Comparing Alternative Policies to Reduce Traffic Accidents

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December 2003 • Discussion Paper 03–07

RESOURCES

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Abstract

This paper derives and implements formulas for the welfare effects of differentiated and uniform mileage taxes, gasoline taxes, and per mile insurance premiums, for reducing the external costs of passenger vehicle accidents. The model distinguishes three driver groups and five vehicle groups, and we obtain estimates of external accident costs per mile for each group from crash data.

The (average) external accident cost is estimated at 2.2-6.6 cents per mile. Accidents costs differ substantially across drivers of different ages, but only moderately across different vehicles groups. Annual welfare gains from a mileage tax differentiated across drivers and vehicles according to marginal external costs are $9.4 billion in the benchmark case. The uniform mileage tax and per-mile insurance reform can achieve 76% and 65% of this welfare gain, respectively, while the gasoline tax can achieve only 28% of the welfare gain. Unlike other policies, the gasoline tax induces costly improvements in average fleet fuel economy that have little effect on reducing external costs.

Key Words: traffic accidents; external costs; pricing policies; insurance reform

JEL Classification Numbers: R48; H22; H23

Contents

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Ian W.H. Parry*[*]

1. Introduction

Road accidents impose substantial costs on society: in the United States over 40,000 people were killed in traffic accidents in 2000 and another 3.1 million were injured (US NHTSA 2001). In a widely cited study, Miller (1993) estimated that motor vehicle accidents cost the United States over $300 billion each year.[1] Many of these costs are private (e.g., own injury risk to drivers), but others are external (e.g., pedestrian deaths); hence policies to reduce accidents are potentially justified on economic efficiency grounds. Such policies might be classified into those that reduce vehicle miles traveled (VMT), improve driver care (e.g., speed limits, penalties for drunk driving), improve vehicle safety (e.g., requirements for airbags and child seats), and improve road infrastructure (e.g., crash barriers). This paper focuses on policy approaches to reducing VMT.

One approach is to tax peoples' vehicle miles based on odometer readings, or through telematic systems that are increasingly incorporated in new vehicles. A more fine-tuned policy would involve per mile charges that differ according to driver and vehicle risk. Another policy would be to raise the (federal) gasoline tax;[2] taxing fuel is different from taxing mileage as it encourages people to drive more fuel-efficient vehicles (e.g., Parry and Small 2001). A further option would be to convert insurance premiums from lump-sum annual fees into per-mile charges.[3]

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[1] Fatalities account for 34% of these costs, non-fatal injuries 53% (brain injuries being the largest component), and property damage and time delays 13%.

[2] Reduced accidents are frequently cited as one among several justifications for fuel taxes (e.g., Porter 1999, pp. 194, Litman 1999).

[3] Another set of proposals focus on pay-at-the-pump insurance: under this scheme, drivers pay for auto insurance by a surcharge on gasoline purchases (see Gruenspecht et al. 1994, Allen et al. 1994, and Khazzoom 1999). By converting insurance from a lump-sum fee into a variable cost, this policy is similar to the insurance reform option studied here, though a drawback is that it taxes fuel rather than mileage. It also addresses the problem of uninsured drivers, an issue beyond the scope of this paper.

This paper uses a calibrated analytical model, along with estimates of marginal external accident costs for different driver/vehicle categories obtained from US crash data, to compute the relative efficiency of these policy approaches to addressing accident externalities. The most efficient policy we study is a differentiated mileage tax where each driver/vehicle group is charged a tax equal to its per-mile external cost. The uniform mileage tax is less efficient, as driver/vehicle groups with relatively high/low external costs are under/over taxed. The gasoline tax is less efficient still, as it also causes costly behavioral responses to improve fuel economy, though there is a counteracting benefit if more fuel-efficient vehicles have lower external accident costs. As for insurance reform, market-determined premiums mainly reflect private property and liability damages, which may be only loosely related to external costs, a major component of which is quality of life costs for injuries.

There is little theoretical or empirical literature comparing the welfare properties of these four policies at addressing accident externalities.[4] However, knowing the magnitude of the welfare differences between the policies is obviously important for assessing the economic merits of pursuing one policy approach at the expense of others. There is also little evidence on how the external costs per mile differ across vehicle and driver types, and how they correlate with existing insurance premiums.[5] One exception is a careful analysis of crash data by Miller et al. (1998); they find that external accident costs are similar for cars and light-trucks. This paper uses a similar methodology to estimate external costs, though we distinguish five (rather than two) vehicle classes, different driver groups, and we plug the estimates into formulas for the welfare effects of alternative mileage-reducing policies.

We summarize the main results as follows.

Total external costs are estimated at between \$54 and \$163 billion per annum, or between 2.2 and 6.6 cents per mile driven. Differences in per-mile external costs are much more pronounced across age groups than across vehicle types; they vary from 3.4 to 10.9 cents per mile between intermediate age and young drivers, while they vary between 3.0 and 5.8 cents per

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[4] Most of the prior work in this area focuses on quantifying the magnitude of the economy-wide accident externality per mile (e.g., Delucchi 1997, Jones-Lee 1990, Mayeres et al. 1996, Newbery 1988), the total social costs of traffic accidents (e.g., Miller 1993, Quinet 1994), the effect of higher fuel efficiency standards on fatality risk (e.g., Khazzoom 1997, Crandall and Graham 1989, NRC 2002, Kahane 1997), the effectiveness of vehicle safety mandates (e.g., Levitt and Porter 2000, Mannering and Winston 1995, Peltzman 1975), drunk driving policies (e.g., Levitt and Porter 2001), and speed limits (e.g., Greenstone 2002).

[5] Gayer (2000) estimates the risk of killing other drivers for different vehicles, but according to our estimates, this risk is only a minor portion of total external costs.

mile across different vehicles. External costs are greatest for pickups, and lowest for minivans (the latter are heavily driven by people with children).

The annual welfare gain from the differentiated mileage tax is $9.4 billion in our central case.[6] A uniform mileage tax captures, at most, 76% of this welfare gain; the optimized mileage tax in our central case is 4.4 cents per mile (or 89 cents on a per gallon basis). A tax differentiated across drivers (but not vehicles) and across vehicles (but not drivers) could capture 98% and 78% respectively of the welfare gain from the fully differentiated tax; thus differentiating the tax across drivers is far more important than differentiating it across vehicles. A gasoline tax can only capture 28% of the welfare gain from the (fully) differentiated tax. The gasoline tax leads to costly improvements in fleet fuel economy that have little externality benefit, as the correlation between external costs and fuel economy is weak, and sometimes positive, across different vehicles. At best, insurance reform captures 65% of the welfare gain from the (fully) differentiated tax; this occurs when 73% of existing lump-sum premiums are charged on a per-mile basis. Insurance reform has little advantage over a mileage tax as premiums differ only moderately across different age groups; moreover premiums are often negatively correlated with external costs across vehicles.

Some caveats deserve mention. It is tricky judging exactly what portion of accident costs are external versus the portion that individuals might take into account; however the *relative* welfare ranking of policies is only modestly sensitive to different assumptions. Welfare gains could be increased by levying some of the taxes after an accident has occurred, for example, if the responsible party has been drinking; unlike constant per-mile charges, one-off accident charges would deter behavior that raises the accident risk per mile driven. And our focus is purely on the efficiency of policies at addressing accident externalities; at the end of the paper we discuss how the relative welfare effects of policies might change when account is taken of other motor vehicle externalities and interactions with the broader fiscal system.

The rest of the paper is organized as follows. Section 2 describes the analytical model and derives the welfare formulas. Section 3 discusses parameter values and the estimation of external costs. Section 4 provides the quantitative results. Section 5 offers conclusions and discusses model limitations.

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[6] One other study that estimates the welfare gain from per mile insurance reform is Edlin (1999). He estimates the annual welfare gain at $12.7billion.

2. Analytical Model

2.1 Model Assumptions

Consider a static, long run equilibrium model with the population divided into groups denoted $i = 1 \ldots N$. Groups differ in their driving abilities: some agents are relatively safe drivers (e.g., experienced drivers) while others have a higher accident risk (e.g., inexperienced drivers).

There are $j = 1 \ldots V$ broad vehicle classes—minivans, sport-utility vehicles (SUVs), small cars, etc.—which differ with respect to accident risk and fuel efficiency. Miles driven by agent group i in vehicle j is denoted M_j^i, and economy-wide mileage is:

$$(1) \qquad M = \Sigma_{ij} M_j^i$$

The analysis focuses only on passenger vehicle miles: mass transit, trucks, and motorbikes are ignored.

The private cost to agents from group i from driving a mile in vehicle j, is denoted p_j^i, where

$$(2) \qquad p_j^i = p_G g_j(p_G) + f_j^i$$

p_G is the consumer price of gasoline; to begin with we assume there are no fuel taxes.[7] $g_j(.)$ is the quantity of gasoline required to drive a mile in vehicle j; $1/g_j$ is fuel efficiency or miles per gallon. $g_j' < 0$ because, over the long run, higher fuel prices lead to manufacturers modifying vehicle design to improve fuel economy. f_j^i represents an aggregate of all other private per-mile driving costs expressed in money units (time costs, vehicle wear and tear, the internalized portion of accident costs, parking fees etc.).[8] Aggregate demand for gasoline (G) is:

$$(3) \qquad G = \Sigma_{ij} g_j M_j^i$$

[7] Incorporating positive initial fuel taxes would cause additional efficiency effects as new mileage taxes and higher fuel taxes would compound prior fuel tax distortions. However, a full assessment of the role of prior fuel taxes would need to account for a range of other externalities that are affected directly, or indirectly, by fuel taxes (e.g., pollution, congestion, oil dependency).

[8] We do not explicitly model the fixed costs of driving, such as vehicle purchase costs. In practice, in response to higher driving taxes mileage falls because people buy fewer vehicles and drive them less. We could distinguish these two effects in a more complex model, where households optimize over the number of vehicles and miles per vehicle. For transparency we use a simpler model where households choose only mileage, though we use estimated VMT elasticities that take both effects into account.

Group *i*'s demand function for driving vehicle *j* is:

(4) $M_j^i = M_j^i(p_1^i,...p_V^i)$

where $\partial M_j^i / \partial p_j^i < 0$, and $\partial M_j^i / \partial p_k^i > 0$ for $k \neq j$ as vehicles are substitutes for each other. We take price coefficients to be constant over the relevant range; this is reasonable because the proportionate changes in mileage induced by policies are moderate.

The per-mile marginal external cost from (the risk of) traffic accidents for agent/vehicle group *ij* is denoted by c_j^i > 0; marginal costs are assumed constant over the relevant range. Agents ignore external costs when choosing how much and which vehicle to drive. We assume that technological improvements to increase the fuel economy of a given vehicle type do not affect external costs per mile driven, i.e. c_j^i is independent of g_j.[9] However, we do account for the external effects of changes in average fleet fuel economy to the extent they arise from people substituting between (existing) small and large vehicles.

2.2 Welfare Formulas

2.2.1 Differentiated mileage tax

Under this policy each agent/vehicle group is charged a per-mile tax of c_j^i. The welfare gain from the policy, denoted W^*, can be expressed (see Appendix):

(5) $$W^* = -\frac{1}{2}\Sigma_{ij} c_j^i \Delta M_j^{i*}; \qquad \Delta M_j^{i*} = \Sigma_k \frac{\partial M_j^i}{\partial p_k^i} c_k^i$$

where Δ indicates the change in a variable from its pre-tax level. The expression in (5) is the sum of a series of Harberger triangles for each agent/vehicle group shown by the shaded area in Figure 1; each triangle has height equal to the (marginal) external cost per mile, and base equal to the reduction in mileage. Note that the change in mileage depends on both the own-price

[9] It is not clear whether external costs would increase or decrease with technological improvements in fuel economy. If manufacturers reduce vehicle weight this can make them less safe to their occupants, though this risk might be internalized in the vehicle purchase decision. Moreover, safety depends on the discrepancy in weight between different vehicles in a collision; if most of the weight reduction occurs in light trucks rather than cars, road safety could improve overall as the average weight discrepancy between colliding vehicles is reduced. Furthermore, there are a whole host of other technological changes, other than downweighting, that might be used to improve fuel economy and that have no obvious implications for safety (e.g., improved engine and transmission efficiency, modifications to reduce aerodynamic drag and rolling resistance—see NRC 2002, ch. 3).

effect, and cross-price effects from the increase in other vehicle prices. Thus the reduction in demand, and hence welfare gain, is lower because higher prices of other vehicles partly offset the reduction in demand from the own price effect.[10]

Manipulating (5) we can express the welfare gain per mile as:

$$(6)\qquad w^* = \frac{W^*}{M^0} = -\frac{1}{2}\Sigma_{ij} c_j^i m_j^i \Sigma_k \eta_{jk}^i c_k^i$$

where

$$(7)\qquad m_j^i = M_j^{i0} / M^0 ; \qquad \eta_{jk}^i = \frac{\partial M_j^i}{\partial p_j^i}\frac{1}{M_j^{i0}}$$

0 denotes an initial value, m_j^i is the (initial) share for agent/vehicle group *ij* in total mileage ($\Sigma_{ij} m_j^i = 1$), and η_{jk}^i is the proportionate reduction in mileage for agent/vehicle group *ij* following an incremental increase in agent *i*'s price for driving vehicle *k*.

2.2.2 Uniform mileage tax

Suppose the government levies a tax of t^M per mile, which is uniform across all agent/vehicle groups. The welfare gain from this policy can be expressed (see Appendix):

$$(8)\qquad W^M = -\Sigma_{ij} c_j^i \Delta M_j^{iM} + (t^M / 2)\Sigma_{ij} \Delta M_j^{iM} ; \qquad \Delta M_j^{iM} = \Sigma_k \frac{\partial M_j^i}{\partial p_k^i} t^M$$

where superscript *M* denotes an equilibrium value.

The first term in (8) is the reduction in external costs, equal to the external cost per mile times the reduction in mileage, aggregated over agent/vehicle groups. The second term is efficiency cost of the tax itself (excluding effects on externalities); it equals the sum of a series of triangles with height equal to the mileage tax and base equal to the reduction in mileage for the particular agent/vehicle group. Compared with the differentiated tax, for an agent/vehicle group with relatively high external costs, $c_H > t^M$, the mileage tax is too low and welfare is lower by the shaded triangle in Figure 2(a); for a group with relatively low external costs, $c_L < t^M$, the tax is too high and welfare is lower by the shaded triangle in Figure 2(b).

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[10] Equation (5) is one of several standard ways to express the welfare effect from a set of tax changes (e.g., Harberger 1974, pp. 38). In deriving it, we use the Slutsky symmetry property. Implicitly, we assume that tax revenues are returned to households in transfer payments, so price effects are (approximately) compensated.

From (7) and (8) the welfare gain per mile can be expressed:

$$(9) \qquad w^M = -t^M \Sigma_{ij} (c_j^i - t^M / 2) m_j^i \Sigma_k \eta_{jk}^i$$

2.2.3 Gasoline tax

Suppose the government imposes a tax of t^G per unit on gasoline. Analogous to (8) the welfare effect of this tax is (see Appendix):

$$(10) \qquad W^G = -\Sigma_{ij} c_j^i \Delta M_j^{iG} + (t^G / 2)\Delta G\,; \qquad \Delta M_j^{iG} = \Sigma_k \frac{\partial M_j^i}{\partial p_k^i} t^G g_k\,;$$

$$\Delta G = \Sigma_{ij} g_j M_j^i - \Sigma_{ij} g_j^0 M_j^{i0} = \frac{dG}{dp_G} t_G$$

Again, the first term is the aggregate reduction in external costs from reduced driving; in this case the per mile price increase for an agent/vehicle group is the gasoline tax times the gasoline requirement per mile. The second term in (10) is the welfare loss triangle from the gasoline tax itself; it is expressed as one-half times the gasoline tax times the aggregate reduction in gasoline demand, ΔG. The reduction in gasoline demand implicitly summarizes three effects that reduce fuel use: an overall reduction in driving, a substitution away from existing vehicles with low fuel efficiency towards existing vehicles with high fuel efficiency, and, within a vehicle class, long-run technological improvements by manufacturers to improve fuel economy (or lower g_j).

There are two main differences between the gasoline tax and the uniform mileage tax. First, for an equivalently scaled tax, the costs of the gasoline tax (ignoring externalities) will be larger. This is because the fuel tax causes more substitution effects: in addition to less driving, a gasoline tax promotes (costly) improvements in average fuel economy. These costs are represented by reductions in consumer surplus under the aggregate demand curve for gasoline. The second difference is that the per-mile charge differs across vehicles under the gasoline tax to the extent that gasoline per mile g_j differs across vehicles. If gasoline per mile and external cost are positively correlated (i.e. larger vehicles have larger external costs), the gasoline tax will reduce external costs by more than an equivalently scaled uniform mileage tax.

Manipulation of (10), and using (7), yields the per mile welfare gain:

$$(11) \qquad w^G = -t^G \Sigma_{ij} c_j^i m_j^i \Sigma_k \eta_{jk}^i g_k + \frac{1}{2} \eta_G t_G^2 \bar{g}^0 / p_G ;$$

$$\bar{g}^0 = G^0 / M^0 ; \qquad \eta_G = \frac{dG}{dp_G} \frac{p_G}{G^0} < 0$$

where $\bar{g}$ is (initial) average gasoline consumption per mile and η_G is the price elasticity of demand for gasoline.

2.2.4 Insurance reform

For this policy we define β as the portion of existing premiums that are currently perceived on a lump-sum annual basis that become perceived on a per-mile basis under the reform. We also denote q_j^i as the initial lump-sum premium for agent/vehicle group ij, expressed as the fixed annual payment divided by miles driven; thus the perceived increase in the variable per-mile cost of driving is βq_j^i. Analogous to (8) the welfare effect of this policy is:

$$(12) \qquad W^I = -\Sigma_{ij} c_j^i \Delta M_j^{iI} + \Sigma_{ij} (\beta q_j^i / 2) \Delta M_j^{iI} ; \qquad \Delta M_j^{iI} = \Sigma_k \frac{\partial M_j^i}{\partial p_k^i} \beta q_k^i$$

Again, welfare terms are the reduction in external costs from reduced driving, and the efficiency cost triangles from introducing new per-mile charges. In theory, insurance reform could be more or less efficient than the equivalently scaled uniform mileage tax, depending on whether premiums are positively or negatively correlated with external costs across driver/vehicle groups. Using (7) and (12), the per-mile welfare effect can be expressed:

$$(13) \qquad w^I = -\Sigma_{ij} (c_j^i - \beta q_j^i / 2) m_j^i \Sigma_k \eta_{jk}^i \beta q_k^i$$

3. Parameter Assessment

To estimate the magnitude of accident externalities we need to make a number of assumptions, particularly the portion of accident costs that are external. We develop a "low-cost" and "high-cost" scenario, and split the difference for a "medium-cost" scenario.

3.1 Accident data

The FARS (Fatality Analysis Reporting System) data provides information on all traffic accidents in the United States involving a fatality. The GES (General Estimates System) data provides national estimates of all traffic accidents (with and without fatalities), extrapolated from a sample of police-reported crashes in 400 jurisdictions selected to be representative of overall US conditions.[11] Both data sets provide information on the number and severity of all injuries in the accident, and characteristics of all vehicles and drivers involved. We use the FARS data to cover all accidents with fatalities and the GES data for all other accidents. In each case we take an annual average of all data over the three-year period 1998–2000.

Table 1 provides a brief summary. On average 33,503 people were killed each year in accidents involving passenger vehicles; 13% of those were pedestrians and cyclists, 43% were vehicle occupants involved in single-vehicle crashes, and 44% were occupants in multi-vehicle crashes.[12] The numbers of non-fatal injuries are large relative to the number of fatalities, implying that non-fatal injuries can still be a significant component of social cost even though the relative cost per non-fatal injury is small. Non-fatal injuries are classified according to the KABCO system used in police-reported data.

3.2 Social costs per injury

The social costs of traffic accidents consist of injury costs, property damage, and traffic holdups. Injury costs can be subdivided into quality of life costs and various economic costs—medical expenses, emergency services, lost market production, insurance, and legal costs. Our assumptions about the value of these costs are shown in Table 2; for the most part, they are updated figures from a comprehensive study by Miller (1993).[13] For fatalities, we assume the

[11] Both data sets are collected by the National Highway Traffic Safety Administration (US NHTSA). See *www-fars.nhtsa.dot.gov* and *ftp://ftp.nhtsa.dot.gov/GES.* Following Miller (1998), pp 18, we scale up non-fatal injuries by 12% and 9% for police and survivor under-reporting respectively.

[12] These figures exclude people killed in mass transit, heavy trucks, work vans, and motorbikes.

[13] We thank Eduard Zaloshnja for providing these figures. The Federal Highway Administration routinely uses Miller's estimates in valuing accident costs (e.g., US FHWA 2002). Miller's estimates average over accidents with single and multiple injuries. Therefore, for example, the social cost of one accident involving a disabling and an evident injury would be $193,821 (combining costs from Table 2).

value of life is $3 million;[14] for non-fatal injuries value of life costs are measured by quality-adjusted life years (QUALYs). Quality of life costs tend to swamp other costs for more serious injuries, and total costs per fatality swamp those per non-fatal injury.

3.3 Driver/vehicle groups

We divide drivers into those under age 25, age 25 to 70, and over 70.[15] Vehicles are divided into small cars (compact and sub-compact), large cars (intermediate and full-size), SUVs, minivans and pickups. Thus we have 15 driver/vehicle groups in total.

3.4 External portion of accident costs

We assume that all costs (listed in Table 2) from pedestrian/cyclist injuries are external. These are divided up and assigned equally among the drivers in each crash involving a pedestrian/cyclist injury.

In single-vehicle crashes we assume that quality of life costs for injuries to all vehicle occupants are internal costs for the driver. For multi-vehicle crashes it is tricky deciding whether injuries to other vehicle occupants are external or not. The externality depends on how the presence of one extra vehicle affects the severity-adjusted accident rate for other vehicles. All else the same, an extra vehicle on the road raises the likelihood that other vehicles will be involved in a collision; however, because people tend to drive slower and more carefully in heavier traffic, a given accident will be less severe. A common assumption is that (on average) the severity-adjusted accident rate for other vehicles does not change, thus there is no externality on other drivers.[16] We assume this in our low-cost case; in our high-cost scenario we assume that

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[14] This measures people's willingness to pay for reduced risk per death avoided. A meta analysis by Mrozek and Taylor (2002) based on 38 studies assessing workplace risks and wage differentials puts the value of life at $2 million, which is consistent with recent evidence from direct survey techniques (Krupnick and Morgenstern 2002, pp. 440-441). Miller (2000), Table 5, puts the value of life at $3.7 million (in 1995 dollars). We use a compromise value.

[15] We experimented with separating male and female drivers, and subdividing drivers aged 25 to 70, but this made little overall difference to the results. We also experimented by sub-dividing driver groups into those with and without prior crash records; however, we were unable to obtain reliable estimates of mileage shares for these subgroups, and our results were very sensitive to different assumptions about allocating mileage across the sub-groups. Therefore, we excluded this decomposition from the analysis.

[16] See Mayeres and Proost (1996), US FHWA (2000), and Newberry (1988)'s low-cost scenario. Some studies suggest that the severity-adjusted accident rate for other drivers may actually fall with more traffic (e.g., Fridstrøm and Ingebrigtsen 1991, Fridstrøm 1999); if so the marginal externality on other drivers is negative! See Small and Gomez-Ibanez (1999) for further discussion.

one driver's external costs include $1/(n-1)$ of the injuries to other drivers, where n is the number of vehicles in the crash.

It is not clear to what extent drivers internalize property damage. At one extreme, if insurance is truly lump sum and premiums do not change in response to accidents, then all property damage is external. In practice people pay deductibles and premiums vary, albeit moderately, with previous crash record and stated annual mileage. In our low-, medium- and high-cost scenarios we assume 0%, 25% and 50% of total property damage is external, respectively. Travel delay costs for all accidents are treated as external in all scenarios.[17]

Medical costs, emergency services, and legal/court costs are mainly covered by group or government insurance, though individuals may pay a minor portion of costs through deductibles, increased liability premiums, etc.[18] We assume 85% of these costs for all accidents are external. We assume drivers would take into account the risk of lost lifetime wages from injuries to themselves; these costs are only external for pedestrian/cyclist non-fatal injuries.[19] In the low- and high-cost scenarios 0% and 100% of wage costs for non-fatal injuries to other vehicle occupants are treated as external.

3.5 VMT

We use data from the National Personal Transportation Survey to estimate VMT shares for each driver/vehicle group.[20] The result is shown in Table 3: cars account for 61% of mileage and light trucks 39%; drivers age 25-70 are by far the largest group, accounting for 84% of mileage. Total passenger-vehicle VMT per annum, averaged over 1998-2000, was 2,471 billion;[21] we allocated this among groups according to the VMT shares in Table 3. Dividing total external costs for each group by their VMT gives external costs per mile.

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[17] Each driver in an accident is assigned $1/n$ of the total (external) property damages and travel delay costs for that accident.

[18] For example, most medical insurance is offered through employer-sponsored policies that are not rated based on automobile accident records.

[19] Estimates of the value of life for fatalities usually take into account lost wages.

[20] We used the 1995 and 2001 surveys, weighting the former by 0.33 and the latter by 0.67 to approximate for 1999.

[21] From www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2000.pdf.

3.6 Insurance premiums

These are shown in Table 4. Data from the New Jersey Department of Banking and Insurance were used to estimate annual premiums according to the different driver categories, holding vehicle type constant.[22] Diving by our VMT estimates for driver groups yields premiums on a per-mile basis. These are 6.9, 5.6 and 7.0 cents per mile respectively for age groups under 25, 25–70 and over 70, with a mean premium of 5.9 cents per mile.

Holding driver type constant, we assume that insurance premiums vary across vehicle types in proportion to vehicle price.[23] Vehicle prices were obtained by aggregating over vehicle categories in Kleit (2002). Premiums are computed by multiplying the average premium (5.9) by the vehicle price relative to the mean vehicle price; they vary from 4.6 (small cars) to 7.7 cents per mile (SUVs). Premiums for individual driver/vehicle groups were obtained by multiplying the premium for that vehicle by the premium for that driver group relative to the mean premium.

3.7 Gasoline elasticity and fuel economy

Reviews of the many time-series and cross-sectional studies of demand for gasoline conducted before 1990 generally find price elasticities between –0.5 and –1.1; however more recent studies often find values about half as large in magnitude.[24] We adopt low, medium and high elasticity values of –0.3, –0.5 and –0.7 for η_G.

We assume on-road fuel efficiency ($1/g$) of 24.9 miles per gallon for small cars, 20.3 for large cars, 18.2 for SUVs, 18.8 for minivans, and 16.7 for pickups; mean fuel economy is 20.3.[25]

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[22] We used data for South Bergen County, which has a mix of urban and suburban areas and many companies offering policies. New Jersey insurance costs are above the national average; therefore we scaled our absolute costs to national averages reported in Davis (2000)

[23] For a given vehicle price and driver type, the collision and liability components of insurance premiums do not vary very much across the broad vehicle classifications in our analysis (though they may for individual models).

[24] See Dahl and Sterner (1991), Table 2, Goodwin (1992), Table 1, and US DOE (1996), pp. 5-13 to 5-15 and 5-82 to 5-87.

[25] Figures obtained from NRC (2002), Table 4.2, aggregating vehicle classes using sales shares obtained from US DOT (2002). We follow NRC (2002) in assuming that on-road fuel economy is 15% lower than recorded by EPA-required dynamometer testing.

3.8 Driving elasticities.

We begin with estimates of own-and cross-price elasticities for new vehicle sales shown in Table 5 obtained by simulating the General Motors (GM) model (with vehicle categories aggregated according to our classifications) and then make two adjustments to them. For simplicity, we take elasticities to be uniform across different driver groups.

In the GM model, the own-price vehicle elasticities reflect a combination of substitution into other (new) vehicles, people holding on used vehicles longer, and an overall reduction in demand for driving. The first effect accounts for 30–40% of the own-price effect across vehicle types; the division of the remainder among the latter two effects is unknown. Since we model a long-run equilibrium, we need to remove the substitution between new and used vehicles from the own-price effect; we scale back all the own-price elasticities from the GM model by a proportion ϕ, where ϕ is set at 0.35, with range 0.2 to 0.5.

There is an extensive empirical literature on the elasticity of VMT with respect to the price of gasoline, which we denote $\eta^{MG} = (dM / dp_G) p_G / M$. Using this expression, the proportionate change in mileage following a unit increase in the price of driving is $\eta^{MG} / (\bar{g} p_G)$.[26] Our second adjustment ensures that, in aggregate, mileage effects are consistent with estimates of η^{MG}. It involves multiplying all elasticities in the GM model by the following scalar:

$$(3.1) \qquad \gamma = \frac{\eta^{MG} (\bar{g} p_G)^{-1}}{\Sigma_{ij} m_j^i \left\{ (1-\phi)\varepsilon_{jj}^i + \Sigma_{k \neq j} \varepsilon_{jk}^i \right\}}$$

where ε denotes an elasticity from the GM model, and the denominator in this expression is the proportionate reduction in aggregate mileage that would be predicted using these elasticities. We use a benchmark value of –0.2 for η_{MG}, with range –0.1 to –0.3,[27] and we assume a retail gasoline price of 140 cents per gallon.[28]

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[26] Note from (2) that, on average, $dp_j^i / dp_G = \bar{g}$.

[27] See Goodwin (1992), Greene et al. (1999), pp. 6-10, and US DOE (1996). Comparing with our values for η_G, this means that around 30–45% of η_G reflects reduced driving, and 55–70% increases in fuel efficiency from vehicle substitution and long run technological improvements.

[28] Retail prices have varied between \$1.10 and \$1.83 per gallon between 1996 and 2002. See www.eia.doe.gov/emeu/international/gas1.html.

4. Quantitative Results

4.1 Average external costs per mile

Table 6 shows computations of the external accident cost in cents per mile averaged across all driver/vehicle groups, $\Sigma_{ij} c^i_j m^i_j$, and decomposed into various components. The average external cost is 2.2, 4.4, and 6.6 cents respectively, in the low-, medium-, and high-cost scenarios.[29] Multiplying by VMT, the aggregate external costs of accidents are between $54 and $163 billion per annum (about 0.7 to 1.7% of GDP) and $109 billion in the medium cost scenario. In the medium scenario quality of life costs account for 55% of total external costs, property damage 7%, traffic holdups 4%, and other economic costs 34%.[30]

4.2 External costs across vehicles and drivers

Table 7 decomposes external costs for each vehicle group and each driver group, and Table 8 summarizes total external costs per mile for all the driver/vehicle groups.[31]

Differences in external costs are much more pronounced across age groups than across vehicle types; they vary from 3.4 to 10.9 cents per mile between intermediate age and young drivers, while they vary between 3.0 and 5.8 across different vehicles.[32] Furthermore, there appears to be no obvious correlation between external costs and vehicle size/weight, or fuel economy.

External costs for small cars are 9% above the average for all vehicles while those for large cars are 10% below average, and although external costs are 31% above the average for

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[29] A recent assessment of other evidence by Parry and Small (2001) deduced a mid-point estimate of 3.0 cents per mile (see also US FHWA 2000a, and Mayeres et al. 1996 for Belgium). Parry and Small assume a driver does not affect the severity-adjusted accident rate for other drivers, but also that the value of life is $4.8 million rather than $3.0 million; making these adjustments would reduce our mid-point estimate to 3.08 cents per mile. Our scenarios are meant to illustrate possibilities over a broad range of assumptions; the "medium" scenario should not necessarily be regarded as the "best-estimate".

[30] The quality of life costs for non-fatal injuries are much smaller than those for fatalities in the case of pedestrians, but about the same for other vehicle injuries; in other words, a pedestrian is more likely to be killed, when hit by a vehicle, than someone in a vehicle.

[31] Relative costs across different groups are similar in all three cost scenarios.

[32] Besides inexperience, younger drivers are more likely to drink and drive. Of all drivers under 25 involved in fatal accidents, 28.5% had blood alcohol (BAC) levels of 0.01 grams/deciliter or higher, while 22.6% of drivers 25 and older involved in fatal accidents exceeded this BAC level (US NHTSA, 2001).

pickups, they are 18% and 31% below average for SUVs and minivans, respectively. Given speed and other factors, pickups do more damage to other road users in a collision, and may crash more frequently if drivers feel safer in them compared with cars. The relatively low costs for minivans and SUVs reflect in part their ownership concentration among households with children; drivers with children may take more care, and are less likely to drink and drive, compared with other motorists.[33] External costs are a little higher for small cars than for large cars, reflecting the ownership concentration of the former among young drivers.

4.3 Welfare gains from differentiated mileage tax

Table 9 shows the welfare gain in cents per mile from eq. (6), and as an annual dollar amount for the whole economy. In the benchmark case the welfare gain is 0.38 cents per mile, or $9.4 billion per annum.

Welfare gains are very sensitive to alternative scenarios for external costs, as they affect both the height of the welfare gain triangles in Figure 1, and the base. Welfare gains fall to only $2.4 billion in the low-cost scenario, but rise to $21.2 billion in the high-cost scenario. Results are also sensitive to the overall mileage elasticity; varying this parameter changes the base of the triangles in Figure 1 in the same proportion. Welfare gains vary between $4.7 and $14.1 billion, as the overall mileage elasticity is halved and doubled, respectively.[34]

4.4 Policy comparison

Figure 3 shows the welfare gains from other policies, expressed as a fraction of the welfare gain from the differentiated mileage tax. Results are for the benchmark parameter values, however alternative scenarios for external costs and mileage elasticities have little effect on relative welfare effects.

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[33] 25% of miles driven by the age 25-70 group is in SUVs and minivans; the corresponding figures for the under 25 and over 70 groups are 12% and 10% (from Table 3).

[34] Results are not very sensitive to varying the relative magnitude of the own-price effects relative to cross-price effects, given an overall mileage elasticity.

The uniform mileage tax is optimized at 4.4 cents per mile—the mean external cost—yielding a maximum welfare gain equal to 76% of the welfare gain under the differentiated tax. If instead the tax were differentiated according to external costs across drivers, but not vehicles, its welfare potential would be 98% of that under the fully differentiated tax; if it were differentiated across vehicles but not drivers, the welfare potential would be 78% of that under the differentiated tax (these results are not shown in Figure 3). This underscores the point that it is far more important to differentiate the tax across drivers than across vehicles.

The gasoline tax is easily the worst of the policies analyzed. It captures a maximum of only 28% of the welfare gains under the differentiated mileage tax. The optimized tax is 30 cents per gallon, while the optimized uniform mileage tax would be equivalent to a tax of 89 cents per gallon (given an average miles per gallon of 20.3).[35]

The key problem with this policy is that it induces costly improvements in average fleet fuel economy (see also Parry and Small 2001). Ignoring externalities, the cost of the policy (i.e. the aggregate loss in consumer surplus) is about 2.5 times the cost of a mileage tax, for a given total reduction in mileage; this is because the assumed own-price elasticity of demand for gasoline is about 2.5 times as large as the elasticity of total mileage with respect to the gasoline price. And very little of these added costs are offset by additional externality benefits under the gasoline tax, given the very weak correlation between fuel economy and external costs across vehicles. If we assume, hypothetically, that all of the gasoline demand elasticity was due to reduced mileage, and none due to improvements in fuel efficiency, then the welfare gain would be indicated by the dashed curve in Figure 3(b), which is similar to that for the uniform mileage tax.

The welfare gain from insurance reform is comparable with that of the uniform mileage tax. It achieves 65% of the welfare gain under the differentiated tax when the increase in per-mile charges is equivalent to 73% of current premiums ($\beta = 0.73$); in this case the average increase in premiums is 4.3 cents per mile. Although drivers with higher external costs face larger per-mile charges, the difference in premiums across age groups is much smaller than the difference in their external costs (see Tables 4 and 8). And premiums bear little resemblance to external costs across vehicles; for example, premiums are relatively high for SUVs and minivans, while these vehicles have relatively low external costs.

[35] For comparison, the current gasoline tax is about 40 cents/gallon (18 cents at the federal level and on average about 22 cents at the state level). However, there are many other considerations in setting optimal fuel taxes, besides their effect on accidents (e.g., Parry and Small 2001).

5. Conclusion

The policy lessons might be summed up as follows. First, according to our estimates the welfare potential of gasoline taxes at reducing external accident costs is less than half that of uniform VMT charges or per mile insurance reforms: gasoline taxes induce costly behavioral responses to improve fuel economy that result in little additional accident externality benefit. Second, the uniform VMT tax can achieve 76% of the welfare gain from the differentiated mileage tax; nearly all the welfare difference between the differentiated and uniform mileage taxes stems from charging different rates to drivers of different age, rather than varying taxes across vehicle types. Third, differences in premiums across driver groups are modest relative to the differences in external costs and, across vehicle types, differences in premiums are often negatively related to differences in external costs. Nonetheless, converting most of existing insurance from lump sum to a per-mile basis still achieves around 65% of the welfare gains from a differentiated mileage tax.

The least efficient policy in our analysis—the gasoline tax—is probably the least politically feasible policy in practice.[36] In contrast, we might envisage a gradual transition towards per mile insurance. Low-mileage drivers have an incentive to opt out of traditional insurance in favor of mileage-based insurance, and this is becoming increasingly feasible with telematic systems incorporated in new vehicles. And the government might encourage this trend through tax credits and rewards for states that promote per-mile policies in the formula used to allocate highway funds.

How do other externalities and fiscal considerations affect the desirability of taxing mileage versus taxing fuel? Fuel-related externalities, which include future climate change damages from carbon emissions and macroeconomic disruption and other costs from oil dependency, are obviously better addressed through fuel taxes. However, studies suggest that the magnitudes of these externalities are more moderate relative to those associated with accidents and congestion (e.g., Portney et al., 2003).

Traffic congestion depends on distance traveled and is obviously more directly addressed through mileage-based charges than fuel taxes, particularly charges that vary with time-of-day and location. Loosely speaking, the same might apply for local air pollution as emissions

[36] In 1993 the Clinton Administration achieved an increase in the federal gasoline tax rate of only 4 cents per gallon, despite a major effort. Since then the rate has remained constant in nominal terms despite general price inflation.

regulations on new vehicles are defined in terms of grams per mile and (for the most part) standards are the same across vehicle types. And to the extent that some taxation of driving might be justified on Ramsey tax grounds, this also favors mileage taxes over gasoline taxes. In theory, and leaving aside externality considerations, an optimal tax system involves some taxation of individual activities (or commodities) if those activities are relatively price insensitive, or more precisely, are relatively weak substitutes for leisure: this appears to be the case for driving. Parry and Small (2001) compute the Ramsey tax component of an optimal mileage tax at the equivalent of about $1 per gallon; if the tax were on fuel instead, they find the Ramsey component is much lower at 27 cents per gallon, as the price sensitivity of fuel is greater than that for mileage.

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Appendix

Deriving (5). Following analogous expressions to those in Harberger (1974), Ch. 2, the welfare effect from imposing a tax of c_1^i on agent *i*'s mileage for vehicle 1 is:

$$\text{(A1)} \quad -\frac{1}{2}c_1^i \frac{\partial M_1^i}{\partial p_1^i} c_1^i - \Sigma_{k=2}^V c_k^i \frac{\partial M_k^i}{\partial p_1^i} c_1^i$$

The first term is the welfare gain triangle from the own-price effect that internalizes the externality; the triangle has height equal to marginal external cost, and base equal to the reduction in mileage from the own-price increase, $-(\partial M_1^i / \partial p_1^i)c_1^i$. The second term is the welfare loss from cross-price or substitution effects into other vehicles. It equals the marginal external cost for other vehicle mileage, times the increase in mileage in response to the higher price for vehicle 1 mileage, $(\partial M_k^i / \partial p_1^i)c_1^i$, and aggregated over all other vehicles. Using the Slutsky symmetry property:

$$\text{(A2)} \quad c_k^i \frac{\partial M_k^i}{\partial p_1^i} c_1^i = \frac{1}{2} c_k^i \frac{\partial M_k^i}{\partial p_1^i} c_1^i + \frac{1}{2} c_1^i \frac{\partial M_1^i}{\partial p_k^i} c_k^i$$

Substituting (A2) in (A1), and using the definition of ΔM_1^i in (5) gives:

$$\text{(A3)} \quad -\frac{1}{2}c_1^i \Delta M_1^i - \frac{1}{2}\Sigma_{k=2}^V c_k^i \frac{\partial M_k^i}{\partial p_1^i} c_1^i$$

Imposing a tax of c_2^i on agent *i*'s mileage for vehicle 2 leads to a welfare effect of:

$$\text{(A4)} \quad -\frac{1}{2}c_2^i \frac{\partial M_2^i}{\partial p_2^i} c_2^i - \Sigma_{k=3}^V c_k^i \frac{\partial M_k^i}{\partial p_2^i} c_2^i$$

This expression is analogous to that in (A1) except that, since the distortion for vehicle 1 mileage has been removed by the first tax, there is no welfare effect from the cross-price effect on its demand. Using the Slutsky symmetry property to obtain an analogous expression to that in (A3), and aggregating for the total welfare change from the two taxes gives:

$$\text{(A5)} \quad -\frac{1}{2}c_1^i \Delta M_1^i - \frac{1}{2}c_2^i \Delta M_2^i - \frac{1}{2}\Sigma_{k=3}^V c_k^i \frac{\partial M_k^i}{\partial p_2^i} c_2^i$$

Continuing until all vehicles have been taxed, and then aggregating over agents, yields the expression in (5).

Deriving (8). The welfare effect from imposing a tax of t^M on agent *i*'s mileage in vehicle 1 is (see Harberger 1974, Ch. 2):

$$\text{(A6)} \quad -c_1^i \frac{\partial M_1^i}{\partial p_1^i} t^M + \frac{1}{2} t^M \frac{\partial M_1^i}{\partial p_1^i} t^M - \left\{ c_2^i \frac{\partial M_2^i}{\partial p_1^i} t^M + c_3^i \frac{\partial M_3^i}{\partial p_1^i} t^M + \ldots \right\}$$

The first term is the gain from the reduction in external costs from the own-price effect, the second term is the efficiency cost of the tax from the own price effect (ignoring externalities) and the remaining terms are welfare effects from the increase in demand for other vehicles. Now imposing a tax of t^M on the second vehicle gives rise to a welfare change of:

$$\text{(A7)} \quad -c_2^i \frac{\partial M_2^i}{\partial p_2^i} t^M + \frac{1}{2} t^M \frac{\partial M_2^i}{\partial p_2^i} t^M - \left\{ (c_1^i - t^M) \frac{\partial M_1^i}{\partial p_2^i} t^M + c_3^i \frac{\partial M_3^i}{\partial p_2^i} t^M + \ldots \right\}$$

These terms are analogous, although the welfare effect from the increase in demand for vehicle 1 depends on its external cost net of the tax on that vehicle. Imposing a tax of t^M on the third vehicle leads to a welfare effect of:

(A8)

$$-c_3^i \frac{\partial M_3^i}{\partial p_3^i} t^M + \frac{1}{2} t^M \frac{\partial M_3^i}{\partial p_3^i} t^M - \left\{ (c_1^i - t^M) \frac{\partial M_1^i}{\partial p_3^i} t^M + (c_2^i - t^M) \frac{\partial M_2^i}{\partial p_3^i} t^M + c_4^i \frac{\partial M_4^i}{\partial p_3^i} t^M + \ldots \right\}$$

Repeating until all vehicles have been taxed, aggregating over the welfare change at each stage, and across agents, we can obtain (8), after using the symmetry property:

$$\text{(A9)} \quad t^M \frac{\partial M_j^i}{\partial p_k^i} t^M = \frac{1}{2} t^M \frac{\partial M_j^i}{\partial p_k^i} t^M + \frac{1}{2} t^M \frac{\partial M_k^i}{\partial p_j^i} t^M$$

Deriving (10). Again, this is a straightforward application of the general welfare formulas in Harberger (1974), Ch. 2. The welfare effect of the gasoline tax can be expressed as the sum of the welfare change in the (economy-wide) gasoline market, and from the changes in demand for mileage across driver/vehicle groups. The welfare change in the gasoline market is simply the price wedge introduced by the gasoline tax, times the aggregate reduction in gasoline demand. The welfare change effect of the change in mileage is simply the per-mile external cost, multiplied by the change in mileage from the increase in the per-mile driving cost (equal to the gasoline per mile times the gasoline tax), and aggregated over all driver/vehicle groups.

Table 1. Accident Summary
(annual average, 1998-2000)

Breakdown by injury type	number of injuries
K - Fatal	33,503
A - Disabling	326,547
B - Evident	719,037
C - Possible	1,513,270
O - Property damage only	2,390,322
UI - Injured, severity unknown	18,867
U - Unknown if injured	254,288
Breakdown of fatalities	%
Pedestrian & cyclist	0.13
single vehcile crashes	0.43
multi-vehicle crashes	0.44

Source: Obtained from FARS and GES data.

Table 2. Components of Social Cost per Injury Type
($)

	fatal K	disabling A	evident B	possible C	property damage only O	injured, sev. unknown UI	unknown if injured U
Medical	22,095	19,471	5,175	3,485	140	4,662	1,551
Household productivity at 4% discount	0	6,944	1,854	1,244	85	1,236	556
Lost wages at 4% discount	0	25,014	6,239	4,160	155	4,186	2,029
Legal costs at 4%discount	102,138	5,167	1,101	681	15	911	349
Insurance administative at 4% discount	37,120	5,999	1,776	1,181	152	1,354	647
Property damage	10,273	4,357	3,824	3,413	1,642	3,618	3,565
Police & fire services	833	175	112	90	31	81	44
Travel delay	5,247	885	797	785	696	795	780
Employer costs	0	1,679	665	461	67	480	178
Total cost without QALYs	186,408	69,479	21,543	15,500	2,983	17,323	9,699
value of life/QALYs at 4% discount	3,000,000	83,239	19,560	10,725	464	10,976	5,739
Total cost	3,186,408	152,718	41,103	26,225	3,447	28,299	15,438

Source: Updated figures from Miller (1993) and author's own assumptions.

Table 3. Breakdown of VMT by Driver and Vehicle Group
(%)

	<25	25-70	>70	total
small	5.9	23.5	0.9	30.3
large	2.8	25.5	2.7	31.0
SUV	1.1	12.4	0.2	13.7
minivan	0.4	7.9	0.3	8.6
pick-up	1.8	14.2	0.4	16.4
total	11.8	83.7	4.5	100

Source: National Personal Transportation Surveys, 1995 and 2001.

Table 4. Insurance Premiums by Driver and Vehicle Group
(cents per mile)

	<25	25-70	>70	average
small	5.8	4.3	5.4	4.6
large	7.8	5.9	7.3	6.2
SUV	10.0	7.5	9.4	7.7
minivan	8.3	6.2	7.8	6.4
pick-up	7.2	5.4	6.8	5.6
average	6.9	5.6	7.0	5.9

Source: New Jersey Department of Banking and Insurance.

Table 5. Own and Cross-Price Elasticities (Unadjusted)

		1% increase in price of vehicle:				
		small	large	SUV	minivan	pick-up
% change	small	-2.88	0.51	0.06	0.02	0.06
in	large	0.70	-2.50	0.14	0.08	0.03
quantity	SUV	0.26	0.37	-2.19	0.30	0.33
of vehicle	minivan	0.08	0.19	0.17	-2.31	0.06
	pick-up	0.10	0.08	0.14	0.06	-1.53

Source: Obtained from the General Motors model.

Table 6. Summary of External Costs for All Accidents
(cents per mile)

Cost component	Low	Scenario Medium	High
Quality of life costs			
Ped. & cycl. deaths	0.56	0.56	0.56
Ped. & cycl. injuries	0.21	0.21	0.21
Other vehicle deaths	0.00	0.81	1.62
Other vehicle injuries	0.00	0.84	1.69
Property damage	0.15	0.30	0.44
Traffic holdups	0.17	0.17	0.17
Other economic costs			
medical, emergency serv., legal, etc.	1.07	1.07	1.07
wages/household production	0.05	0.44	0.84
Total (cents/mile)	2.20	4.39	6.59
Total ($ billion)	54	109	163

Table 7. Breakdown of External Costs for Vehicle and Driver Groups
(cents per mile)

	vehicle group					driver group		
Cost component	small car	large car	SUV	minivan	pick-up	<25	25-70	>70
Quality of life costs								
Ped. & cycl. deaths	0.58	0.51	0.43	0.42	0.77	1.29	0.44	0.68
Ped. & cycl. injuries	0.26	0.21	0.16	0.14	0.18	0.49	0.16	0.30
Other vehicle deaths	0.60	0.58	0.80	0.59	1.61	1.83	0.67	0.80
Other vehicle injuries	0.93	0.80	0.68	0.58	1.04	2.07	0.65	1.14
Property damage	0.38	0.28	0.22	0.21	0.29	0.77	0.23	0.33
Traffic holdups	0.21	0.16	0.12	0.12	0.16	0.43	0.13	0.19
Other economic costs								
medical, emerg. serv., legal, et	1.33	0.97	0.84	0.69	1.19	2.91	0.80	1.39
wages/household production	0.50	0.42	0.35	0.30	0.52	1.08	0.34	0.59
Total (cents/mile)	4.80	3.94	3.59	3.04	5.76	10.87	3.42	5.43

Table 8. Total External Cost Across all Driver/Vehicle Groups
(cents per mile)

	<25	25-70	>70	average
small	10.0	3.5	5.8	4.8
large	10.9	3.1	4.9	3.9
SUV	11.3	2.9	5.1	3.6
minivan	10.5	2.6	5.2	3.0
pick-up	13.5	4.7	8.3	5.7
average	10.9	3.4	5.4	4.4

Table 9. Welfare Gain from Differentiated Mileage Tax

scenario	cents per mile	$billion
benchmark	0.38	9.4
external costs		
low	0.10	2.4
high	0.86	21.2
overall mileage elasticity		
halved	0.19	4.7
doubled	0.57	14.1

Figure 1. Welfare Gain from First Best Policy

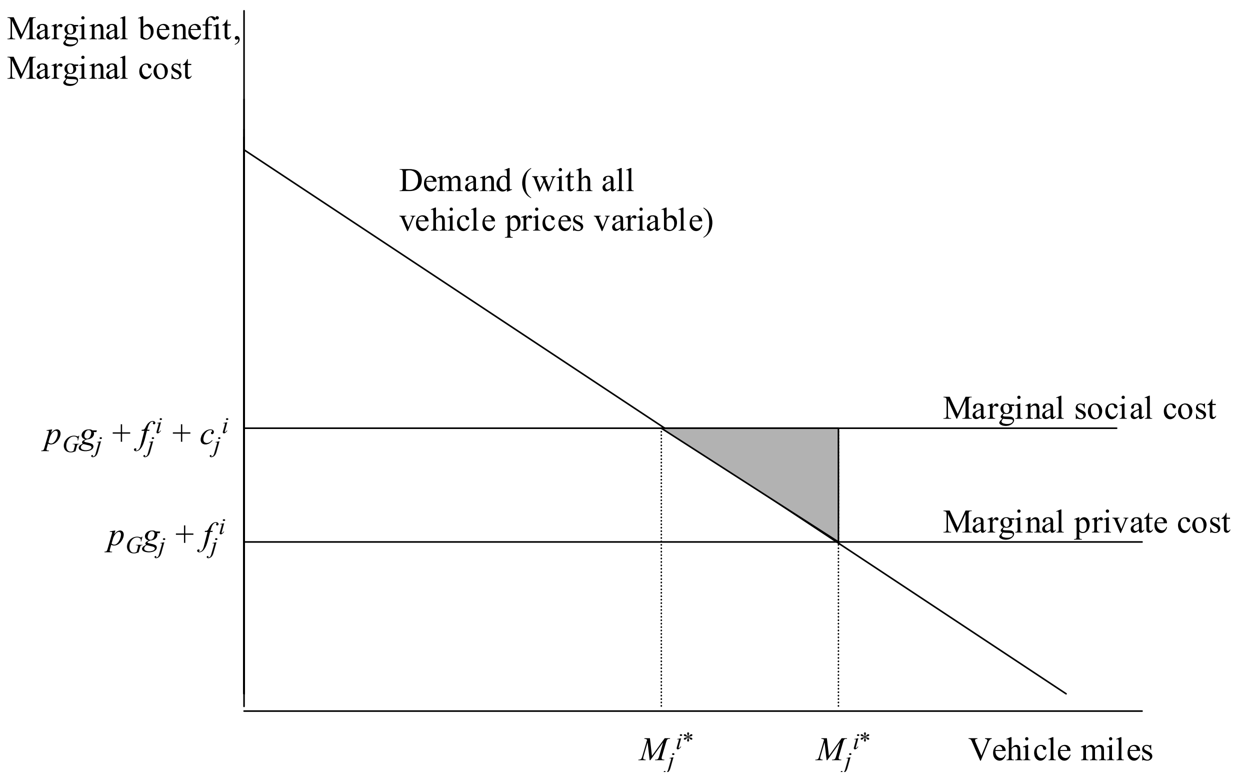
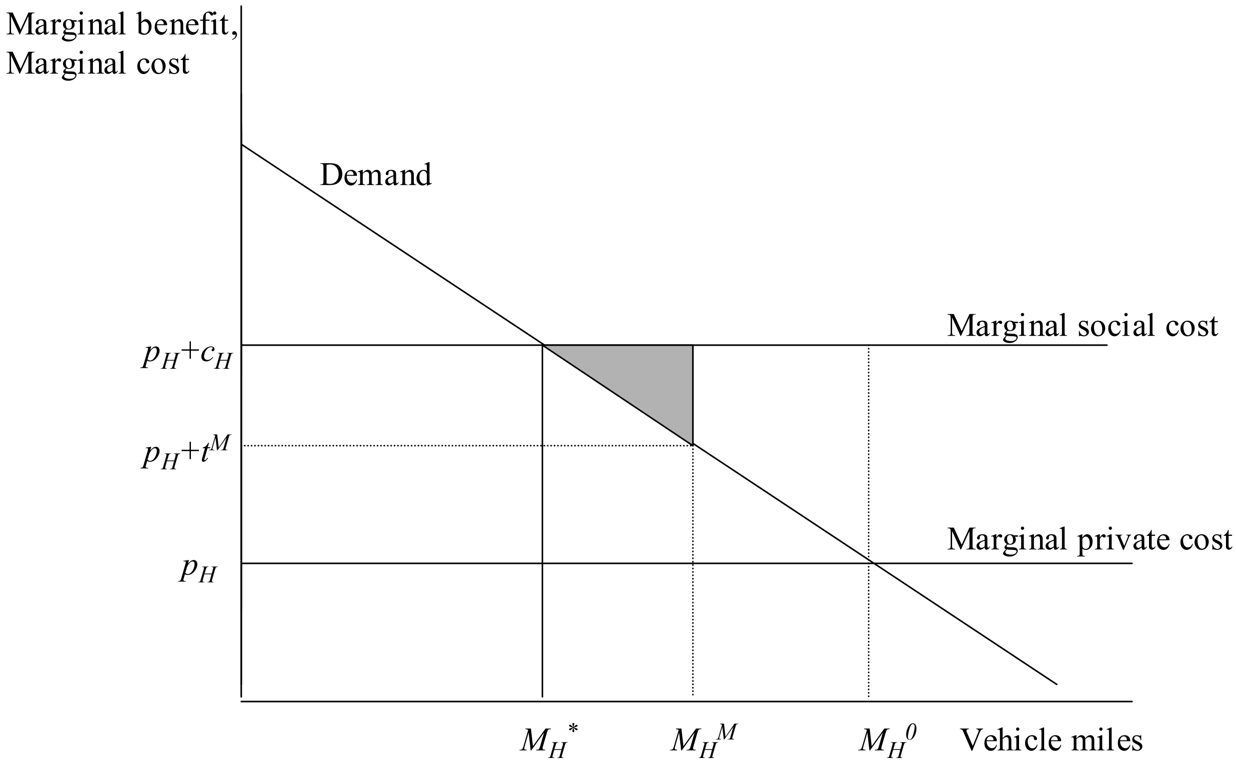
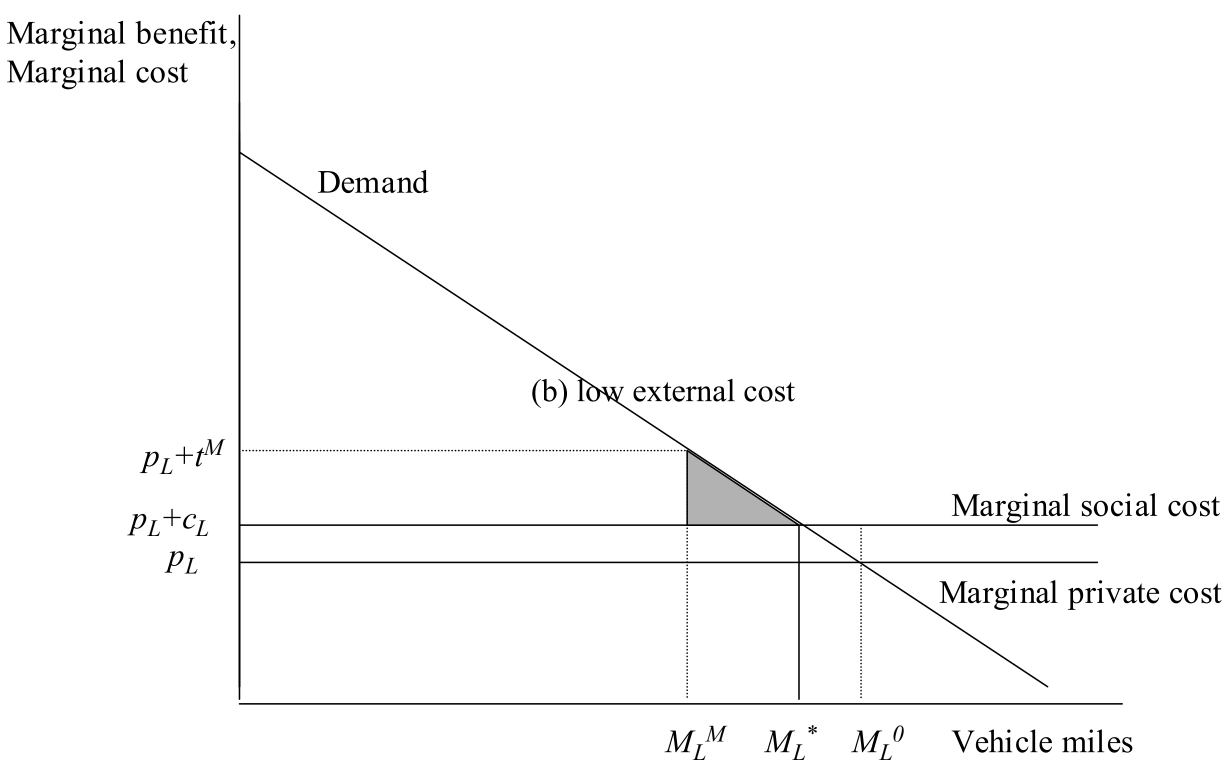


Figure 2. Welfare Effect of a Uniform Mileage Tax

(a) high external cost





(b) low external cost

Figure 3. Welfare Gain from Policies Compared with Differentiated Tax