Is Pay-As-You-Drive Insurance a Better Way to Reduce Gasoline than Gasoline Taxes?

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Abstract

Gasoline taxes are widely perceived as the most efficient instrument for reducing gasoline consumption because they exploit all behavioral responses for reducing fuel use, including reduced driving and improved fuel economy. At present, however, higher fuel taxes are viewed as a political nonstarter.

Pay-as-you-drive (PAYD) auto insurance, which involves replacing existing lump-sum premiums with premiums that vary in proportion to miles driven, should be more practical, since they do not raise driving costs for the average motorist. We show that when impacts on a broad range of motor vehicle externalities are considered, PAYD also induces significantly higher welfare gains than comparable gasoline tax increases, for fuel reductions below 9%. The reason is that under PAYD, all of the reduction in fuel use, rather than just a fraction, comes from reduced driving; this produces a substantial additional efficiency gain because mileage-related external costs (especially congestion and accidents) are relatively large in magnitude.

Key Words: gasoline tax; pay-as-you-drive insurance; mileage tax; welfare effects; motor vehicle externality

JEL Classification Numbers: H21, H23, R48

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1. Introduction

Despite concerns about U.S. dependence on a volatile world oil market, greenhouse gases from fuel combustion, and air quality effects of mobile source emissions, substantially higher federal gasoline taxes are currently a political nonstarter. Any fuel conservation measures that might be more politically palatable are perceived to be inferior to gasoline taxes on efficiency grounds.[1] This paper challenges the latter assertion: it shows that a policy that could be far more feasible than a large increase in fuel taxes can also achieve a significant reduction in fuel demand, with a dramatically larger welfare gain.

The policy is pay-as-you-drive (PAYD) insurance, which is motivated on the grounds of reducing mileage, particularly by high-risk drivers, and reducing the number of uninsured drivers by lowering premiums for low-mileage vehicles. Under PAYD, auto insurance companies would switch from annual lump-sum premiums to premiums levied on annual miles driven, scaled by a driver's rating factor (which would vary with age, crash record, and region). By converting some of the fixed costs of vehicle ownership into costs that vary with mileage, the policy reduces the distance that vehicles are driven and thereby reduces fuel demand. And unlike under higher fuel taxes, driving costs (fixed plus variable) for the average motorist do not increase; hence political opposition to this policy should be more muted.

To some extent, we may see a market-driven transition to PAYD over the next decade or two, given that technology for monitoring vehicle mileage is improving rapidly, and that low-mileage drivers (who currently subsidize high-mileage drivers) have an incentive to opt for

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[1] One caveat to this has to do with the contentious issue of whether vehicle buyers undervalue lifetime fuel costs; if they do, fuel economy regulations could be a more effective way to increase fuel economy than fuel taxes (e.g., Greene 1998).

PAYD.[2] However, even in the absence of externalities discussed here, tax incentives may still be warranted to hasten such a transition because individual insurance companies do not consider benefits to other companies from reduced accident risks when its own clients convert to PAYD (Edlin and Karaca-Mandic 2004).

Ignoring externalities, gasoline taxes are far superior to PAYD on cost-effectiveness grounds because they exploit all behavioral responses for reducing fuel demand. They encourage motorists to drive less, manufacturers to incorporate fuel-saving technologies in new vehicles, and consumers to choose smaller, fuel-efficient vehicles. PAYD provides incentives to drive less but not to improve fuel economy.

However, this argument does not account for impacts on a range of motor vehicle externalities. Estimates of combined mileage-related externalities—traffic congestion, accidents, and local emissions (regulated on a grams per mile basis)—are an order of magnitude larger than for combined fuel-related externalities—greenhouse gases and oil dependency (see below). For a given reduction in fuel demand, PAYD will reduce mileage-related externalities far more than fuel taxes, since all (rather than just a portion) of the reduction in fuel demand comes from reduced driving. We estimate that fully implementing PAYD would reduce gasoline demand by 11.4 billion gallons (9.1%) and increase social welfare by $19.3 billion per year. The same fuel reduction could be achieved by increasing the federal gasoline tax from 18 to 45 cents per gallon, but resulting welfare gains are $6.2 billion, just 32% of those under PAYD.

We also show that PAYD is slightly more efficient than a simple tax on vehicle miles traveled (VMT) for a given fuel reduction and even performs fairly well relative to a fully optimized VMT tax. A VMT tax reduces both miles per vehicle and the vehicle stock; the latter

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[2] Nearly tamperproof odometers and wireless communication systems or global positioning systems (GPS) transponders are increasingly incorporated in new vehicles. Odometer readings might be made (and forwarded to insurance companies) when vehicles are taken in for emissions inspections or tune-ups, reported by auto owners themselves with random verification checks, or recorded remotely on an ongoing basis.

Experiments with PAYD 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 insurance plans. The Texas legislature recently passed legislation authorizing auto insurance companies to offer per mile insurance, and state governments in Maryland and Connecticut also are considering measures to encourage PAYD.

Earlier, economists had advocated pay-at-the-pump (PATP) insurance (e.g., Vickrey 1968, Khazzoom 1999). PATP is inferior to PAYD because charges do not vary with driver characteristics and much of the response to fuel taxes comes from improvements in fuel economy rather than reduced driving (Parry 2004).

effect is neutralized under PAYD, given that overall insurance costs are (approximately) unchanged. Efficiency gains from reducing miles per vehicle exceed those from reducing vehicle demand because in the latter case, fixed insurance costs partly internalize externalities; consequently, a policy that achieves all of a given reduction in fuel demand through reduced miles per vehicle induces a higher welfare gain.[3]

Our analysis is highly simplified (e.g., we assume homogeneous drivers and vehicles) and is meant to provide only a first comparison of the welfare effects of fuel taxes and PAYD, accounting for impacts on a broad range of externalities. At the end of the paper we discuss caveats and ways the analysis might be usefully extended in future work.

Below we sketch out a simple analytical model, discuss parameter values, demonstrate the above results, and discuss limitations.

2. Analytical Model

A. Assumptions

Consider a static model with a large number of representative agents, each with utility:

$$(1) \qquad U = u(C, M) - E_F(\overline{F}) - E_M(\overline{M}), \quad M = vm$$

All variables are expressed in per capita terms on an annualized basis, a bar denotes an economywide variable perceived as exogenous by individual agents, $u(.)$ is quasi-concave in its arguments, and E'_F, E'_M > 0. C is a (unit price) general consumption good, F is fuel consumption, and M is VMT, equal to the number of vehicles purchased, v, times miles per vehicle, m (v is continuously variable in the aggregate).

E_F is disutility from fuel-related externalities caused by other agents; it represents (future) damages from climate change caused by greenhouse gas emissions, the uninternalized risk of macroeconomic disruption costs from oil price shocks (e.g., due to temporarily idled labor and

[3] The flavor of our results might be anticipated from Edlin (2003), who uses insurance premium data to estimate welfare gains from PAYD, and Parry and Small (2004), who estimate welfare effects of gasoline and VMT taxes. This paper differs by comparing all three policies for given reductions in fuel demand accounting for all the major

capital), and the "optimum tariff" from U.S. monopsony power in the world oil market. E_M is disutility from mileage-related externalities; it represents costs of traffic congestion, local emissions (regulated on a grams per mile basis), and traffic accidents. The latter includes, for example, injury risk to pedestrians and other road users but (for now) excludes claims on insurance companies; own driver injury risks are internalized in agents' travel decisions.[4]

The agent's budget constraint is as follows:

(2a) $$C + v(p_v + p_m m) = I + G + \pi$$

(2b) $$p_m = p_F / f + p_i + t_M + \theta(m), \quad p_F = q_F + t_F$$

(2c) $$p_v = p_a + p_P(f)$$

In (2a), p_v and p_m are the (fixed) cost of owning a vehicle and the (variable) per mile driving cost, respectively; I, π, and G are exogenous to individual agents and denote labor income, profit income, and a cash transfer from the government.

In (2b), per mile costs consist of four components. p_F/f is fuel costs where p_F is the consumer price of gasoline, equal to the producer price q_F plus a specific tax t_F, and f is fuel economy, or miles per gallon. p_i and t_M denote insurance premiums perceived on a per mile

auto externalities. Of course, there are more efficient policies than PAYD and VMT taxes to reduce mileage externalities (e.g., peak-period pricing to reduce congestion), but these policies are beyond our scope.

[4] For discussions of motor vehicle externalities, see FHWA (2000), Litman (2003), Parry and Small (2004), and Porter (1999); on accidents and oil dependency in particular, see Miller et al. (1998) and Leiby et al. (1997) respectively.

basis and a VMT tax, respectively; both are initially set at zero.[5] θ is maintenance costs, where $\theta'(m) > 0$.[6]

In (2c), vehicle ownership costs consist of an annual lump-sum insurance premium p_a, and (annualized) vehicle purchase costs $p_P(f)$. Given other vehicle attributes, consumers pay more for a more fuel-efficient vehicle, $p'_P > 0$, since this requires incorporation of technologies to improve engine efficiency and transmission, reduce vehicle drag and rolling resistance, and so forth. Lump-sum insurance partly internalizes externalities in the vehicle purchase decision, but not in the decision of how much vehicles are driven.

Agents choose *C, v*, *m*, and *f* to maximize (1) subject to (2).

The government budget constraint, equating spending with revenues from fuel taxes, is as follows:

(3) $G = t_F F \, , F = M \, / \, f$

where *F* is total fuel use. Higher (or lower) fuel tax revenues are reflected in higher (or lower) household transfers.[7]

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[5] Current premiums give modest discounts for low-mileage drivers, but because most drivers are significantly above or below the discount threshold, the per mile premium is effectively zero. However, the more people drive, the more likely they are to be in accidents and face higher premiums for the several years; by ignoring this, our results moderately overstate the effectiveness of PAYD.

Our analysis also abstracts from vehicle registration fees, which currently average about $200 per year (Harrington and McConnell 2004). Incorporating them would moderately reduce efficiency gains from introducing a VMT tax relative to those from PAYD.

[6] Per mile maintenance costs increase with greater use; this component is included simply to ensure that many vehicles (rather than one) are purchased by the representative agent.

[7] In practice, revenues might be used to finance highway projects or reduce other distortionary taxes. However, this possibility may not greatly strengthen the case for fuel taxes vis-à-vis PAYD. For example, Shirley and Winston (2004) estimate that the (average) social rate of return on highway projects is around 5%; because this is a typical discount rate used in project evaluation, their estimate suggests that the social value of an additional $1 of highway spending may be approximately $1.

All firms are competitive, produce all market goods using labor with constant returns, and provide the level of fuel economy demanded by consumers; market equilibrium equates production costs per vehicle with $p_P(f)$. Insurance companies are also competitive, with expected profits:

(4) $$\pi = v(p_a + (p_i - x)m) \equiv 0$$

where x is the expected insurance claim per mile driven (reflecting property damages and a portion of medical services). Profits accrue to households who own firms and are zero in equilibrium.

B. Welfare Effects from Reducing Fuel

(i) Gasoline tax. The welfare change (in dollars), denoted W, from a marginal increase in t_F can be expressed (see Appendix) thus:

(5) $$\frac{dW}{dt_F} = \left\{ t_F - \frac{E'_F}{\lambda} \right\} \frac{dF}{dp_F} + \left\{ p_a - m\frac{\tilde{E}'_M}{\lambda} \right\} \frac{dv}{dp_F} - \frac{\tilde{E}'_M}{\lambda} v \frac{dm}{dp_F}$$

where λ is the marginal utility of income and $\tilde{E}'_M = E'_M + x$ denotes marginal external mileage costs, inclusive of costs borne by insurance companies. All of the three price coefficients are assumed negative.

The first term on the right in (5) is the welfare effect in the gasoline market. It is positive if the marginal external cost of fuel externalities, E'_F / λ, exceed the gasoline tax; if not, agents are overcharged for the social costs of fuel use and a reduction in fuel demand reduces efficiency. Second is the welfare effect from the reduction in vehicle demand; this is positive so

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Suppose instead we valued extra revenue at its dollar amount plus the efficiency gain that would obtain from using it to reduce distortionary labor income taxes. However, a full assessment of fiscal interactions must account for the effect of higher driving costs on reducing real household wages and labor supply, and thereby compounding efficiency costs of labor taxes. This efficiency loss may not offset all of the gains from recycling additional fuel tax revenues in other tax reductions *if* driving is a relative leisure complement (Parry and Small 2004), though it may still offset a large portion of them. Although PAYD raises no revenue for recycling, it may not compound efficiency costs from prior labor taxes either, as it has no first order effect on overall driving costs.

long as the marginal external cost per vehicle, $m\tilde{E}'_M / \lambda$, exceeds the per vehicle insurance premium. Third is the welfare gain from the reduction in mileage as agents drive vehicles less intensively in response to higher fuel costs; this is an unambiguous welfare gain, since there is no per mile charge to offset external costs.

We assume demand for fuel, vehicles, and miles per vehicle respond to fuel prices as follows:

$$(6) \qquad \frac{F}{F_0} = \left(\frac{p_F}{p_F^0}\right)^{\eta_{FF}}, \quad \frac{m}{m_0} = \left(\frac{p_F}{p_F^0}\right)^{\beta_M \beta_m \eta_{FF}}, \quad \frac{v}{v_0} = \left(\frac{p_F}{p_F^0}\right)^{\beta_M (1-\beta_m)\eta_{FF}}$$

where η_{FF} <0 is the gasoline demand elasticity. This reflects changes in fuel economy and in VMT; the latter reflects reduced miles per vehicle (for a given vehicle stock) and reduced demand for vehicles (for a given miles per vehicle). β_M is the (constant) fraction of reduced gasoline that comes from reduced VMT, and β_m is the (constant) fraction of reduced VMT that comes from reduced miles per vehicle.

From (5) and (6) and some manipulation we obtain the welfare effect per gallon of fuel reduction:

$$(7) \qquad -\frac{dW / dt_F}{dF / dt_F} = \frac{E'_F}{\lambda} - t_F + \left\{\frac{\tilde{E}'_M}{\lambda} - \frac{p_a}{m}\right\} f\beta_M (1-\beta_m) + \frac{\tilde{E}'_M}{\lambda} f\beta_M \beta_m$$

Assuming $\tilde{E}'_M / \lambda > p_a / m$, for a given reduction in fuel demand, the larger the fraction of it that comes from reduced VMT, the larger the "ancillary" welfare gain from reduced mileage externalities.

(iii) VMT tax. For this policy, we assume demand functions are as follows:

$$(8) \qquad \frac{F}{F_0} = \left(\frac{p_F^0 + t_M f^0}{p_F^0}\right)^{\beta_M \eta_{FF}}, \quad \frac{m}{m_0} = \left(\frac{p_F^0 + t_M f^0}{p_F^0}\right)^{\beta_M \beta_m \eta_{FF}}, \quad \frac{v}{v_0} = \left(\frac{p_F^0 + t_M f}{p_F^0}\right)^{\beta_M (1-\beta_m)\eta_{FF}}$$

That is, we convert the VMT tax into its equivalent fuel tax at initial fuel economy and use the same elasticities as before, except that because fuel economy is unchanged, we assume fuel demand responds only to the mileage component of the fuel demand elasticity, $\beta_M \eta_{FF}$.

The marginal welfare effect, per gallon of fuel reduction, is the following (see Appendix):

$$(9) \qquad -\frac{dW/dt_M}{dF/dt_M} = \frac{E'_F}{\lambda} - (t_F^0 + t_M f^0) + \left\{ \frac{\tilde{E}'_M}{\lambda} - \frac{p_a}{m} \right\} f^0 (1 - \beta_m) + \frac{\tilde{E}'_M}{\lambda} f^0 \beta_m$$

Note two main differences from (7). First, and most important, efficiency gains from reducing mileage-related externalities are *not* scaled back by the fraction β_M, since all (rather than a fraction) of the reduction in fuel use comes from reduced driving. Second, the tax distortion, converted to its equivalent in the gasoline market, $t_F^0 + t_M f^0$, will be greater for a given reduction in fuel; a higher tax is required because only miles driven, and not fuel economy, falls in response to the tax.

(ii) PAYD. An increase in the per mile insurance cost p_i is equivalent to an increase in the VMT tax t_M, except that revenues are rebated to consumers in a lower annual fee, p_a. We assume no change in vehicle demand[8]; hence, analogous to (9) and (10), demand functions and the marginal welfare effects are as follows:

$$(10) \qquad \frac{F}{F_0} = \left(\frac{p_F^0 + p_i f^0}{p_F^0} \right)^{\beta_M \beta_m \eta_{FF}}, \qquad \frac{m}{m_0} = \left(\frac{p_F^0 + p_i f^0}{p_F^0} \right)^{\beta_M \beta_m \eta_{FF}}$$

$$(11) \qquad -\frac{dW/dp_i}{dF/dp_i} \approx \frac{E'_F}{\lambda} - (t_F^0 + p_i f^0) + \frac{\tilde{E}'_M}{\lambda} f^0 \beta_m$$

Note that p_i will exceed t_M for a given reduction in fuel demand because the vehicle component of the change in mileage is absent. Thus, the equivalent tax distortion in the fuel market is larger than under the VMT tax. However, the welfare gain from reduced mileage is

[8] This assumption would be exact if miles per vehicle were unchanged, and hence total insurance costs were unchanged (from Equation 4). Mileage and total insurance costs both fall moderately, so it is unclear whether vehicle demand would increase or decrease; however, any effect is likely to be very slight.

larger. This is because all of it comes from reduced miles per vehicle, for which none of the externalities are offset by initial insurance premiums.[9]

We take marginal external costs as constant. Total welfare effects for a given fuel reduction under the three policies are obtained by integrating (7), (9), and (11), using (6), (8), and (10).

3. Parameters

Table 1 summarizes assumed parameter values. We note a few brief points here and refer the reader to the sources listed in the table for more discussion and justification of chosen values.

Based on NRC (2002), we adopt values of 12 cents per gallon for carbon damages ($50 per ton of carbon emissions) and 12 cents per gallon for oil dependency externalities ($5 per barrel of oil). Combined externalities—24 cents per gallon—are actually well below the initial (federal and state) fuel tax of 40 cents per gallon, implying a welfare *loss* from the reduction in fuel use itself. Although this result is based on a best assessment of parameter values, fuel-related externalities are particularly contentious.[10] However, it is the mileage-related externalities, rather than the fuel-related externalities, that drive the (absolute) differences between the policies studied here.

Mileage externalities sum to 12 cents per mile, or $2.40 per gallon for an initial miles per gallon of 20. Thus, mileage externalities are *10* times as large as fuel externalities;

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[9] Welfare gains from PAYD would be somewhat greater in a heterogeneous agent model to the extent that rating factors and external accident costs per mile are correlated across drivers, since the reduction in driving would be more concentrated among those with highest risk (Parry 2004).

[10] Economic estimates of future climate change damages are clearly sensitive to assumptions about long-range discount rates and any weights attached to the welfare of rich and poor nations. Most problematic is the difficulty of allowing for the unknown possibility of abrupt, nonlinear climate change.

Estimates of marginal oil dependency externalities are sensitive to assumptions about future oil prices, and risks of political instability in the Persian Gulf are particularly difficult to gauge. Estimates usually exclude Mideast military spending (equivalent to roughly $7 per barrel of oil consumption), since this spending is viewed more as a fixed cost than as a cost that would vary in response to modest changes in oil imports. They also exclude potentially large global welfare losses from exercise of market power by OPEC (e.g., Greene 1991), since this does not in itself drive a wedge between marginal consumer benefit and marginal supply cost in the domestic U.S. oil market.

congestion is the most important (6.5 cents per mile), followed by accidents (4.0), and then local pollution (1.5).[11]

The gasoline demand elasticity is assumed to be –0.55, with 60% of it accounted for by long-run improvements in fuel economy, and 40% due to reduced VMT; of the latter, 67% is assumed to come from reduced mileage per vehicle and 33% from reduced vehicle ownership. Current lump-sum insurance payments are assumed equivalent to 6.5 cents per mile (or $1.30 per gallon at initial fuel economy).

4. Results

Welfare effects under the three policies are shown in Figures 1–3. If PAYD were fully implemented, per mile costs would rise by 6.5 cents and gasoline demand would fall by 11.4 billion gallons (9.1%). The equivalent fuel reduction could be achieved by an increase in the gasoline tax of 27 cents per gallon (or an increase in the federal gasoline tax of 147%), or a VMT tax of 3.9 cents per mile.

Welfare gains from reducing gasoline are substantially higher under PAYD than under fuel taxes. For the 11.4-billion-gallon decrease in fuel use, welfare gains are $19.3 billion under PAYD, but only 32% of this amount under higher gasoline taxes. This is because welfare gains from reduced mileage are $27.4 billion under PAYD, compared with $9.7 billion under fuel taxes; this easily outweighs higher losses in the gasoline market under PAYD ($8.12 billion compared with $3.5 billion under the fuel tax).

Overall, maximized welfare gains under PAYD exceed those under the equivalently scaled VMT tax by $2.1 billion; again, larger welfare gains from reduced mileage under PAYD more than compensate for the larger equivalent fuel tax distortion. We also compute the fully optimized VMT tax at 8.9 cents per mile, given the existing fuel tax; this reduces gasoline

[11] Marginal congestion costs reflect an average across all U.S. cities and rural areas and across peak and off-peak periods, accounting for the smaller sensitivity of driving on congested roads to fuel costs.

demand by 20.6 billion gallons. However, welfare gains from this fully optimized tax are $22.5 billion, only moderately larger than those under PAYD.

5. Conclusion and Suggestions for Future Work

We conclude that PAYD appears to make more sense on efficiency grounds than higher fuel taxes as a first step toward addressing concerns about energy security and greenhouse gases, as long as motor vehicles are dependent on conventional fuels. Other measures will be needed to achieve a more substantial reduction in gasoline use over the long run, and the suite of potential policies includes subsidies for alternative-fuel vehicles, higher fuel economy standards, and mileage taxes, in addition to higher fuel taxes. A lesson from the current paper is that impacts on a broad range of motor vehicle externalities should be factored into any efficiency comparison of these alternative approaches.

However, this paper is meant to provide only a first step in comparing the welfare effects of fuel taxes and PAYD. There are many ways in which the analysis might be usefully extended in future work. One would be to allow for differences in accident risks across drivers. Those with higher risks (e.g., young drivers or those with prior crash records) would face higher per mile charges and would reduce driving more than those with relatively low risks. This would strengthen the welfare gain from PAYD relative to gasoline taxes or a uniform VMT tax. Allowing for differences in risks across vehicles, or across different regions, would have a similar effect.

It could also be useful to model the dynamic transition to PAYD. It is unlikely that PAYD will be mandated; instead, it will likely be increasingly offered as an option. The first people to buy it will be low-mileage drivers, which in turn will increase the lump-sum premiums faced by high-risk drivers. In present value terms, the delay in the conversion of high-mileage drivers could significantly reduce the welfare gains from PAYD relative to those from an immediate increase in fuel taxes.

Finally, exploring the empirical importance for welfare effects of asymmetric information in auto insurance may also be important. Drivers know more about their risks than insurance companies, with the result that their rating factors may not fully reflect their true driving risks;

again, this could limit welfare gains from the differentiation in per mile charges across drivers with different risks under PAYD.

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Appendix

Deriving (5). Using (1)–(4) the consumer's optimization problem is defined by:

(A1) $$V(t_F, p_i, p_a, t_M, G, \pi, E_F, E_M) = \underbrace{MAX}_{C,m,v}\, u(C, mv) - E_F - E_M$$

$$+\lambda\{I + G + \pi - C - v[p_a + p_P(f) + t_M + m(p_i + \theta)m] - (q_F + t_F)F\}$$

where $V(.)$ is indirect utility.

Partially differentiating (A1) gives:

(A2) $$V_{t_F} = -\lambda F\,,\ V_{p_i} = -\lambda M\,,\ V_{p_a} = -\lambda v\,,\ V_{t_M} = -\lambda M\,,\ V_G = V_\pi = \lambda\,,\ V_{E_F} = V_{E_M} = -1$$

Totally differentiating the indirect utility function in (A1) with respect to t_F, keeping p_i, p_a and t_M constant, gives:

(A3) $$\frac{dV}{dt_F} = V_{t_F} + V_\pi \frac{d\pi}{dt_F} + V_G \frac{dG}{dt_F} + V_{E_F} E_F' \frac{dF}{dp_F} + V_{E_M} E_M' \frac{dM}{dp_F}$$

Using (3), (4), (6), with $p_i = 0$:

(A4) $$\frac{dG}{dt_F} = F + t_F \frac{dF}{dt_F}\,, \frac{d\pi}{dt_F} = -xv\frac{dm}{dt_F}$$

Substituting (A2) and (A4) in (A3), and dividing by λ, and using $p_a = xm$, gives (5), where $dW / dt_F = (dV / dt_F)/\lambda$.

Deriving (9). Totally differentiating the indirect utility function in (A1) with respect to t_M, keeping p_i, p_a and t_F constant, gives:

(A5) $$\frac{dV}{dt_M} = V_{t_M} + f^0 \left\{ V_\pi \frac{d\pi}{dt_F} + V_G \frac{dG}{dt_F} + V_{E_F} E_F' \frac{dF}{dp_F} + V_{E_M} E_M' \frac{dM}{dp_F} \right\}\Bigg|^{f=f^0}$$

Here assume an increase in the VMT tax of dt_M is equivalent to an increase in the fuel tax of $f^0 dt_F$, with fuel economy fixed at its initial level, f^0. Thus, analogous expressions to (A4) apply. Substituting these, and (A2) in (A5), and using $F = M / f^0$, and $t_F = t_F^0 + t_M f^0$ gives, after some manipulation:

(A6) $$\frac{1}{\lambda f^0}\frac{dV}{dt_F} = \left\{ t_F^0 + t_M f^0 - \frac{E'_F}{\lambda} \right\} \frac{dF}{dp_F}\bigg|^{f=f^0} + \left\{ p_a - m\frac{\tilde{E}'_M}{\lambda} \right\} \frac{dv}{dp_F} - \frac{\tilde{E}'_M}{\lambda} v \frac{dm}{dp_F}$$

Dividing by $-dF/dt_M \equiv -f^0 dF/dt_F \big|^{f=f^0}$, and using (8), we can obtain (9), after some manipulation.

Table 1. Parameter Values

Parameter	Value	Source
Components of fuel-related externalities		
carbon emissions, cents/gal.	12.0	NRC (2002)
oil dependency, cents/gal.	12.0	NRC (2002)
sum, cents/gal.	24.0	
Components of mileage-related externalities		
congestion costs, cents/mi.	6.5	Parry et al. (2004)
accident costs, cents/mi.	4.0	Miller et al. (1998)
local pollution, cents/mi.	1.5	Parry et al. (2004)
sum, cents/mi.	12.0	
Total fuel demand elasticity	-0.55	Parry/Small (2004)
portion due to reduced VMT	0.4	Parry/Small (2004)
portion of VMT component due to mi./veh.	0.67	Johansson and Schipper (1997)
Initial gasoline tax, cents/gal.	40	Parry/Small (2004)
Initial retail gasoline price	150	Parry/Small (2004)
Initial (on road) fuel economy, mi./gal.	20	Parry/Small (2004)
Initial annual gasoline consumption, billion gals.	130	EIA (2002)
Current insurance costs, cents/mi.	6.5	Litman (2001)

Figure 1. Welfare Effect under Fuel Tax

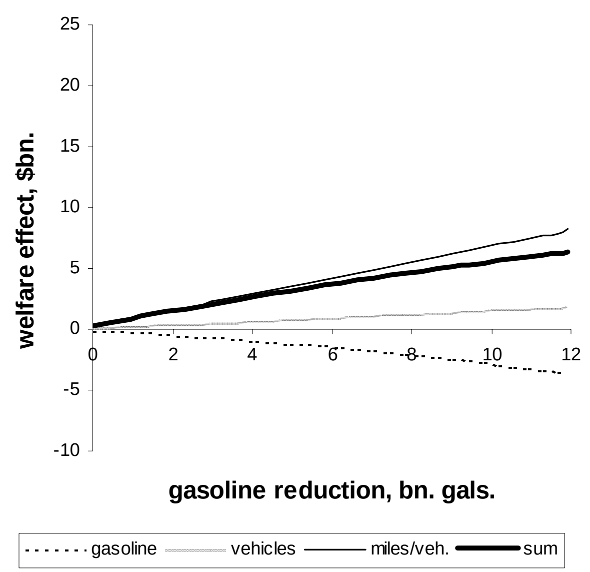

Figure 2. Welfare Effect under VMT tax

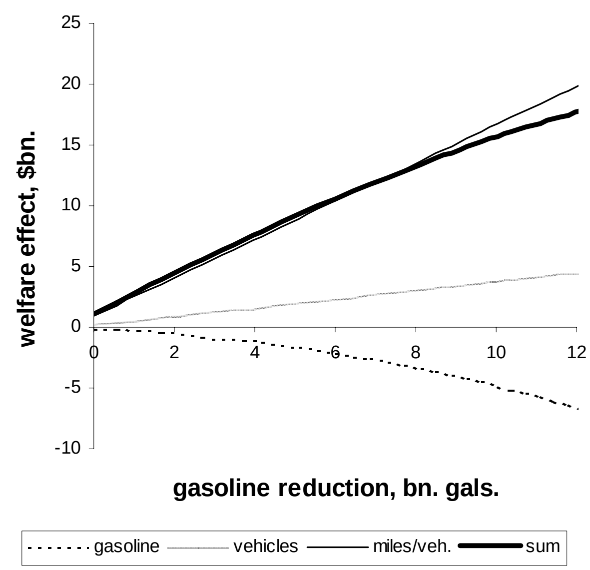

Figure 3. Welfare Effect under PAYD