions also has declined; for example, almost half of HC emissions in 1970 were from mobile sources compared with only 28% in 2003 (EPA 2004).

Estimates of local pollution damages attributed to automobiles are dominated by mortality effects, especially due to particulates. Studies translate vehicle emissions into changes in ambient concentrations of primary and secondary pollutants based on climate, topography, and wind patterns, etc; health effects for exposed population groups are then inferred from epidemiological evidence; finally, monetary damage estimates are obtained from assumptions about people's willingness to pay to avoid health risks, using evidence from revealed and stated preference studies.[3]

Small and Camilla Kazimi (1995) projected pollution costs of 2.3 cents per mile for the Los Angeles region for the year 2000 (updating to 2005$), with a range of 1–8 cents per mile; NOx and HC emissions contribute about equally to these costs, mainly through particulate formation, while CO effects are ignored as their outdoor concentrations are too low to have noticeable health effects. Although meteorological conditions in Los Angeles are especially favorable for pollution formation, Small and Kazimi's estimates are broadly consistent with estimates for other urban areas (Donald McCubbin and Delucchi 1999, U.S. FHWA 2000). Nonetheless, local automobile emissions will continue to decline substantially in upcoming years as far more stringent regulations are phased in and the vehicle fleet turns over (see below); therefore, in terms of future policy reform, other externalities are of greater concern.

[3] An alternative approach that avoids the last two steps is to measure people's willingness to pay for cleaner air by comparing differences in property values across clean and dirty regions controlling for other factors (e.g., V. Kerry Smith and Ju-Chin Huang 1995, Kenneth Chay and Michael Greenstone 2005).

*2.2 Global Air Pollution*

Light-duty vehicles account for a fifth of nationwide emissions of carbon dioxide, which is the leading greenhouse gas (EIA 2005). A fuel tax essentially is equivalent to a tax on vehicle carbon emissions as, unlike for local pollutants, there are no viable technologies for reducing carbon emissions per gallon of fuel combustion.

Economists have attempted to estimate future damages from global warming. One well-known study by William Nordhaus and Joseph Boyer (2000) put the (population-weighted) expected global costs of a 2.5°C warming in 2100 at almost 2.0% of world GDP. Half of this is from the risk of catastrophic or abrupt climate change, which they estimated based on subjective expert judgment about the likelihood of major disruptions to GDP. Another significant damage component is from the possible spread of tropical disease, especially in Africa, which is inferred from data on the incidence of various diseases across different climatic regions, and disability adjusted life years lost per disease. Agricultural effects, allowing for farm-level adaptation to climate change, account for less than 10% of damages, though some countries, such as India, are predicted to suffer more than others. Sea-level rise accounts for a further 6% of damages; costs here reflect the value of inundated land and infrastructure necessary to protect valuable coastal regions. And damages to immobile settlements (e.g., Venice, Bangladesh), or to ecosystems, as measured by willingness to pay to preserve these assets, account for another 6% of costs.

Overall, Nordhaus and Boyer (1999), updated in Nordhaus (2006), put the discounted cost of current carbon dioxide emissions, over their expected 100-year atmospheric life, at equivalent to $20 per ton of carbon (in 2005$). However, there is a ramp-up effect over time with growth in potentially affected world output, improved mitigation technology, and as marginal damages from additional warming rise with the temperature level; the projected cost per ton of carbon rises to $84 by 2050, and $270 by 2100. Most other economic assessments are in the same ballpark (e.g., David Pearce 2005, Robert Mendelsohn et al. 1998); a meta-analysis by Richard Tol (2005) suggests a current upper bound cost of $50 per ton.

A strikingly different conclusion was reached in the recent *Stern Review* (Nicholas Stern 2006), which puts total damages from future warming at 5–20% of world GDP in perpetuity and recommends a current social cost equivalent of $311 per ton of carbon. This much larger estimate partly is explained by assumptions about more rapid warming, greater disruptions from extreme weather events, and a more limited scope for adaptation to climate change. But according to Nordhaus (2007), most of the difference is from their assumption that the social discount rate on future consumption is around 1% rather than 3–5% as assumed in most previous studies; the lower rate greatly magnifies the present value of damages occurring one or two centuries from now, when warming rises beyond 5°C under business as usual assumptions.[4] The appropriate discount rate for such long-range effects remains contentious (Paul Portney and John Weyant 1999). Conventional discount rates currently warrant fairly modest actions to slow

[4] The social discount rate per capita consists of the pure rate of time preference for discounting utility (assumed to be about zero in Stern 2006) and the growth in per capita consumption times the elasticity of marginal utility of consumption. Uncertainty over the future discount rate increases the expected value of the discount-*factor* applied to future damages; this can significantly increase expected marginal damages from today's emissions (Richard Newell and William Pizer 2003).

climate change for future generations, which some object to on ethical grounds; however, much lower rates are inconsistent with observed behavior, lead to perverse results in other contexts (e.g., drastic reductions in current consumption), and imply that the most speculative, distant effects have a large influence on current policy.

A gallon of gasoline contains 0.0024 tons of carbon (NRC 2002); therefore damages of $20, $50 and $300 per ton of carbon translate into 5, 12, and 72 cents per gallon of gasoline, respectively.

*2.3 Oil Dependency*

The United States consumes 21 million barrels of oil a day, of which almost 60% is imported (up from 27% in 1985); gasoline is the single most important source of oil use, accounting for 45% of petroleum products (EIA 2006). Although the EIA (2006) projects oil consumption to increase to 26 million barrels per day by 2025 (with the import share staying roughly constant), they predict that oil use relative to GDP will fall by around 30%, due to continued improvements in energy efficiency and growth in the overall economy outstripping growth in transportation fuel demand. Dependence on oil and foreign imports exposes the economy to energy price volatility and price manipulation (though the United States itself has some market power) and may compromise national security and foreign policy interests; however, the extent to which the market fails in all these regards often is murky.

*2.3.1 Vulnerability to Oil Price Volatility*. Projecting future oil prices is especially hazardous as they are sensitive to so many uncertainties: vehicle growth in China, OPEC behavior, supply from conventional and non-conventional sources (e.g., oil shale and tar sands), policy change in Saudi Arabia, etc. One recent assessment put the likelihood of a temporary $15–$50 per barrel price shock in the next 10 years at about 50% (Phillip Beccue and Huntington 2005). Simulation models and regression analyses suggest that a price shock of this magnitude would lower U.S. GDP by anything from 0.5 to 6.0%, by raising energy costs and deflating demand via a transfer of purchasing power to foreign suppliers (Hillard Huntington 2005). The shock would be more disruptive the greater the extent of market frictions, if the economy is in a slump at the time of the shock, or if there are constraints on monetary and fiscal policy.

However, the extent to which these macroeconomic disruption risks constitute a market failure is questionable. U.S. consumption of oil itself adds little to the risk of a worldwide price shock, and many analysts believe that firms and households adequately account for oil price volatility in their capital investment decisions, use of futures markets, inventory strategies, and so forth (Douglas Bohi and Michael Toman 1996). Others argue that disruption costs partly reflect market imperfections (e.g., price and wage rigidities, under-investment in fuel-efficient technologies) and are therefore not fully internalized. The most widely cited study, by Paul Leiby et al. (1997), puts the uninternalized disruption risks from oil price shocks at around $0–8.50 per barrel of U.S. oil consumption, or 0–20 cents per gallon of gasoline (updated to 2005$), assuming that the private sector internalizes 25–100% of the risk of price shocks.

*2.3.2 Market Power*. Although non-competitive pricing and investment behavior by OPEC countries may reduce global welfare, this fact itself does not drive any price wedge between the domestic U.S. demand curve and the oil import supply curve; if the United States were a price taker in the world oil market, there would be no efficiency basis for an oil tax on market power grounds. However, studies have shown that the United States currently has a limited degree of monopsony power in the world oil market; in principle this justifies an optimum tariff, as is familiar from trade theory, but only if welfare is viewed from a domestic rather than global perspective (which seems inconsistent with measuring climate damages on a global basis). Again, simulations by Leiby et al. (1997) suggest this tariff would amount to around \$3–10 per barrel, or 7–24 cents per gallon of gasoline (updated to 2005\$).[5]

*2.3.2 Military and Geopolitical Costs*. In principle, some portion of U.S. Middle East military expenditures may constitute part of the total external cost of oil dependency. Delucchi and James Murphy (2004) allocate part of the defense budget to Middle East operations, add to this an estimate of the annualized costs to the United States of conflicts in the region (prior to the protracted war in Iraq), and then allocate a portion of these costs to protecting oil supplies for domestic consumption (as opposed to other objectives, such as regional stability). They put the military burden attributed to automobiles at \$0.8–\$8.5 billion a year, or 0.5–6 cents per gallon of gasoline. However the marginal cost of military spending will only equal this average cost if military spending falls in proportion to (modest) reductions in gasoline demand; some analysts view military spending as more of a fixed than a variable cost and, therefore, assume the marginal cost of military spending is zero.

Dependence on oil also may constrain U.S. foreign policy if the government believes that oil-producing nations would disrupt the oil market in response to U.S. policy pressures. However, the overriding concern in the United States has become the flow of petroleum dollars to governments, such as Iran, or other groups, such as terrorists or insurgents in Iraq, that threaten regional or U.S. national security. These broader costs are exceptionally difficult to quantify: although the United States acting unilaterally has very little influence on these revenue flows,[6] oil-conserving technologies developed at home might still have a substantial longer-term impact if they were ultimately deployed in other large, industrializing countries such as China.

Summing up, as with global warming, there is room for legitimate debate about the extent and magnitude of externalities or broader market failures from oil dependence. Our discussion suggests a corrective tax might be anything from roughly 8–50 cents (excluding geopolitical costs); a recent panel of experts (NRC 2002) recommended a value of 12 cents per gallon. Whether the ideal corrective tax should be on consumption of gasoline (and other oil products) or just oil imports depends on whether the objective is to reduce the oil intensity of GDP or dependence on foreign oil, though an import tariff is likely precluded by international trade agreements.

---

[5] An alternative approach has been to estimate optimal oil tariffs in a dynamic setting, accounting for scarcity rents to exhaustible resources and the dependency of current production decisions on the expected path of future tariffs. Summarizing this literature, Newbery (2005b) puts the optimal oil tariff for the United States at \$3.8–\$15.6 per barrel.

[6] For example, a 10% reduction in U.S. oil imports would reduce long-term world oil prices by perhaps 0.5-2%, which is small when set against the recent tripling of oil prices.

*2.4 Traffic Congestion*

Between 1980 and 2003 urban VMT in the United States increased by 111%, against an increase in lane-mile capacity of only 51% (BTS 2004, Tables 1-6 and 1-33); annual urban congestion delays increased from 16 to 47 hours per driver, while the national cost of wasted time from congestion increased from $12.5 to $63 billion (Shrank and Lomax 2005). Clearly a fuel tax, which raises driving costs for all regions at all times of day, is a very blunt instrument for alleviating traffic congestion, which is highly specific to rush hour periods in urban areas; the ideal instrument is a road-specific congestion toll that varies with time of day.

*2.4.1 Theory of Congestion Externalities*. The standard way economists think about traffic congestion is to plot demand, average cost, and marginal cost as a function of vehicle flow, that is, the number of vehicles passing a point on a highway in an hour (Alan Walters 1961, William Vickrey 1963, Kenneth Button 2004, Robin Lindsey and Erik Verhoef 2002). The average cost is vehicle operating costs per mile (mainly fuel), plus the product of time per mile—the reciprocal of speed—and the value of travel time, usually assumed to be around 50% of the wage (Small 1992a, pp. 36–46). At low vehicle flows the average cost curve is flat, but it starts to rise as more vehicles on the road eventually force the motorist to slow down to maintain a comfortable time-separation with the vehicle just ahead. In this analysis, the marginal cost curve lies above the average cost curve as it also reflects the additional travel time costs to all motorists due to added congestion from an extra vehicle mile per unit of time. Since motorists only care about average costs to themselves, efficiency requires a Pigouvian tax equal to the gap between the marginal cost to all drivers and average cost to the individual, at the point where the marginal cost intersects the demand curve.

In the 1960s, however, engineers and economists realized that the flow congestion model was often not a very good description of rush-hour, which is characterized by very high densities, stop and go traffic, and "hypercongestion," where travel speeds are so low that total traffic flow actually declines—often to considerably less than half of road capacity. The existence of hypercongestion seemed to imply that the average cost curve was backward bending. Beginning with Vickrey (1969), models began to appear analyzing "bottleneck" congestion, which results when traffic flow temporarily exceeds capacity at a point, either because of a spike in demand or a sudden reduction in road capacity, such as an intersection with obstructing cross traffic or an accident (Richard Arnott, André de Palma and Robin Lindsay 1993, 1994, Arnott and Marvin Kraus 1995).

Models combining bottleneck and flow congestion appear to have resolved the problem of the backward-bending cost curve. For example, Se-Il Mun (1994) developed a dynamic model of travel between two distant points with a queue in the middle that forms and eventually clears during peak period; the travel cost is determined by the standard speed/flow relation on either side of the bottleneck, but also includes the waiting cost in the queue. The average travel cost over the entire trip is always increasing in the travel flow, and does not bend backwards, as in the traditional model.

Recognition of the important dynamics of congestion does not change the definition of the congestion externality, but it does suggest that estimating it is far more difficult than previously anticipated. Not only is roadway congestion highly variable over time and space, but now delay on a road is understood to be not usually the result of inadequate capacity on that road, but the result of a bottleneck elsewhere in the network. A further difference compared with the traditional formulation is that bottleneck models showed that the costs of congestion are broader than just the pure delay costs as they also include the costs to those who adjust their behavior to avoid congestion by re-scheduling trips or using mass transit (Arnott, de Palma and Lindsay 1994, Small and Xuehao Chu 2003).

*2.4.2 Nationwide Marginal Congestion Costs*. A number of studies estimate congestion costs for individual roads or cities, which is needed for local congestion policies, but few attempt to compute an average over a nation, which is needed to evaluate the federal fuel tax (at least until congestion is fully internalized through peak-period pricing). One exception, based on speed-flow curves, is U.S. FHWA (1997, 2000), which weighted marginal external costs for representative urban and rural roads at different times of day by the respective VMT shares; it put "averaged" marginal external costs at 5 cents per passenger mile, equivalent to $1.05 per gallon at current on-road fuel economy of 21 miles per gallon.

For assessing the congestion effects of fuel taxes, however, this cost 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. That is, higher fuel taxes will have a disproportionately large effect on roads with minimal congestion and a disproportionately small impact on congested roads; Parry and Small (2005) assumed marginal congestion costs of 3.5 cents per mile in their fuel-tax analysis. A later study, by Fischer, Harrington, and Parry (2006), estimates that national average marginal congestion costs (in response to lower fuel costs) are equivalent to 6.5 cents per mile; this is based on a spatially disaggregated model of the Washington, DC, metropolitan area transport network, with results extrapolated to all other U.S. metropolitan areas.[7]

*2.5 Traffic Accidents*

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 VMT in 1960 to 1.5 per 100 million VMT in 2003 (BTS 2004, Table 2-17), reflecting greater seatbelt use, improved vehicle technology, reduced drunk driving, and reduced pedestrian deaths as fewer people are inclined to walk.[8] Again, the theoretically ideal tax to factor accident risks into the costs of driving would not be a fuel tax but a tax on VMT reflecting differences in marginal external costs across drivers, vehicles, and regions. Although there is some consensus on how the total

[7] Both of the nationwide estimates of congestion costs account for bottlenecks in a crude way in the calibration of the speed-flow relations, and the second estimate accounts for the costs of behavior to avoid congestion; neither estimate accounts for non-recurrent congestion delays caused, for example, by weather and road works (accident delays are discussed below).

[8] Fatalities attributed to non-use of seatbelts fell from 13,301 in 1975 to 9,238 in 2000, airbags and child restraints saved 2,488 and 446 lives respectively in 2003, alcohol-involved fatalities fell from 23,167 in 1985 to 17,013 in 2003, and pedestrian deaths per VMT fell 84% between 1960 and 2003 (U.S. NTHSA 2002, Table 21; BTS 2004, Tables 2-25 and 2-30). Data on non-fatal injuries is available from 1990 and also shows a declining trend (BTS 2004, Table 2.17).

(internal and external) costs of traffic accidents can be estimated, separating out the *external* costs and putting them on a marginal basis is much more challenging.

*2.5.1 Social Costs of Traffic Accidents*. Table 1 compiles an estimate of the total social costs of traffic accidents (for all motor vehicles) for the year 2000, based on U.S. NHTSA (2002, Tables 3 and A-1) (see Ted Miller 1993 for an earlier estimate). Costs encompass quality-adjusted life years lost from injuries, property damages to automobiles, travel delays, medical costs, lost productivity in the workplace and at home, and insurance/legal expenses. Total costs are quite substantial at $433 billion (4.3% of GDP), equivalent to an average of 15.8 cents per VMT.

*2.5.2 Marginal Accident Externality*. A common assumption is that injury risks in single-vehicle crashes to the driver and other vehicle occupants are internalized, though whether driving by one individual raises injury risks for other drivers is unclear. All else being the same, the presence of one extra vehicle on the road raises the likelihood that other vehicles will crash, but if people compensate by driving more slowly or more carefully in heavier traffic this will lower both the number and average severity of collisions. The severity-adjusted risk for other drivers may even fall with more traffic, though this may not imply a positive externality, as the compensating behavior is itself costly. Unfortunately, empirical evidence on this issue is limited;[9] recent studies often assume no effects on injury risks to other drivers (e.g., Inge Mayeres, Sara Oschelen and Stef Proost 1996, U.S. FHWA 1997).

Aside from the inter-driver injury issue, studies typically include pedestrian and cyclist injuries in computing marginal external costs (these account for about 13% of fatalities attributed to passenger vehicles). Property damages in single- and multi-vehicle crashes mostly are treated as an external cost given that premiums primarily are levied on a lump sum rather than variable (per mile) basis (though premiums do rise temporarily following a claim); medical costs primarily are external, again because they largely are borne by third parties. Productivity effects, net of taxes, are internal for own-driver injury risks, though the revenue loss to the government is external.

Recent studies using this general approach put the marginal external costs at around 2–7 cents per mile, or 13 to 44% of average accident costs (e.g., U.S. FHWA 1997; Gunnar Lindberg 2001; Mayeres, Oschelen and Proost 1996; Miller et al. 1998; Parry 2004).

*2.5.3 Safety across Vehicle Types*. A further unsettled issue is the relation between vehicle size/weight and safety, which matters for policies that encourage vehicle downsizing or affect fleet composition. 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 safer for other road users, though again compensating behavior by drivers of lighter vehicles may weaken the effect. And all else being the same, light trucks do more damage to the occupants of

[9] Using panel data on state-average insurance premiums and claims, Aaron Edlin and Pinar Karaca-Mandic (2006) find that an additional driver can substantially increase insurance costs for other drivers in urban areas. However, insurance costs are far from a comprehensive measure as they mainly reflect property damages and these account for only 14% of social costs in Table 1; Edlin and Karaca-Mandic find mixed evidence on whether fatality rates increase or decrease with heavier traffic.

other vehicles than cars do, as trucks are heavier, have stiffer frames (and therefore transfer more energy to other vehicles), and have bumper heights that are not compatible with cars.

Most empirical literature on this issue has focused on the relationship between vehicle size/weight and total highway fatalities or injuries, and this literature has mixed results (e.g., Robert Crandall and John Graham 1989, Daniel Khazzoom 1997, Charles Kahane 1997, Douglas Coate and James VanderHoff 2001, Robert Noland 2004). For our purposes, we are interested only 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 factors such as property damage and medical costs.

Studies that use accident data to attribute injuries to different vehicles involved in the crash find only modest differences in external costs per mile between cars and light trucks (U.S. FHWA 1997, Miller et al. 1998, Parry 2004). However, econometric studies by Michelle White (2004) and Ted Gayer (2004), that are able to control for a wide range of non-vehicle characteristics, such as driver age, gender, region, speed, negligence, road class, weather, seatbelt use, etc., reach a different conclusion. For example, White (2004) 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 Other Externalities*

Other highway externalities are small, apply primarily to heavy trucks, or result from other policy failures rather than sub-optimal automobile and fuel policies.

*2.6.1 Noise*. Noise costs (from engine acceleration, tire/road contact, braking, etc.) have been inferred from hedonic property value models that include distance to local roads and traffic volumes as explanatory variables (though it is difficult to control for noise-mitigation barriers, such as hills, sound-proof walls, and double-glazed windows). Delucchi and Hsu Shi-Lang (1998) estimate costs of 0–0.4 cents per mile for passenger vehicles, while U.S. FHWA (1997), Table V-22, puts average external costs at 0.06 cents per mile.

*2.6.2 Highway Maintenance Costs*. Analysts have estimated the effect of axle loads and traffic volumes on pavement damage for different vehicle classes, controlling for factors such as pavement age and 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, Clifford Winston and Carol Evans 1989, Newbery 1988). U.S. FHWA (1997), Table V-9, puts external costs at only 0.06-0.08 cents per mile for passenger vehicles.

*2.6.3 Urban Sprawl*. Although the low cost of auto travel may contribute to urban fringe development, there is little consensus on the magnitude of this effect on external costs such as traffic congestion, loss of habitat, and open space amenities (McConnell and Margaret Walls 2005). Moreover, if sprawl is excessive, this primarily is due to tax preferences for housing and the failure of development fees and zoning restrictions to fully account for the external and infrastructure costs of new development.

*2.6.4 Parking Subsidies*. Many individuals park for free when they work or shop; Litman (2003) puts the costs from these parking subsidies at 3–10 cents per VMT (after dividing subsidies by average distance traveled). Again though, there remains dispute over whether free parking should be attributed as an external cost of automobile use as it results from other pricing distortions, including employee cost sharing and the treatment of parking as a tax-preferred fringe benefit.

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

*2.7 Summary*

Table 2 summarizes, albeit very tentatively, our best assessment of major automobile external costs omitting components, such as the geopolitical costs of oil dependence, that have not been quantified. Given the popular focus on the need to reduce U.S. gasoline consumption because of energy security and climate change, it is striking that these fuel-related externalities add to only 18 cents per gallon while mileage-related externalities (congestion, accidents, and pollution) are equivalent to $2.10 per gallon. Naturally, these figures need to be updated over time; for example, marginal local pollution and accident costs will likely fall in future with improved vehicle technology, while marginal congestion and carbon costs will rise over time.

## *3. Traditional Policies*

This section discusses what historically have 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*

Although gasoline taxes currently average 40 cents per gallon (18.4 cents at the federal level and 22 cents at the state level), they are low not only by international standards (see Figure 2) but also by historical standards. When expressed on a per-mile basis, fuel taxes have declined in real terms by 40% since 1960, due to the failure of nominal rates to keep pace with inflation, and improved fuel economy;[10] this latter trend will only be compounded in the future with the market penetration of hybrid and alternative-fuel vehicles. We first discuss how effective fuel taxes are in reducing fuel consumption and driving and then evaluate the existing level of fuel taxes vis-à-vis fuel-related externalities.

*3.1.1 Behavioral Responses*. The own-price elasticity of gasoline demand has been estimated from time-series models (often with a lag structure imposed) and cross-section data (which are better able to control for household characteristics). A decade ago, reviews pointed to a long-run gasoline demand elasticity of around –0.7 to –1.0 (Carol Dahl and Thomas Sterner 1991, Table

[10] From U.S. DOC (2003), Table 730, and www.vtpi.org/tdm/fueltrends.xls.

2; Phil Goodwin 1992, Table 1; Molly Espey 1996, Table 4). Later U.S. studies that better control for fuel-economy regulations and correlation among vehicle age, use and fuel economy, suggest a less elastic response; another factor may be the decline of fuel costs relative to the value of travel time. U.S. DOE (1996) proposed a long-run fuel price elasticity of –0.38, though other reviews by Goodwin, Joyce Dargay and Mark Hanly (2004) and Stephen Glaister and Dan Graham (2002) put the elasticity at –0.7 and –0.6, respectively. Estimated VMT/fuel price elasticities typically are around –0.1 to –0.3 (Glaister and Graham 2002; Goodwin 1992; Goodwin, Dargay, and Hanly 2004; Greene, James Kahn, and Robert Gibson 1999; Olof Johansson and Lee Schipper 1997; Paul Schimek 1996; Small and Kurt Van Dender 2006). Therefore, around 20–60% of the gasoline demand elasticity appears to reflect changes in VMT, while the other 40–80% reflects long-run changes in average fleet fuel economy, as manufacturers incorporate fuel-saving technologies into new vehicles and consumers buy smaller vehicles.

*3.1.2 Second-Best Fuel Taxes*. Assuming, for now, that more finely tuned pricing policies are unavailable, there are two alternative conceptual approaches to gauging the efficient level of fuel taxes (Newbery 2005a). One is to estimate the Pigouvian tax and then consider whether additional taxation might be warranted on broader fiscal grounds; the other is to have the fuel tax be chosen in part to guide highway spending toward efficient levels.

*Pigouvian Tax*. The Pigouvian gasoline tax, denoted by $t_G^P$, is given by (Parry and Small 2005):

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

where $E_F$ is the cost per gallon of carbon and oil dependence and $E_M$ is the cost per mile of local pollution, congestion, and accidents. $\beta$ is the fraction of the gasoline demand elasticity due to reduced mileage; the smaller the tax-induced reduction in fuel use that comes from reduced driving, the smaller the reduction in mileage-related externalities per gallon of fuel conservation and, correspondingly, the smaller the Pigouvian tax. Finally, $f$ is average on-road vehicle fuel economy, which converts mileage externalities into costs per gallon, though it will vary with the fuel tax. Let fuel economy be $f = f^0\{(p_G + t_G)/(p_G + t_G^0)\}^{(1-\beta)\eta_{GG}}$, where $p_G$ is the pre-tax price of gasoline, $\eta_{GG}$ is the (constant) own-price gasoline demand elasticity, and 0 denotes a current value.

Suppose we use the figures in Table 2 along with $\beta = 0.4$, $\eta_{GG} = -0.55$, $p_G = \$1.60$, $t_G^0 =$ 40 cents, and $f^0 = 21$. Then, using (3.1), and the fuel economy/fuel price relation, the Pigouvian tax would be \$1.11 per gallon, nearly three times the current tax.

*Broader Fiscal Rationale for Fuel Taxes*. Additional fuel taxation might be justified when the efficient balance between fuel taxes and labor income taxes in financing the government's overall budget is considered. In fact this is a timely issue; given looming pressures on the entitlement system, there have been calls for higher fuel taxes and other environmental taxes as part of deficit reduction packages (to reduce the need for future increases in other taxes).

Leaving aside distributional issues, and collapsing the broader fiscal system into a single tax on labor income, the optimal fuel tax can be decomposed into an externality correcting and a fiscal or Ramsey tax component, where the latter is positive if the taxed commodity is a relatively weak substitute for leisure. Using this approach, Parry and Small (2005) put the optimal fuel tax at 17 cents per gallon more than the pure Pigouvian tax when marginal fuel-tax revenues finance a proportionate reduction in labor income taxes. Sarah West and Roberton Williams (2006) suggest a somewhat larger upward adjustment to the optimal tax based on their econometric estimates of the gasoline/leisure cross-price elasticity. The upward adjustment would be larger still if, following the recycling of fuel-tax revenues in income tax cuts, account were taken of efficiency gains in the tax-distorted capital market, and efficiency gains from reducing distortionary tax preferences for housing, employer medical insurance, and other fringe benefits (Lans Bovenberg and Lawrence Goulder 1997, Parry and Antonio Bento 2000).[11] Accounting for broader fiscal considerations therefore can strengthen the efficiency case for raising fuel taxes above their current levels, though the overall optimal fuel tax is difficult to pin down, given uncertainty over behavioral responses to broader tax adjustments.

*Using Fuel Taxes to Promote Efficient Highway Spending*. Taking a somewhat different perspective, Newbery (2005a) argues for dividing fuel taxes into a road-user charge set to cover the maintenance and capital costs of the road network and an additional component to account for externalities other than congestion and road damage (with excess revenue going to the general government).

The rationale for the road-user charge is that if, on average, motorists are taxed for their contribution to congestion and pavement damage, then earmarking revenues will lead to the efficient level of spending on highway maintenance and expansion, assuming constant returns to spending and that projects are determined by a cost–benefit criterion (Newbery 1988, Button 2004). Any change in the composition of road-user charges would be revenue-neutral; thus, the introduction of congestion pricing in urban areas (and pavement damage pricing for heavy trucks) automatically would result in compensation to the average motorist (though perhaps not to owners of commercial vehicles), through a rearrangement of nationwide fuel taxes. For the United Kingdom, Newbery (2005a) puts the road-user component at about half of the current fuel tax; pollution and other externalities bring the optimal tax up to about 70% of the UK fuel tax, or more than $2 per gallon.

*3.1.3 Obstacles to Raising Fuel Taxes*. Whichever of the two conceptual approaches outlined above is taken, the current level of fuel taxation in the United States appears to be too low, leaving aside the issue of better pricing instruments. Nonetheless, skeptics of higher fuel taxes maintain that such taxes are unfair, are politically untenable, or that governments may end up wasting the extra revenue.

[11] In contrast, Louis Kaplow (2005) finds that the optimal environmental tax equals the Pigouvian tax for "distribution neutral" tax shifts in heterogeneous agent models; this result stems from his assumptions that the taxed commodity is an average leisure substitute and that all external costs reduce the marginal value of work relative to the marginal value of leisure.

As regards equity, most incidence studies find that gasoline taxes are regressive because lower-income groups have larger budget shares for gasoline. However, regressivity is mild when a measure of lifetime or permanent income is used in place of annual income (e.g., James Poterba 1989, 1991, CBO 1990, Erik Casperson and Gilbert Metcalf 1994), though some have argued against using lifetime income due to liquidity and other constraints on the ability to smooth consumption over the life cycle (Thomas Barthold 1994). A more comprehensive distributional analysis also would take into account who benefits from the recycling of fuel-tax revenues; moreover, low-income groups may benefit more (relative to their income) from the mitigation of congestion and other highway externalities, as VMT and the value of travel time decline relative to income for wealthier households (Mark Wardman 2001).

Even if any distributional concerns could be fully addressed through adjustments to the broader fiscal and benefit system, there has been immense political opposition to higher fuel taxes in the United States. Most likely this opposition is due in part to politically powerful auto manufacturers and oil companies, as well as to the greater vulnerability of households to fuel prices in the United States, where annual gasoline consumption per capita is around 470 gallons compared with only 90 gallons in Western Europe.[12] Just because gasoline tax increases have been politically unpalatable in the past, however, does not mean that they will be infeasible 10 or 20 years down the road; pressure for higher fuel (or other automobile) taxes from those concerned about global warming, energy dependence, under-funded highways, and widening federal deficits, is only likely to intensify.

Some observers have questioned whether revenues from any fuel-tax increase would be used wisely. Without any change in existing legislation, most of the extra revenue would be returned to state governments for highway projects, roughly in proportion to their share of total lane mile capacity. The federal cost share in these projects, which ranges up to 90%, is difficult to justify by appealing to the benefits accruing to citizens of other states (Wallace Oates 2006). It is easy to see how, in such a funding environment, the selection of projects to go forward would be less than optimal. Despite this argument however, estimates of the social rate of return to highway spending are typically within a range of around 0–30%, compared with a social discount rate of around 5% (TRB 2006, Ch. 3). This suggests that at the margin many highway projects would still increase efficiency, though not all analysts agree on this (Chad Shirley and Clifford Winston 2004). For more substantial gasoline tax increases, legislation might specify that revenues in excess of the desired level of highway spending accrue to the U.S. Treasury, though whether that would ultimately lead to a reduction in other taxes, or higher general public spending is unclear. Ideally perhaps, any excess revenues would be earmarked for other socially desirable spending, such as basic R&D into clean-fuel vehicles, or be included in a broader package of environmental taxes that raises enough revenue to cut income taxes by an amount that can be clearly specified in the accompanying legislation.

### *3.2 Fuel-Economy Standards*

The Corporate Average Fuel Economy (CAFE) program, established in the wake of the 1973 oil crisis, requires automobile manufacturers to meet standards for the average fuel

[12] From www.eia.doe.gov/emeu/international/contents.html. Consistent with this last point, Henrik Hammar, Asa Löfgren, and Sterner (2002) find that high gasoline consumption causes lower gasoline prices across OECD nations.

economy of their passenger vehicle fleets. The light-truck standard will be increased to 22.2 miles per gallon by 2007, while the standard for cars, 27.5 miles per gallon, has been fixed since 1985. Although the CAFE program significantly boosted fuel economy during the 1980s, it is unclear whether the standards presently are binding or not (Small and Van Dender 2006). Moreover, due to the rising share of light-duty trucks, which now account for half of new vehicle sales, average fuel economy of new passenger vehicles is still below its peak in 1987 (see Figure 3).[13]

Higher CAFE standards have been rationalized on the grounds that they reduce carbon emissions and oil dependence, as well as possibly addressing a market failure from consumer undervaluation of fuel economy. We take up both of these issues.

*3.2.1 Do Externalities Warrant Higher CAFE Standards?* Raising CAFE standards actually may increase the (net) costs of highway externalities (Andrew Kleit 2004; Fischer, Harrington, and Parry 2006), even though higher fuel taxes would decrease them.

This paradox can be explained by decomposing the change in external costs, net of existing taxes, following an incremental adjustment to either policy into two components. First is the change in gasoline demand times external costs per gallon from fuel-related externalities *net* of the currently prevailing fuel tax, which incorporates some of the societal costs of driving into the fuel price; second is the change in VMT times marginal costs from externalities that vary with distance traveled rather than fuel use. Increasing the fuel tax above its current level actually reduces efficiency in the gasoline market if external costs from carbon emissions and oil dependence are below 40 cents per gallon (as they are in Table 2). However, this effect is offset easily by externality benefits from reducing congestion, accidents, and local pollution as VMT falls; hence the Pigouvian fuel tax is (much) greater than the current tax. In contrast, higher fuel-economy standards actually increase, rather than reduce, VMT as they lower fuel costs per mile driven, though the increase in VMT is modest. Nonetheless, the impact of tightening CAFE could be to increase external costs overall (at least external costs that have been quantified).[14]

*3.2.2 Information Market Failures*. Even if the externality rationale for higher fuel-economy standards may be open to question, might they be justified by another, informational market failure? As documented by NRC (2002), there is a wide range of existing and emerging technologies for increasing new-vehicle fuel economy for which the discounted, lifetime fuel

[13] Manufacturers must pay a penalty of $55 per vehicle for every 1 mpg that their fleet average falls below the relevant standard. A lower standard for light-trucks originally was permitted to limit the burden on industrial interests, though this argument lost its relevance with the rapid growth in use of light trucks for passenger vehicles.

[14] Small and van Dender (2005) project that only around 10% of fuel savings from improved fuel economy will be offset by extra driving. The effect of tighter fuel economy regulation on mileage is not symmetrical to the effect of higher fuel taxes; in each case the demand for vehicles falls (either because vehicle prices or fuel costs increase), having a counteracting effect in the first case, and a reinforcing effect in the second.

The above discussion assumes the value of a dollar of gasoline tax revenue is a dollar; as suggested above, the social value may exceed a dollar, given that revenues are earmarked for highway spending. In this case the efficiency loss from the reduction in gasoline tax revenues is slightly larger, as it crowds out socially desirable public spending (Fischer, Harrington, and Parry 2006).

savings appear to exceed the upfront installation costs. Are there reasons why such seemingly cost-effective technologies may not be adopted by the market, without more stringent regulation?

One possibility is that consumers undervalue new-vehicle fuel economy because they have short planning horizons, high discount rates, care more about other vehicle attributes, or do not expect savings to be reflected in used-vehicle prices (Greene 1998). Unfortunately, there is little in the way of solid empirical (as opposed to anecdotal) evidence on this hotly contested issue.[15] Another possibility is that engineering studies have ignored alternative uses for new technologies; the economic cost of a technology used to improve fuel economy is the larger of its installation cost and its potential value if used instead to enhance other vehicle attributes such as horsepower (Austin and Dinan 2005). And a final possibility, particularly given current fuel prices, is that emerging technologies will penetrate the market over time in response to consumer demand for better fuel economy, in which case higher mileage standards may have little effect.

Whether higher fuel-economy standards would increase or reduce efficiency or have little effect remains unsettled. Kleit (2004) and Austin and Dinan (2005) find that costs from binding increases in standards of 3–4 miles per gallon would cost around $3–4 billion or more, assuming market adoption of all privately cost-effective technologies. Higher fuel-economy standards significantly increase efficiency only if carbon and oil dependence externalities greatly exceed the mainstream estimates in Table 2, or if consumers perceive only about a third of the actual fuel-economy benefits (Fischer, Harrington, and Parry 2006). Economic analyses strongly support higher fuel taxes over higher fuel-economy standards (Kleit 2004, Austin and Dinan 2005, West and Williams 2005). Although it can be argued both ways, if the only immediate choice is to do nothing or to gradually increase CAFE standards, we ourselves would probably lean toward the latter given, the potential geopolitical benefits of reduced oil dependence.

*3.2.3 Accidents and CAFE*. Tighter fuel-economy regulations may affect external accident costs to the extent that: (a) total VMT changes, (b) the share of cars versus light trucks in the vehicle fleet changes, and (c) manufacturers produce smaller or lighter vehicles. The first effect probably is fairly minor, while the second could be important if the lower standard for light trucks were removed, for example, by allowing trading of CAFE credits across cars and light trucks. There is little solid evidence on how vehicle downweighting would affect a comprehensive measure of accident externalities.

### *3.3 Emissions Standards and Related Policies*

The principal instrument targeted at local emission rates is the set of new-vehicle grams-per-mile exhaust standards for HC, NOx, and CO introduced in the 1970 Clean Air Act (CAA), and subsequently tightened over time. In fact, once the "Tier Two" standards (which apply to all cars and light trucks) are fully phased in, new-vehicle emissions rates will be just 0.8–5.0%, of

[15] Although there is an empirical literature finding that consumer discount rates exceed market rates for many energy saving technologies, we are aware of only one study, by Mark Dreyfus and Kip Viscusi (1995), applied specifically to automobiles. They estimated implicit consumer discount rates for future fuel savings of 11–17%, though average interest rates on car loans were 13–15% during their sample period, suggesting that high discount rates may reflect credit constraints rather than myopia. A big data problem has been controlling for all other relevant vehicle characteristics when comparing prices of vehicles with different fuel economy.

pre-1970 rates (Table 3); these reductions have been achieved through technology improvements such as the three-way catalyst that adjusts the air/fuel ratio using computer-controlled sensors.[16] The 1977 CAA Amendments also required programs subjecting vehicles to periodic emissions inspections and, if necessary, repairs to meet the standard for regions with air-quality problems.

Automotive fuels also are subject to various regulations. According to Newell and Kristian Rogers (forthcoming), the phase-out of leaded gasoline produced benefits (e.g., health improvements from reduced incidence of high blood pressure) that exceeded the control costs, and also facilitated the use of catalytic converters to control other emissions. The 1990 CAA Amendments required that oxygenated fuels be used in certain urban areas during winter, a requirement that since has been replaced by an ethanol mandate (see below). And, to reduce evaporative HC emissions, the reformulated gasoline program specifies a maximum allowable fuel vapor pressure during summer in areas out of compliance with national ozone standards.

EPA conducted a retrospective cost–benefit analysis of the CAA over 1970–1990 and a prospective analysis for 1990–2010 (EPA 1997, 1999). The retrospective analysis put the costs of auto-emissions controls at $5.5 billion in 1990, while the prospective study, which includes the costs of tighter emissions standards, inspection and maintenance programs, and the reformulated and oxygenated fuel programs, estimates costs at $9.1 billion and $12.3 billion for 2000 and 2010, respectively (in 1990$). Although the benefits of reduced automobile emissions are not explicitly decomposed from those attributable to stationary sources in these analyses, it seems highly likely that they would exceed the estimated control costs.

In theory, the ideal instrument to control local tailpipe emissions would be an emissions tax levied on each vehicle that varied with local population exposure and time of year. However, the existing combination of emissions standards, inspection programs, fuel taxes, and fuel regulations does not rely on the measurement of in-use emissions, and thus may be simpler to administer. Moreover, there may not be much difference on cost-effectiveness grounds as together these instruments exploit all the potential margins for emissions reductions.

### *3.4 Alternative Fuel Policies*

Government policies also encourage production of and research into a variety of emerging and potential alternatives to gasoline.

Ethanol receives a federal tax credit of 51 cents per gallon, and the 2005 Energy Policy Act imposes minimum ethanol purchase requirements on refineries. However, due to opposition from agricultural and producer interests, ethanol imports have high tariffs. Ethanol is blended with gasoline to make E10 (10% ethanol, 90% gasoline) although at modest extra cost, flexible-fuel vehicles can be produced to run on either gasoline or an 85% ethanol blend (these vehicles are further encouraged through CAFE credits). Ethanol currently is produced from corn however, once the production technology has evolved, the hope is to produce cellulosic ethanol from switchgrass and other fibrous plants; cellulosic ethanol would not consume valuable farmland

[16] Due to its unique air-quality problems, California can set its own standards, and these have generally been stricter than the federal standards. Other states may adopt the California standards but not set their own independent standards.

and, accounting for energy used in fuel production, the carbon savings over a gallon of gasoline are around 80%, compared with 20% for corn ethanol (Newell 2006). Although EIA (2005) projects ethanol production will rise to 10–14 billion gallons by 2030, this is still less than a tenth of projected gasoline demand.

The government also is subsidizing an effort to develop vehicles that run on electricity produced from a reaction between hydrogen and oxygen, but the technological challenges are formidable (NAS 2004). These include the high cost of hydrogen fuel cells, the problem of safe on-board storage (even compressed hydrogen takes up far more space than other fuels); the current high costs of producing hydrogen from fossil fuels or water; and the cost of transitioning to a fuel distribution network based on hydrogen. A possible intermediate technology that could become competitive, at least after substantial advances in battery technology, is the plug-in hybrid, which combines an internal combustion engine, regenerative braking, and on-board battery storage that can be recharged from a power socket.

The new ethanol mandate (if binding) seems likely to reduce efficiency, given the large pre-existing tax-preference for ethanol (not to mention agricultural subsidies for corn production), and the relatively modest per-gallon externalities from gasoline itself. And studies suggest that the incremental costs of reducing gasoline dependence through subsidizing the adoption of alternative fuel vehicles more generally rise sharply, as they are more expensive and have shorter driving ranges than their gasoline counterparts (e.g., Alan Krupnick and Walls 1992, Walls 1996, Kazimi 1997, Leiby and Jonathan Rubin 2001). Although it makes sense to invest in a diverse portfolio of basic R&D prospects to reduce long-term oil dependence, tax credits for alternative fuels or alternative-fuel vehicles are far less efficient instruments than fuel taxes, as they do not exploit the entire range of fuel conserving options, which include reduced use, and improved fuel economy, of conventional vehicles.

## *4. Emerging Pricing Policies*

We now discuss more finely tuned instruments for addressing congestion and accidents that ideally would complement fuel taxes and that have become feasible with advances in electronics and telecommunications.

### *4.1 Congestion Tolls*

Although congestion pricing, which involves charging motorists the difference between marginal costs to all drivers and average travel cost to the individual at a point in time, largely has been ignored by transportation policymakers to date, the confluence of several factors makes this an especially favorable time for its serious consideration.[17] One is the increasing difficulty of building new roads, due to rising urban property values and opposition from neighborhood and environmental groups, along with the realization that road building is partly self-defeating as it

[17] Many roads have tolls for revenue collection, but these vary little by time of day. 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, and the less effective cordon toll rings implemented in several Norwegian cities in the 1980s (Georgina Santos 2004).

encourages more driving.[18] Another is the growing need for new fiscal instruments to pay for highways, given the steady erosion of real fuel-tax revenue per VMT and the recognition that road pricing would aid in indicating where capacity additions would have greatest benefit (TRB 2006, Todd Goldman and Martin Wachs 2003). Furthermore, congestion fees now can be deducted electronically by in-vehicle transponders, thereby avoiding bottlenecks at worker-operated tollbooths, or through direct billing with on-board global positioning systems. But there remain formidable practical and political obstacles to widespread implementation of ideal congestion pricing.

On the practical side, it may be computationally infeasible to estimate marginal congestion costs on every single link and intersection in an urban road network, particularly given that pricing at one point diverts traffic elsewhere within the network, and that stop-and-go queues at bottlenecks are subject to rapid and substantial change. Even if such a pricing system could be reliably simulated, it would impose substantial information processing costs on drivers; moreover, their ability to respond to charges that vary in real time may be limited once the trip has begun. Thus far, most actual or proposed congestion pricing schemes vary with time of day (rather than with real-time traffic conditions) and are confined to major urban expressways, or cordon tolls; this more piecemeal approach limits efficiency gains, partly because of worse congestion resulting elsewhere in the network (e.g., Small and Jia Yan 2001, Erik Verhoef 2005, Newbery and Santos 2002). Moreover, toll levels may not be second-best optimal if they are set by private, revenue-maximizing operators.

On the political side, electronic toll collection raises privacy concerns, even though systems can be designed to avoid the central collection of travel information; in fact market penetration of transponders is surprisingly low so far—less than 50% in most U.S. toll road systems (ETTM 2002). Another barrier is that, prior to the distribution of congestion toll revenues, many motorists are worse off in terms of paying tolls that exceed their value of travel time savings; this makes some observers pessimistic that congestion pricing will ever be widely implemented (e.g., Genevieve Giuliano 1992).

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 (1992b) and Goodwin (1994) recommend a mix of spending on transportation alternatives, road improvements, and reductions in other taxes, while a stated preference study by Harrington, Krupnick and Anna Alberini (2001) finds a discernable increase in support for congestion pricing when toll revenues are recycled in the form of other local tax reductions.[19] Another possibility is to begin with pricing reforms for which there is the least opposition, such as converting high occupancy vehicle (HOV) lanes to high occupancy/toll (HOT) lanes that single-occupant vehicles can pay to use and then building new toll-lane capacity to create a network of premium lanes covering an entire urban area (Robert Poole and Kenneth Orski 2001, TRB 2006).

[18] Some day, freeway capacity might be dramatically increased without more pavement; advanced sensing technologies, which are already being incorporated into high-end vehicles, together with embedded detectors in highways, may permit "platoons" of vehicles to travel together at high speed under computer control with minimal headway between vehicles (Roberto Horowitz and Pravin Varaiya 2000).

[19] Productive use of revenues is also important to ensure that congestion tolls are efficiency improving overall (Parry and Bento 2001).

In Europe, congestion pricing may be on the verge of breaking out into much more widespread use. Following the successful cordon toll introduced in central London in 2003, the national U.K. government is considering replacing its fuel taxes with a system of per-mile charges that would vary sharply with region and time of day (Jonathan Leape 2006, Santos 2004, Ch. 11). Stockholm introduced a time-varying cordon toll in 2006 and heavy truck tolls have been introduced in Germany and Switzerland. Although there is growing interest in the United States, congestion pricing has been slower to get off the ground, and applications have been limited to the construction of HOT lane capacity (e.g., SR91 in Orange and Riverside Counties in Southern California, I-15 in San Diego, and I-10 in Houston).

*4.2 Charging for Accident Risk*

In this last section, we focus on innovative pricing policies to internalize accident risks into the choice of how much to drive.[20] As already mentioned, the ideal policy would be to charge drivers according to the marginal external accident cost per mile, though measuring how this varies across individuals, vehicles, and regions is problematic. Still, even a uniform VMT tax is more cost-effective at reducing accidents than fuel taxes as all, rather than a portion, of the behavioral response to it comes from reduced driving.

In fact a form of charging by the mile for accident risk may emerge on its own through the market. This is pay-as-you-drive (PAYD) insurance under which a person's insurance payment would vary in direct proportion to annual VMT scaled by the driver's (and possibly the vehicle's) relative risk factor. This risk factor would be determined by insurance companies, and it has been estimated that the charge for the average motorist would be around 6 cents per mile (Litman 2004b). PAYD would provide incentives to limit driving trips, unlike the current insurance system where annual premiums depend only weakly on mileage, and these incentives would be greatest for the drivers with highest risk factors. 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. Edlin (2003) estimates substantial efficiency gains from switching to PAYD, particularly when the reduction in the entire spectrum of auto externalities is taken into account.[21]

[20] Pricing and various non-pecuniary penalties are also used to deter drunk drivers, though the expected penalty per trip is well below the external cost per trip, due to the very small likelihood of arrest (Donald Kenkel 1993, Steven Levitt and Jack Porter 2001). A promising new technology for deterring recidivism is the alcohol interlock ignition technology, which is increasingly required for DUI offenders in New Mexico.

[21] PAYD schemes are emerging 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.

## *5. Conclusion*

It could be argued that the externality rationale for higher fuel taxes has come and gone. Electronic road pricing offers the only real hope of addressing relentlessly increasing urban gridlock, while encouraging a transition to mileage-based insurance would improve highway safety more effectively. And local tailpipe emissions are rapidly declining with improved technology to meet progressively more stringent new-vehicle emissions standards.

That leaves climate change and oil dependence, but even for these problems other policies are more appropriate. Climate change requires an economy-wide approach, particularly given that most of the low-cost options for emissions abatement are in the power sector. Economists typically favor a carbon tax imposed upstream on fossil fuels, moderately scaled at first but rising steadily over time, with credits for downstream carbon capture and sequestration.[22] Similarly, taxing all oil products, including aviation fuel, diesel fuel, home heating oil, and petrochemicals, would be more cost-effective than taxing gasoline alone. Moreover, higher energy taxes need to be buttressed with technology policies if a radical transition away from fossil fuels is to be achieved over the next generation or two, though economic analysis is needed on how prevailing R&D spending, and its composition across different technological possibilities, could be improved.

Nonetheless, given that the widespread adoption of the ideal set of externality taxes is unlikely in the near term, a progressive increase in the federal gasoline tax seems to make sense after all, given that it is administratively simple, and unlike fuel-economy standards, it favorably affects all the externalities and raises revenue. The model here might be the “fuel-tax escalator” in place in the United Kingdom during the 1990s under which the nominal tax rate automatically increased each year; a four cent–per gallon increase each year would double (federal and state) fuel taxes within a decade. Legislation could be introduced to require periodic review and re-authorization of the fuel-tax escalator and possibly require its suspension in the event of an oil price shock, or if revenues from other road-user fees become more significant. The thorniest issue would be designing legislation to ensure the productive use of additional revenue flows. Initially, given the pressure on local transportation budgets, revenues might remain earmarked for highways. Down the road, legislation might require that revenues be combined with those from other environmental taxes, such as carbon taxes (or auctioned carbon permits), and used to lower personal income taxes or pay down the federal deficit.

[22] Taxes have a number of advantages over a cap-and-trade permit approach (Nordhaus 2006). For example, freely allocated permits do not raise government revenues, they transfer large rents from energy consumers to (wealthy) stockholders in energy companies, volatility in carbon prices can deter large fuel-saving capital investments, and rancorous negotiations over country-level quotas would be avoided if agreement were only needed on a harmonized carbon tax.

*References*

Arnott, Richard, André de Palma, and Robin Lindsey. 1993. "A Structural Model of Peak-Period Congestion: A Traffic Bottleneck with Elastic Demand." *American Economic Review* 83: 161-179.

Arnott, Richard, André de Palma, and Robin Lindsey. 1994. "The Welfare Effects of Congestion Tolls with Heterogeneous Commuters." *Journal of Transport Economics and Policy* 18: 139-161.

Arnott, Richard, and Marvin Kraus. 1995. "Financing Capacity in the Bottleneck Model." *Journal of Urban Economics* 38: 272-290.

Austin, David, and Terry Dinan. 2005. "Clearing the Air: The Costs and Consequences of Higher CADE Standards and Increased Gasoline Taxes." *Journal of Environmental Economics and Management* 50: 562-582.

Banks, James H. 1981. "Freeway Speed-Flow-Concentration Relationships: More Evidence and Interpretations." *Transportation Research Record* 1225: 53-60.

Barthold, Thomas. 1994. "How Should We Measure Distribution?" *National Tax Journal* 46: 291-99.

Beccue, Phillip C., and Hillard G. Huntington. 2005. "As Assessment of Oil Market Disruption Risks." Energy Modeling Forum, Stanford University, Stanford, CA.

Bohi, Douglas R., and Michael A. Toman. 1996. *The Economics of Energy Security*. Kluwer Academic Publishers, Boston, MA.

Bovenberg, A. Lans, and Lawrence H. Goulder. 1997. "Costs of Environmentally Motivated Taxes in the Presence of Other Taxes: General Equilibrium Analyses." *National Tax Journal* 50: 59-88.

BTS, 2004. *National Transportation Statistics 2004*. Bureau of Transportation Statistics, U.S. Department of Transportation, Washington, DC.

Button, Kenneth. 2004. "The Rationale for Road Pricing: Standard Theory and Latest Advances." In Georgina Santos (ed.) *Road Pricing: Theory and Evidence.* Research in Transportation Economics 9, Elsevier, New York: 3-25.

Casperson, Erik, and Gilbert Metcalf. 1994. "Is a Value Added Tax Regressive? Annual Versus Lifetime Incidence Measures." *National Tax Journal* 47: 731-746.

CBO, 1990. *Federal Taxation of Tobacco, Alcoholic Beverages, and Motor Fuels*. U.S. Congressional Budget Office, Washington, DC.

Chay, Kenneth Y., and Michael Greenstone. 2005. "Does Air Quality Matter? Evidence from the Housing Market." *Journal of Political Economy* 113: 376-424.

Chernick, Howard, and Andrew Reschovsky. 1997. "Who Pays the Gasoline Tax?" *National Tax Journal* 50: 233-260.

Coate, Douglas, and James VanderHoff. 2001. "The Truth about Light Trucks." *Regulation* Spring: 22-27.

Crandall, Robert W., and John G. Graham. 1989. "The Effects of Fuel Economy Standards on Automobile Safety." *Journal of Law and Economics* 32: 97-118.

Dahl, Carol, and Thomas Sterner. 1991. "Analyzing Gasoline Demand Elasticities: A Survey." *Energy Economics* 2: 203-210.

De Borger, Bruon, and Stef Proost. 2001. *Reforming Transport Pricing in the European Union*. Edward Elgar, Northampton, MA.

Delucchi, Mark A., and James Murphy. 2004. *US Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles*. Institute of Transportation Studies, University of California, Davis, CA.

Delucchi, Mark A. and Shi-Ling Hsu. 1998. "External Damage Cost of Noise Emitted from Motor Vehicles." *Journal of Transportation and Statistics* 1: 1-24.

Delucchi, Mark A. 2000. "Environmental Externalities of Motor Vehicle Use." *Journal of Transport Economics and Policy* 34: 135-168.

Dockery, Douglas W., C. Arden Pope, Xiping Xu, John D. Spengler, James H. Ware, Martha E. Fay, Benjamin G. Ferris, and Frank E. Speizer. 1993. "An Association Between Air Pollution and Mortality in Six U.S. Cities." *New England Journal of Medicine* 329: 1753-59.

Dreyfus, Mark K., and W. Kip Viscusi. 1995. "Rates of Time Preference and Consumer Valuations of Automobile Safety and Fuel Efficiency." *Journal of Law and Economics* 38: 79-98.

Edlin, Aaron S. 2003. "Per-Mile Premiums for Auto Insurance." In Richard Arnott, Bruce Greenwald, Ravi Kanbur, and Barry Nalebuff (eds.), *Economics for an Imperfect World: Essays In Honor of Joseph Stiglitz*. CMIT Press, Cambridge.

Edlin, Aaron S., and Pinar Karaca-Mandic. 2006. "The Accident Externality from Driving." *Journal of Political Economy* 114: 931-955.

EIA. 2005. *Annual Energy Review*. Energy Information Administration, U.S. Department of Energy, Washington, DC.

EIA. 2006. *Annual Energy Outlook 2006 with Projections to 2030*. Energy Information Administration, U.S. Department of Energy, Washington, DC.

EPA.1997. *The Benefits and Costs of the Clean Air Act, 1970 to 1990*. U.S. Environmental Protection Agency, Washington DC.

EPA. 1999. *The Benefits and Costs of the Clean Air Act, 1990 to 2010*. U.S. Environmental Protection Agency, Washington DC.

EPA. 2004. *Air Emissions Trends – Continued Progress Through 2004*. U.S. Environmental Protection Agency, Washington DC. Available at www.epa.gov/airtrends/2005/econ-emissions.html.

Espey, Molly. 1996. "Explaining the Variation in Elasticity Estimates of Gasoline Demand in the United States: A Meta-Analysis." *Energy Journal* 17: 49-60.

ETTM. 2002. *United States Toll Facilities*. ETTM on the Web. Available at www.ettm.com.

Fischer, Carolyn, Winston Harrington, and Ian W.H. Parry, 2006. "Should Automobile Fuel Efficiency Standards be Tightened?" Discussion paper, Resources for the Future, Washington, DC.

Gayer, Ted. 2004. "The Fatality Risks of Sport-Utility Vehicles, Vans, and Pickups Relative to Cars." *Journal of Risk and Uncertainty* 28: 103-33.

Gerard, David, and Lester B. Lave. 2004. "Why Gas Taxes and Fuel Economy Standards are Too Low: The Economics of the CAFE Reconsidered." Discussion paper, Carnegie Mellon University.

Giuliano, Genevieve. 1992. "An Assessment of the Political Acceptability of Congestion Pricing." *Transportation* 19: 335-358.

Glaister, Stephen, and Dan Graham. 2002. "The Demand for Automobile Fuel: A Survey of Elasticities." *Journal of Transport Economics and Policy* 36: 1-25.

Goldman, Todd, and Martin Wachs. 2003. "A Quiet Revolution in Transportation Finance: The Rise of Local Option Transportation Taxes." *Transportation Quarterly* 57: 19-32.

Goodwin, P.B. 1992. "A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes." *Journal of Transport Economics and Policy*: 26: 155-169.

Goodwin, Phil B. 1994. "Road Pricing or Transport Planning?" In Johansson Börje and Lars-Göran eds., *Road Pricing: Theory, Empirical Assessment and Policy*. Springer.

Goodwin, Phil B., Joyce Dargay, and Mark Hanly. 2004. "Elasticities of Road Traffic and Fuel Consumption With Respect to Price and Income: A Review." *Transport Reviews* 24: 275-292.

Greene, David L. 1998. "Why CAFE Worked." *Energy Policy* 26: 595-614.

Greene, David L., Donald W. Jones and Mark A. Delucchi. 1997. *The Full Costs and Benefits of Transportation: Contributions to Theory, Method, and Measurement*. Springer, New York.

Greene, David L., James R. Kahn, and Robert C. Gibson 1999. "Fuel Economy Rebound Effect for Household Vehicles." *The Energy Journal* 20:1-31.

Hall, Fred L., and Lisa M. Hall. 1990. Capacity and Speed Flow Analysis of the QEW in Ontario. *Transportation Research Record* 1287: 108-118.

Hammar, Henrik, Asa Löfgren, and Thomas Sterner. 2002. "Political Economy Obstacles to Fuel Taxation: Using Granger Non-Causality Test to Gauge the Strength of Lobbying." Environmental Economics Unit, Göteborg University (Sweden), Working paper.

Harrington, Winston, Alan J. Krupnick, and Anna Alberini. 2001. "Overcoming Aversion to Congestion Pricing." *Transportation Research A* 35: 87-105.

Harrington, Winston, and Virginia McConnell. 2004. "Motor Vehicles and the Environment." In Tom Tietenberg and Henk Folmer, *The International Yearbook of Environmental and Resource Economics*, Edward Elgar, Northampton, MA, pp. 190-268.

Hoerner, Andrew J., and Benoît Bosquet. 2001. *Environmental Tax Reform: The European Experience*. Center for a Sustainable Economy, Washington, DC.

Horowitz, Roberto, and Pravin Varaiya. 2000. "Control Design of an Automated Highway System." *Proceedings of the IEEE* 88: 913-925.

Huntington, Hillard G. 2005. "The Economic Consequences of Higher Crude Oil Prices." Energy Modeling Forum, Stanford University, Stanford, CA.

Johansson, Olof, and Lee Schipper. 1997. "Measuring the Long-Run Fuel Demand of Cars: Separate Estimations of Vehicle Stock, Mean Fuel Intensity, and Mean Annual Driving Distance." *Journal of Transport Economics and Policy* 31: 277-292.

Kahane, Charles J. 1997. *Relationships Between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*. DOT HS 808 570, U.S. National Highway Traffic Safety Administration, Washington, DC.

Kaplow, Louis. 2005. "On the (Ir)Relevance of Distribution and Labor Supply Distortion to Government Policy." *Journal of Economic Perspectives* 19: 159-176.

Kazimi, Camilla. 1997. "Valuing Alternative Fuel Vehicles in Southern California," *American Economic Review Papers and Proceedings* 87: 265-271.

Kenkel, Donald S. 1993. "Do Drunk Drivers Pay Their Way? A Note on Optimal Penalties for Drunk Driving." *Journal of Health Economics* 12: 137-149.

Khazzoom, J. Daniel. 1997. "Impact of Pay-at-the-Pump on Safety Through Enhanced Vehicle Fuel Efficiency." *The Energy Journal* 18:103-133.

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

Krupnick, Alan and Margaret Walls. 1992. "The Cost-Effectiveness of Methanol for Reducing Motor Vehicle Emissions and Urban Ozone." *Journal of Policy Analysis and Management* 11: 373-396.

Leape, Jonathan. 2006. "The London Congestion Charge." *Journal of Economic Perspectives* 20: 157-176.

Lee, Douglas B. 1993. *Full Cost Pricing of Highways*. Department of Transportation, Washington, DC.

Leiby, Paul, Donald W. Jones, T. Randall Curlee, and Russell Lee. 1997. *Oil Imports: An Assessment of Benefits and Costs*. Oak Ridge National Laboratory, ORNL-6851.

Leiby, Paul N., and Jonathan Rubin. 2001. "Effectiveness and Efficiency of Policies to Promote Alternative Fuel Vehicles." *Transportation Research Record* 1750: 84-91.

Levitt, Steven D., and Jack Porter. 2001. "How Dangerous are Drinking Drivers?" *Journal of Political Economy* 109: 1198-1237.

Lindberg, Gunnar. 2001. "Traffic Insurance and Accident Externality Charges." *Journal of Transport Economics and Policy* 35: 399-416.

Lindsey, Robin, and Erik T. Verhoef. 2002. "Traffic Congestion and Road Pricing." In Kenneth J. Button and D.A Hensher (eds.), *Handbook of Transport Systems and Traffic Control*, 77-104, Pergamon, Oxford.

Litman, Todd. 2003. *Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications*. Victoria Transport Policy Institute, Victoria, Canada. www.vtpi.org/tca.

Litman, Todd. 2004a. *London Congestion Pricing: Implications for Other Cities*. Victoria Transport Policy Institute, Victoria, Canada. www.vtpi.org/tca.

Litman, Todd, 2004b. *Pay-As-You-Drive Vehicle Insurance Converting Vehicle Insurance Premiums Into Use-Based Charges*. Victoria: Victoria Transport Policy Institute.

Mayeres, Inge, Sara Ochelen, and Stef Proost. 1996. "The Marginal External Costs of Urban Transport." *Transportation Research D* 1: 111-130.

McCubbin, Donald R., and Mark A. Delucchi. 1999. "The Health Costs of Motor Vehicle Related Air Pollution," *Journal of Transport Economics and Policy* 33: 253-286.

McConnell, Virginia D., and Margaret A.Walls, 2005. *The Value of Open Space: Evidence from Studies of Nonmarket Benefits*. Resources for the Future, Washington, DC.

Mendelsohn, Robert O., Wendy N. Morrison, Michael E. Schlesinger, and Natalia G. Andronova. 1998. "Country-Specific Market Impacts of Climate Change." *Climatic Change* 45: 553-569.

Miller, T.R., D.T. Levy, R.S. Spicer, and D.C. Letina. 1998. "Allocating the Costs of Motor Vehicle Crashes Between Vehicle Types." *Transportation Research Record* 1635: 81-87.

Miller, Ted R. 1993. "Costs and Functional Consequences of US Roadway Crashes." *Accident Analysis and Prevention* 25: 593-607.

Mun, Se-Il. 1994. "Traffic Jams and the Congestion Toll." *Transportation Research B* 28: 365-375.

NAS. 2001. *Evaluating Vehicle Emissions Inspection and Maintenance Programs*. National Academy of Sciences. Board on Environmental Studies and Toxicology. National Academies Press, Washington, DC.

NAS. 2004. *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. National Academies Press, Washington, DC.

Newbery, David M. 1988. "Road Damage Externalities and Road User Charges." *Econometrica* 56: 295-316.

Newbery, David M. 2005a. "Road User and Congestion Charges." In Sijbren Cnossen, *Theory and Practice of Excise Taxation*. Oxford University Press, New York.

Newbery, David M. 2005b "Why Tax Energy?" *The Energy Journal* 26: 1-40.

Newbery, David M., and Georgina Santos. 2002. "Estimating Urban Road Congestion Charges." Discussion paper 3176. Center for Economic Policy Research, London, UK.

Newell, Richard G. 2006. "What's the Big Deal About Oil?" *Resources* 163: 6-10.

Newell, Richard G., and William A. Pizer. 2003. "Discounting the Distant Future: How Much Do Uncertain Rates Increase Valuations?" *Journal of Environmental Economics and Management* 46: 52-71.

Newell, Richard G., and Kristian Rogers. Forthcoming. "The Market-Based Lead Phasedown." In C. Kolstad and J. Freeman, eds., *Carrots, Sticks and Sledgehammers: Are Market Instruments Really Better for Environmental Protection?* Oxford University Press, Oxford.

Noland, Robert B. 2004. "Motor Vehicle Fuel Efficiency and Traffic Fatalities." *The Energy Journal* 25: 1-22.

Nordhaus, William D. 2006. "Life After Kyoto: Alternative Approaches to Global Warming Policies." *American Economic Review* 96: 31-34.

Nordhaus, William D. 2007. "The *Stern Review* on the Economics of Climate Change." *Science*, forthcoming.

Nordhaus, William D., and Joseph Boyer. 2000. *Warming the World: Economic Models of Global Warming*. MIT Press, Cambridge, MA.

NRC. 1992. *Automotive Fuel Economy: How Far Should we Go?* National Academies Press, Washington, DC.

NRC. 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. National Academies Press, Washington, DC.

Oates, Wallace E. 2006. "On the Theory and Practice of Fiscal Decentralization." IFIR Working Paper No. 2006-05, Institute for Federalism and Intergovernmental Relations.

OECD. 2005. *Energy Prices and Taxes: Quarterly Statistics, First Quarter, 2005*. Organization for Economic Cooperation and Development, Paris.

Parry, Ian W.H. 2004. "Comparing Alternative Policies to Reduce Traffic Accidents." *Journal of Urban Economics* 56: 346-368.

Parry, Ian W.H., and Antonio M. Bento. 2000. "Tax Deductions, Environmental Policy, and the "Double Dividend" Hypothesis." *Journal of Environmental Economics and Management* 39: 67-96.

Parry, Ian W.H., and Antonio M. Bento. 2001. "Revenue Recycling and the Welfare Effects of Road Pricing." *Scandinavian Journal of Economics* 103: 645-671.

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

Pearce, David 2005. "The Social Cost of Carbon." In Dieter Helm (ed.), *Climate-Change Policy*, Oxford University Press, Oxford, UK.

Peirson, John, Ian Skinner, and Roger Vickerman. 1995. "Estimating the External Costs of UK Passenger Transport: The First Step towards an Efficient Transport Market." *Environment and Planning A* 27: 1977-1993.

Poole, Robert W., and C Kenneth Orski. 2002. *HOT Networks: A New Plan for Congestion Relief and Better Transit*. Policy Study No. 305. Reason Public Policy Institute, Los Angeles, CA.

Porter, Richard C. 1999. *Economics at the Wheel: The Costs of Cars and Drivers*. Academic Press, San Diego, CA.

Portney, Paul, and John P. Weyant. 1999. *Discounting and Intergenerational Equity*. Resources for the Future, Washington, DC.

Poterba, James M. 1989. "Lifetime Incidence and the Distributional Burden of Excise Taxes." *American Economic Review* 79: 325-330.

Poterba, James M. 1991. "Is the Gasoline Tax Regressive?" *Tax Policy and the Economy* 5: 145-164.

Quinet, Emile. 2004. “A Meta-Analysis of Western European External Costs Estimates.” *Transportation Research Part D* 9: 465-476.

Rothengatter, Werner. 2000. “External Effects of Transport.” In Jacob B. Polak and Arnold Heertje, eds., *Analytical Transport Economics: An International Perspective*. Edward Elgar, Cheltenham, UK: pp. 79-116.

Santos, Georgina. 2004 (ed.). *Road Pricing: Theory and Evidence.* Research in Transportation Economics 9, Elsevier, New York: 3-25.

Schimek, Paul. 1996. “Household Vehicle Ownership and Use: How Much Does Residential Density Matter?” *Transportation Research Record* 1552: 120-130.

Schrank, David, and Timothy Lomax. 2005. *The 2005 Urban Mobility Report*. Texas Transportation Institute, Texas A&M University, College Station, TX.

Schwartz, Joel. 1994. “Air Pollution and Daily Mortality: A Review and Meta Analysis.” *Environmental Research* 64: 36-52.

Shirley, Chad, and Clifford Winston. 2004. “Firm Inventory behavior and the Returns from Highway Infrastructure Investments.” *Journal of Urban Economics* 55: 398-415.

Small, Kenneth A., and Camilla Kazimi. 1995. “On the Costs of Air Pollution from Motor Vehicles,” *Journal of Transport Economics and Policy* 29: 7-32.

Small, Kenneth A., and Kurt Van Dender. 2006. “Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect.” *Energy Journal* 28: 25-52.

Small, Kenneth A., and Xuehao Chu. 1997. “Hypercongestion.” *Journal of Transport Economics and Policy* 37: 319-352.

Small, Kenneth A. 1992a. *Urban Transportation Economics*. Harwood Academic Publishers, Chur, Switzerland.

Small, Kenneth A. 1992b. “Using the Revenues from Congestion Pricing.” *Transportation* 19: 359-381.

Small, Kenneth A., and Xuehao Chu. 2003. “Hypercongestion.” *Journal of Transport Economics and Policy* 37: 319-352.

Small, Kenneth A., Clifford Winston, and Carol A. Evans. 1989. *Road Work*. Brookings Institution, Washington, DC.

Small, Kenneth A., and Jia Yan. 2001. “The Value of Value Pricing of Roads: Second-Best Pricing and Product Differentiation.” *Journal of Urban Economics* 49: 310–36.

Smith, V. Kerry, and Ju-Chin Huang. 1995. “Can Markets Value Air Quality? A Meta-Analysis of Hedonic Property Value Models.” *Journal of Political Economy* 103: 206-227.

Stern, Nicholas. 2006. *Stern Review: The Economics of Climate Change*. Cambridge University Press, Cambridge, MA.

Tol, Richard S.J. 2005. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." *Energy Policy* 33: 2064-2074.

TRB. 2006. *The Fuel Tax and Alternatives for Transportation Funding*. Transportation Research Board, Washington, DC.

U.S. DOC. 2003. *Statistical Abstract of the United States 2003*. U.S. Department of Commerce, Census Bureau, Washington, DC.

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

U.S. FHWA. 1997. *1997 Federal Highway Cost Allocation Study*. U.S. Federal Highway Administration, Department of Transportation, Washington, DC. www.fhwa.dot.gov/policy/hcas/final/index.htm.

U.S. FHWA. 2000. *Addendum to the 1997 Federal Highway Cost Allocation Study Final Report*. U.S. Federal Highway Administration, Department of Transportation, Washington, DC.

U.S. NHTSA. 2002. *The Economic Impact of Motor Vehicle Crashes 2000*. National Highway Traffic Safety Administration, U.S. Department of Transportation, Washington, DC.

Verhoef, Erik T. 2005. "Second-Best Congestion Pricing Schemes in the Monocentric City." *Journal of Urban Economics* 58: 367-388.

Vickrey, William. 1963. "Pricing in Urban and Suburban Transport." *American Economic Review* 53: 452-465.

Vickrey, William. 1969. "Congestion Theory and Urban Investment." *American Economic Review* 59: 251-60.

Walls, Margaret. 1996. "Valuing the Characteristics of Natural Gas Vehicles: An Implicit Markets Approach." *Review of Economics and Statistics* 78: 266-76.

Walters, Alan. 1961. "The Theory and Measurement of Private and Social Costs of Highway Congestion." *Econometrica* 29: 676-97.

Wardman, Mark. 2001. "A Review of British Evidence on Time and Service Quality Valuations." *Transportation Research E* 37: 107-128.

West, Sarah, and Roberton C. Williams. 2006. "Empirical Estimates for Environmental Policy Making in a Second-Best Setting." *Journal of Public Economics*, forthcoming.

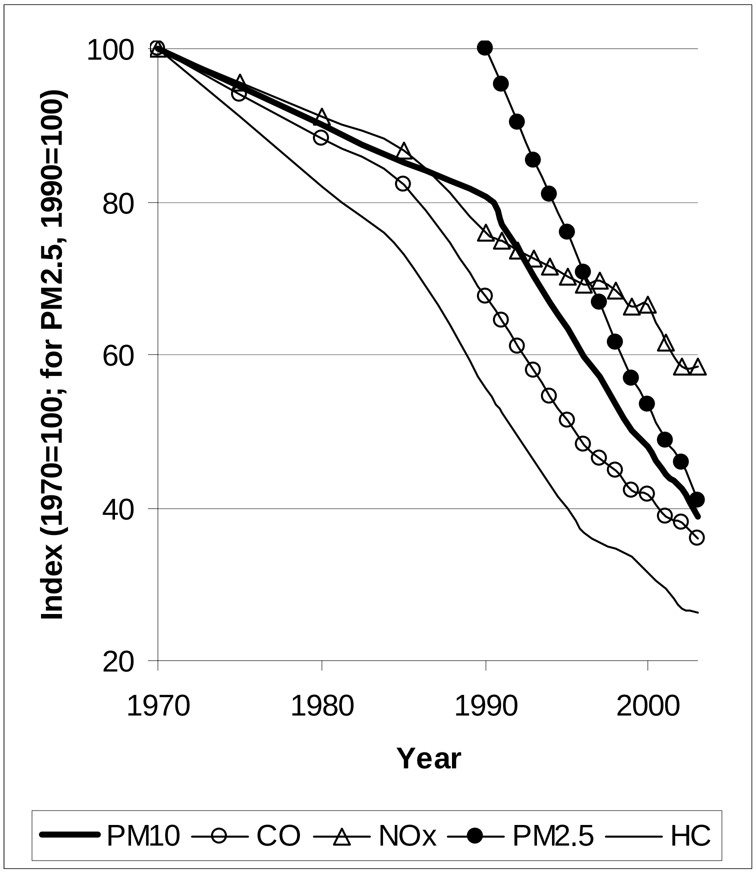
West, Sarah, and Roberton C. Williams. 2005. "The Cost of Reducing Gasoline Consumption." *American Economic Review Papers and Proceedings* 95: 294-299.

White, Michelle. 2004. "The "Arms Race" on American Roads; the Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety." *Journal of Law and Economics* XLVII: 333-356.

Yang, Hai and Hai-Jun Huang. 1998. "Principles of Marginal Cost Pricing: How Does It Work in a General Road Network?" *Transportation Research A* 32:45-54.

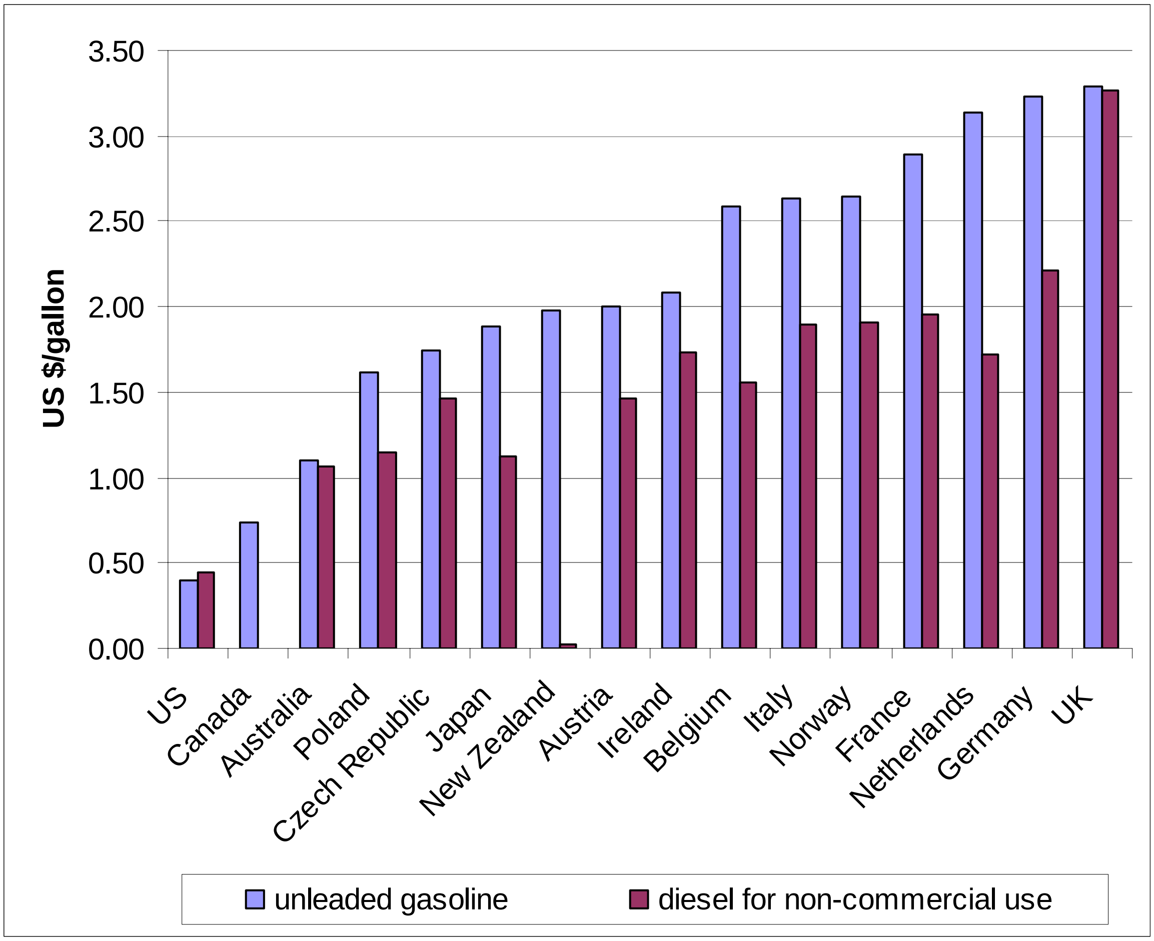
*Figures and Tables*

**Figure 1. Total Vehicle Emissions Relative to Base Year**



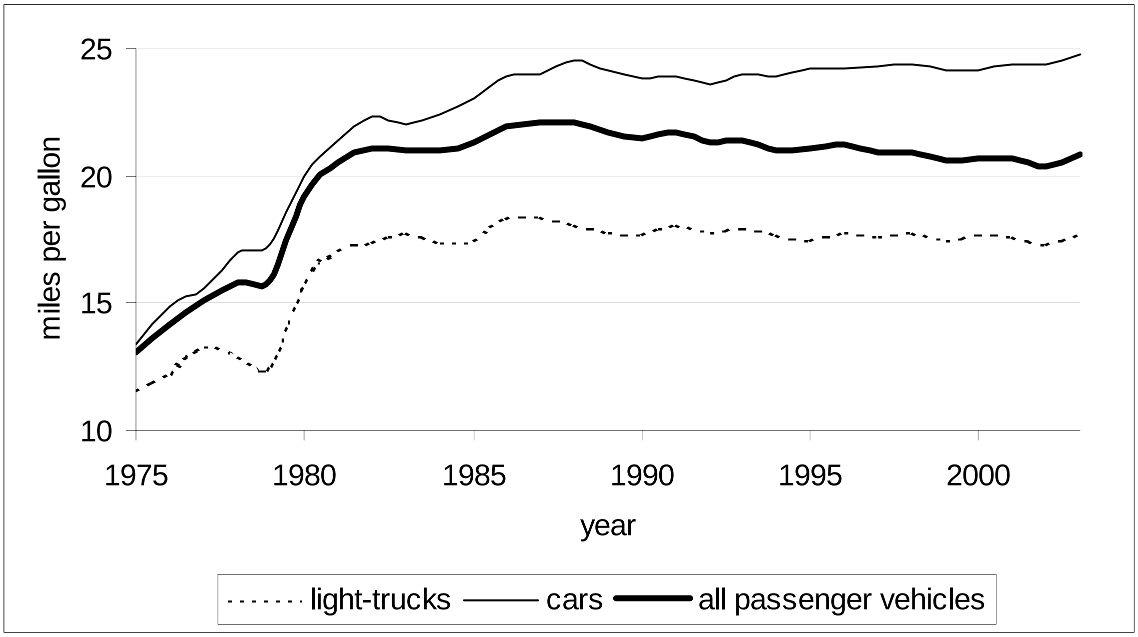

Source: From EPA's MOBILE model (EPA 2004). This model simulates fleet-wide emissions by classifying existing on-road vehicles by type and vintage, and applying emissions coefficients to those vehicles.

**Figure 2. Fuel Taxes for Selected Countries, 2004**




Source: OECD (2005).

**Figure 3. Certified Fuel Economy of New Passenger Vehicles**




Source: NRC (2002).

TABLE 1
SOCIAL COSTS OF TRAFFIC ACCIDENTS IN THE UNITED STATES, 2000

| | Property damage only | Minor injury | Serious injury | Fatalities | All injuries |
|---|---|---|---|---|---|
| Number of injuries | 23,631,696 | 7,208,043 | 607,882 | 41,821 | 31,489,442 |
| Total cost per injury, $ | 2,532 | 10,401 | 259,718 | 3,366,387 | 13,766 |
| quality adjusted life years | 0 | 2,880 | 135,275 | 2,389,179 | 6,444 |
| property damage | 1,484 | 2,845 | 4,982 | 10,273 | 1,875 |
| travel delay | 803 | 776 | 1,004 | 9,148 | 812 |
| medical & emergency services | 31 | 1,539 | 33,899 | 22,928 | 1,106 |
| market and household productivity | 98 | 70 | 291 | 795,601 | 3,058 |
| insurance & legal | 116 | 1,131 | 45,965 | 139,258 | 617 |
| Total injury costs, $billion | 60 | 75 | 158 | 141 | 433 |

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

Note. Minor injuries are those with quality-adjusted life years below $4,500.

TABLE 2
SUMMARY OF EXTERNAL COSTS

| | cent/gal.[a] | cents/mile[a] |
|---|---|---|
| Central values for marginal external costs | | |
| Fuel-related costs | | |
| Greenhouse warming | 6 | 0.3 |
| Oil dependency | 12 | 0.6 |
| sum | 18 | 0.9 |
| Mileage-related costs | | |
| Local pollution | 42 | 2.0 |
| Congestion, cents/mile | 105 | 5.0 |
| Accidents | 63 | 3.0 |
| sum | 210 | 10.0 |

Notes
[a]Costs converted assuming on-road fuel economy of 21 miles per gallon.

TABLE 3
NEW 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 | 0.25 | 3.4 | 0.4 |
| 2004-07 | 0.09 | 4.2 | 0.07 |

Source: NAS (2001).