DISCUSSION PAPER

December 2009 ■ RFF DP 09-52

How Much Should Highway Fuels Be Taxed?

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RESOURCES FOR THE FUTURE

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Abstract

This paper provides an updated assessment of economically efficient taxes on gasoline (used by light-duty vehicles) and diesel (used by heavy-duty trucks) to address various highway externalities in the United States. The (second-best) corrective fuel taxes are estimated, and we discuss the implications of fuel economy regulations and prospective (nationwide) controls on carbon emissions. We also examine how optimal fuel taxes depend on how they interact with the broader fiscal system. Our baseline estimates of the corrective taxes on gasoline and diesel are $1.23 and $1.15 per gallon, respectively. However, optimal fuel taxes can be substantially higher if extra revenues are used to reduce distortionary income taxes, or substantially lower if revenues are not used to enhance economic efficiency.

Key Words: gasoline tax, diesel tax, externalities, corrective tax, fiscal interactions, revenue recycling

JEL Classification Numbers: H21, H23, R48

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1. Introduction

The United States imposes, at the federal and state level, excise taxes of about 40 cents/gallon on gasoline and 45 cents/gallon on diesel for heavy trucks; the federal tax on these fuels is currently 18.4 and 24.4 cents/gallon, respectively (FHWA 2007, Tables 8.2.1 and 8.2.3). U.S. tax rates are low by international standards—for example, in many European countries gasoline taxes exceed $2/gallon—though the United States is somewhat unusual in taxing diesel more heavily than gasoline, albeit only slightly (see Figure 1).

Traditionally, the level of fuel taxes in the United States has been governed by highway spending needs: fuel tax revenues account for about two-thirds of the approximately $100 billion in revenues raised from all highway user fees.[1] However, there is growing debate about both the appropriate level of federal fuel taxes and their status as a dedicated revenue source.

One reason is the weakening link between fuel taxes and highway spending, since a rising portion of this spending has been financed through nonhighway revenues (e.g., local sales and property taxes) and some fuel tax revenues have been diverted for other purposes (e.g., transit projects). Moreover, there is concern about the erosion of real fuel tax revenues per vehicle mile, especially with the recent tightening of fuel economy regulations, and the failure of nominal tax rates to rise with inflation (federal gasoline and diesel taxes were last increased in 1993). However, whether revenues are earmarked or not, the critical (though poorly understood) economic issue is what level of fuel taxation is warranted on fiscal grounds.

Another reason for interest in fuel taxes is the increasingly apparent disparity—due to inadequate taxation—between the societal cost of automobile trips and the private cost borne by motorists. These broader costs reflect the global warming potential of CO_2 emissions and, possibly, consequences from the economy's dependence on a volatile world oil market under the influence of unstable suppliers (see Figure 2). Gasoline and (truck) diesel fuel accounted for 20

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[1] TRB (2006). Other revenue comes from vehicle license and registration fees, tolls, and various taxes on commercial trucks.

and 6 percent, respectively, of nationwide carbon emissions in 2008, and for 46 and 13 percent of oil use, respectively.[2]

Meanwhile, road congestion worsens as relentlessly expanding demand for highway travel outpaces capacity growth (see Figure 3). The average motorist in very large urban areas in the United States lost 54 hours to traffic delays in 2005, up from 21 hours in 1982 (BTS 2008, Table 1.63). Traffic accidents are yet another major externality. About 40,000 people have been killed on U.S. highways each year for the past 25 years (BTS 2008, Table 2.18).

Finally, recent and prospective developments in related policies have implications for efficient fuel taxation, including the new fuel economy regulations and the possibility of a nationwide greenhouse gas cap-and-trade program. Furthermore, advances in electronic metering technology and experience with area pricing in London have raised the prospects for vehicle mileage tolls in the United States; tolls are a far better tool for congestion management than fuel taxes (Santos and Fraser 2006). Similarly, there is growing interest in pay-as-you-drive automobile insurance as a way to internalize accident externalities (Bordhoff and Noel 2008; Greenberg 2009).

Now is therefore an opportune time for an updated assessment of the appropriate role of fuel taxes. Here we focus largely on efficiency considerations—that is, what the ideal tax system should look like from a purely economic perspective. The conceptual framework for optimal fuel taxes has been developed previously. Moreover, there is substantial empirical literature on U.S. highway externalities and behavioral responses to fuel prices, though in some cases (e.g., global warming damages) the literature remains highly unsettled. This paper pulls together prior analytical studies, updates parameter values, and provides some new findings. The latter relate to the implications of recent policy developments and of alternative revenue recycling options. The paper also provides a comparison of optimal gasoline and diesel taxes for the United States, using consistent methodology and assumptions. We summarize some major points as follows.

In our baseline assessment, the corrective gasoline tax is $1.23/gallon, with congestion and accidents together accounting for about three-quarters of this tax. This estimate might be viewed as a lower bound because we use conservative values for global warming and perhaps for oil dependence externalities, both of which are highly unsettled. However, if a binding, nationwide cap-and-trade program were introduced, there would be no global warming benefit, since emissions are fixed. On the other hand, the corrective tax may rise to $2/gallon in the

[2] From www.eia.gov and BTS (2009), Tables 4.13 and 4.14.

presence of (pervasively binding) fuel economy regulations. In this case, more of a given tax-induced gasoline reduction must come from reduced driving (and less from fuel economy improvements), which magnifies the congestion and accident benefits per gallon of fuel reduction. Conversely, pricing of congestion and other externalities through mileage tolls would dramatically lower the corrective gasoline tax, conceivably even below its current level, though such comprehensive tolling is likely a long way off.

However, an unbiased assessment must account for how fuel taxes interact with distortions in the economy created by the broader fiscal system. In fact, the optimal gasoline tax is extremely sensitive to alternative revenue uses. Conceivably, it could rise to $3/gallon if revenues are recycled in highly efficient ways, most notably cuts in income taxes that distort factor markets and create a bias toward tax-favored spending. On the other hand, if recycling does not increase efficiency, the case for higher gasoline taxes appears to be reversed. This is because efficiency gains from externality mitigation are counteracted by efficiency losses in the labor market as higher fuel prices drive up transportation prices relative to leisure.

Under baseline parameters, we put the corrective diesel tax at $1.15/gallon, though underlying determinants are different than for the corrective gasoline tax. Road damage plays a significant role in the corrective diesel tax. Congestion and accidents are less important (even though trucks take up more road space) because a given tax-induced reduction in diesel saves only about a third as many vehicle miles as the same reduction in gasoline (because heavy trucks travel fewer miles per gallon). Again, however, when we account for interactions with the broader fiscal system, the optimal tax is highly dependent on revenue use and varies between essentially zero, when revenues are returned lump-sum, and $3 per gallon, when revenues finance income tax reductions.

Our optimal tax estimates should not be taken too literally because we are relying on parameter evidence that is tentative if not highly speculative in some cases (e.g., for oil dependence externalities). No doubt fuel tax assessments will evolve over time, perhaps even radically, with refinements in valuation methodologies, changes in transportation characteristics (e.g., emission rates, congestion levels), and related policy developments (e.g., the spread of congestion pricing).

The rest of the paper is organized as follows. Section 2 provides conceptual details on the corrective gasoline tax. Section 3 presents calculations of this tax. Section 4 discusses linkages between fuel taxes and the broader fiscal system. Section 5 discusses optimal diesel taxes. A final section offers concluding remarks and briefly discusses some caveats, including distributional concerns, feasibility, and the role of induced innovation.

2. Corrective Gasoline Tax: Analytical Underpinnings

Currently, for the United States, it is reasonable to assume that gasoline and diesel are used exclusively by passenger vehicles and heavy trucks, respectively. Therefore we can focus on passenger vehicle externalities when assessing gasoline taxes and heavy truck externalities when assessing diesel taxes (with one caveat, noted later).[3]

Consider, based on a modified version of Parry and Small (2005), a long-run static model where the representative household solves the following optimization problem:

(1a) $$\underbrace{Max}_{m,v,g,X} \; u(v,m,X,\, E_G(\overline{G}), E_M(\overline{M})) \quad + \quad \lambda\{I + GOV - [(p_G + t_G)gm + t_M m + c(g)]v - p_X X\}$$

(1b) $$G = gM \;, M = vm$$

All variables are in per capita terms and a bar denotes an economy-wide variable perceived as exogenous by individuals.

v denotes the vehicle stock (vehicle choice is a continuous variable because we are averaging over many households), m is miles driven per vehicle, and g is gasoline consumption per mile driven, or the inverse of fuel economy. G and M are therefore aggregate gasoline consumption and miles driven, respectively. X is a general consumption good. E_G(.) and E_M(.) are externalities that vary in proportion with gasoline and mileage, respectively (see below). I denotes (fixed) household income and GOV is a government transfer, to capture the recycling of fuel tax revenues (alternative revenue uses are discussed later). $c(g)$ is the fixed cost of vehicle ownership, which is higher for more fuel-efficient vehicles, reflecting the added production costs of incorporating fuel-saving technologies. p_G and p_X denote the fixed producer prices for gasoline and the general good, while t_G is the (nationwide average) gasoline excise tax. t_M is a unit tax on vehicle mileage. Households choose v, m, g, and X to maximize utility u(.) subject to a budget constraint equating income with spending on gasoline, mileage taxes, vehicles, and other goods (λ is a Lagrange multiplier).[4]

E_G(.) includes greenhouse gases and possible energy security externalities associated with dependence on oil. E_M(.) includes accident risk and road congestion. Local tailpipe emissions are

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[3] In many European countries a substantial portion of the car fleet runs on diesel. In this case the corrective diesel tax will reflect a weighted average of externalities from passenger vehicles and heavy trucks, while substitution among gasoline and diesel passenger vehicles would affect the corrective gasoline tax.

[4] Our analysis abstracts from the possibility of a market failure associated with consumer undervaluation of fuel economy. Whether and to what extent there is such a market failure remains an unsettled issue in the empirical literature.

also included in $E_M(.)$, given that all new passenger vehicles must meet the same emissions-per-mile standards, regardless of their fuel economy, and that (because of the durability of emissions control systems as well as emissions inspection programs) emission rates now show relatively modest deterioration as vehicles age (Fischer et al. 2007).[5] Road wear and tear and noise are ignored because they are primarily caused by heavy trucks (FWHA 2000).

The corrective gasoline tax, denoted t_G^C, is (see Appendix):

(2a) $$t_G^C = e_G + \beta \cdot (e_M - t_M) / g$$

(2b) $$e_G = -u_{E_G} E'_G / \lambda, e_M = -u_{E_M} E'_M / \lambda$$

(2c) $$\beta = \frac{g \cdot dM / dt_G}{dG / dt_G}$$

e_G and e_M denote the marginal external costs (or monetized disutility) from gasoline use and mileage in \$/gallon and \$/mile, respectively.

The corrective tax in (2a) consists of the marginal external cost from greenhouse gases and from oil dependence. It also includes combined marginal external costs from congestion, accidents, and local emissions, net of any internalization through mileage taxes, scaled by two factors. First is miles per gallon ($1/g$), to convert costs into \$/gallon. However, miles per gallon is endogenous and will rise as higher fuel prices raise the demand for more fuel-efficient vehicles. In turn, this multiplies the contribution of mileage-related externalities to the corrective tax, because an incremental reduction in gasoline use is now associated with a larger reduction in vehicle miles. The second factor, denoted β and defined in (2b), is the fraction of the incremental reduction in gasoline use that comes from reduced mileage, as opposed to improved fuel economy. The smaller is β, the smaller the contribution of mileage-related externalities to the corrective gasoline tax. In fact, if all of the incremental fuel reduction came from improved fuel economy, and none from reduced driving, then $\beta = 0$ and congestion, accidents, and local pollution would not affect the corrective tax.

We adopt the following functional forms:

[5] Besides tailpipe emissions, local pollutants are also released upstream during oil shipping, refining, and fuel distribution. However, partly because of tight regulations, the resulting environmental damages are relatively small—about 2 cents/gallon, according to NRC (2002).

(3) $$\frac{M}{M^0} = \left(\frac{p_G + t_G}{p_G + t_G^0}\right)^{\eta_M}, \frac{g}{g^0} = \left(\frac{p_G + t_G}{p_G + t_G^0}\right)^{\eta_g}$$

η_M and η_g denote, respectively, the elasticity of vehicle mileage and gasoline/mile with respect to gasoline prices, and 0 denotes an initial value. The gasoline demand elasticity η_G is the sum of these two elasticities. We take all elasticities as constant (a common assumption) which implies β is also constant.

The welfare gain (W_G) from raising the gasoline tax from its current level to the corrective level is (see Appendix):

(4) $$W_G = \int_{t_G^0}^{t_G^C} (t_G^C - t_G) \frac{dG}{dt_G} dt_G$$

Thus, W_G is given by the shaded triangle in Figure 4.

3. Computing the Corrective Gasoline Tax

In this section, we discuss the corrective tax under benchmark parameter assumptions and alternative scenarios. Benchmark parameters are representative of year 2007 or thereabouts.

A. Global Warming Externalities

A gallon of gasoline produces 0.0088 tons of CO_2. Some studies (e.g., Nordhaus 2008) put the marginal damage from current CO_2 emissions at about \$10/ton, while others value it at about \$80/ton (e.g., Stern 2007), implying damages of \$0.09 or \$0.70/gallon.[6] To be conservative, we use the former for our benchmark case and the latter for sensitivity analysis.

One reason for the different estimates is that—due to long atmospheric residence times and the gradual adjustment of the climate system—today's emissions have intergenerational impacts and the present value of their damages is highly sensitive to assumed discount rates. Some analysts (e.g., Heal 2009) argue for using low rates to discount intergenerational impacts on ethical grounds (i.e., to avoid discriminating against people just because they are born in the future). Others (e.g., Nordhaus 2007) view market discounting as essential for meaningful policy analysis (i.e., to avoid perverse policy implications in other contexts).

[6] Marginal damages in Stern (2007) are substantially reduced if future global climate is rapidly stabilized through aggressive mitigation policies.

A second reason for different CO_2 damage assessments (though not between Nordhaus and Stern) has to do with the treatment of extreme catastrophic risks. In particular, it is possible that the marginal damages from CO_2 emissions are arbitrarily large if the probability distribution over future climate damages has “fat tails”—that is, the probability of increasingly catastrophic outcomes falls more slowly than marginal utility rises (with diminished consumption) in those outcomes (Weitzman 2009). This reflects the possibility of unstable feedback mechanisms in the climate system, such as a warming-induced release of underground methane (itself a greenhouse gas) leading to a truly catastrophic warming. Others (e.g., Nordhaus 2009) have critiqued the fat tails hypothesis on the grounds that we can head off a future catastrophic outcome by radical mitigation measures and deployment of last-resort technologies (e.g., by removing atmospheric carbon, or by scattering particulates in the atmosphere to deflect incoming sunlight) in response to future learning about the seriousness of climate change.

For our purposes, the above controversies would be redundant if a binding cap-and-trade system is imposed on nationwide CO_2 emissions. In this case, any CO_2 reductions from higher gasoline taxes would be offset by higher emissions in other sectors. In contrast, under an economy-wide CO_2 tax, higher gasoline taxes would reduce nationwide emissions, though benefits per ton would be net of the CO_2 tax.

B. Oil Dependence

One possible externality from oil dependence is macroeconomic disruption costs from the risk of oil price shocks. However, to what extent private markets adequately internalize these risks (in inventory decisions, financial hedging, purchase of high fuel economy vehicles, etc.) is much disputed. The most widely cited study is Leiby (2007), who puts the uninternalized macroeconomic disruption cost at about $0.10/gallon for 2004; Brown and Huntington (2009) reach similar conclusions. Some analysts also suggest that a gasoline tax can proxy for an oil import tariff, which could increase U.S. welfare given its monopsony power in the world oil market. However, whether this component should factor into fuel tax assessments is unclear given that an oil import tariff would reduce welfare from a global, as opposed to U.S., perspective, and could even reduce U.S. welfare if other countries retaliated with trade protection measures.

Oil dependence may also constrain U.S. foreign policy, for example, by making U.S. governments reluctant to press for human rights and democratic freedoms in oil-exporting nations. And oil revenue flows may also help fund terrorist activities and unsavory governments. However, valuing these types of geopolitical costs is extremely difficult. Moreover, even if U.S.

oil consumption were significantly curtailed, the proportionate reduction in these petrodollar flows would be relatively small unless other major oil-consuming countries followed suit.

We assume $0.10/gallon for oil dependence externalities, though this might be viewed as a (probably conservative) “placeholder” until we have a better handle on externality valuation.

C. Other Externalities

There is reasonable consensus on local pollution damages from automobiles. We follow Small and Verhoef (2007, 104–105) and assume damages of $0.01/mile nationwide. Mortality effects (caused primarily by particulates rather than ozone) account for the vast bulk of damages. Small and Verhoef assume that the value of a statistical life (VSL) for quantifying mortality is $4.15 million, after accounting for discounting of the time lag between pollution exposure and mortality, and a smaller VSL for seniors who are most at risk. Local pollution damages will likely continue their downward trend over time as the fleet turns over and a greater share of vehicles will have been subject to recently tightened new-vehicle emissions standards.[7]

Parry and Small (2005) assume marginal congestion costs of $0.035/mile. This is based on a Federal Highway Administration (FHWA 2000) assessment that averages the marginal congestion costs for representative road classes across urban and rural areas and time of day. Marginal traffic delays are inferred from traffic speed and traffic flow curves and are monetized assuming that the value of travel time is half the market wage. The $0.035/mile figure includes an adjustment for the relatively weaker sensitivity of congested, peak-period driving (which is dominated by commuting) to fuel prices, compared with off-peak driving. We use an updated value of $0.045/mile, given that nominal wages grew about 22 percent between 2000 and 2007 while congestion delays increased by about 8 percent (CEA 2009, Table B 47; Schrank and Lomax 2009, Table 4).[8]

For accidents, Parry and Small (2005) assume a marginal external cost of $0.03/mile. External costs include injury risks to pedestrians, a large portion of the medical and property damage costs borne by third parties, and the tax revenue component of injury-induced workplace productivity losses (other accident costs, such as injury risks in single-vehicle collisions, and

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[7] The “Tier Two” standards imply emission rates for new vehicles of just 0.8–5.0 percent of pre-1970 rates.

[8] We view the congestion cost figure as conservative. For example, based on extrapolating congestion costs nationwide from a network model of the Washington, D.C., road network, Fischer et al. (2007) put marginal congestion costs at $0.065/mile.

forgone take-home wages from productivity losses, are assumed internal).[9] We use a value of $0.035/mile for the marginal externality, after updating for a VSL of $5.8 million, now used by U.S. Department of Transportation (this VSL is higher than for pollution deaths because people killed on roads are typically younger and die more quickly).[10]

D. Elasticities and Other Data

We assume the pre-tax fuel price p_G is $2.30/gallon, the combined federal and state gasoline tax is $0.40/gallon, and initial gasoline consumption is 140 billion gallons.[11] For the benchmark case we assume initial on-road fuel economy ($1/g$) is 22 mpg (BTS 2008, Table 4.23). The long run gasoline demand elasticity is assumed to be -0.4, with half of the response coming from improved fuel economy and half from reduced mileage (some combination of reduced vehicle demand and reduced miles per vehicle). Thus $\eta_g = -0.2$, $\eta_M = -0.2$ and $\beta = 0.5$. These assumptions are based largely on Small and Van Dender (2006).[12]

As a result of legislation in 2007 and administrative action begun in 2009, fuel economy standards were fully integrated with new targets for reducing CO_2 emissions per mile for new automobiles. By 2016, manufacturers will be required to meet standards equivalent to 39 mpg for the average fuel economy of their new car fleets, and 30 mpg for their light-truck fleets (prior standards were 27.5 mpg for cars and 24.0 mpg for light trucks). To the extent that these regulations will be binding on all auto manufacturers, as opposed to a subset, the gasoline/mile elasticity will be substantially reduced, implying a much smaller β. In fact, the regulations will likely be binding even if fuel prices increase by more than $2/gallon, though there will still be some price responsiveness because motorists can substitute new cars for new light trucks and use existing high-mpg vehicles more intensively (Small 2009). In the sensitivity analysis, we consider a case when the fuel economy elasticity is 0.1 (based approximately on Small 2009), implying $\beta = 0.67$. For this case we set initial (on-road) fuel economy for passenger vehicles at

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[9] Whether and to what extent external costs should also include injury risk to other vehicle occupants in multivehicle collisions is unsettled. All else the same, the presence of one extra vehicle on the road raises the collision risk for all other vehicles (because they have less road space); however, an offsetting factor is that people may drive more slowly or more carefully in heavier traffic.

[10] To the extent that higher fuel taxes encourage consumers to purchase cars instead of light trucks, there may be an added externality gain that our figure does not capture. This is because accident externalities appear to be larger for light trucks (e.g., Li 2009; White 2004).

[11] From Parry and Small (2005) and www.eia.gov.

[12] The estimated magnitude of gasoline demand elasticities has declined over time, reflecting the declining share of fuel costs in total (i.e., time plus money) travel costs. In addition, the relatively low cost technological opportunities for improving vehicle fuel economy have been progressively exploited.

29 mpg (on-road fuel economy is lower than certified fuel economy for new vehicles by about 15 percent).

Finally, we set $t_M = 0$ in the benchmark case, since the nationwide revenue from automobile tolls is very small relative to gasoline tax revenues. In sensitivity analysis we consider full internalization of mileage-related externalities through mileage tolls ($t_M = e_M$).[13]

E. Optimal Tax Estimates

Table 1 summarizes the corrective gasoline tax (in 2007 dollars), its impacts under our benchmark parameters, and various sensitivity analyses, in which the parameters are varied one at a time.

Under benchmark parameters, the corrective tax is $1.23/gallon. Congestion and accidents contribute most to the corrective tax, $0.52 and $0.41/gallon, respectively. Global warming, oil dependence, and local pollution each contribute about the same, $0.09–$0.12/gallon. Increasing the tax from the current rate of $0.40/gallon to the corrective level moderately increases fuel economy to 23.2 mpg and reduces overall gasoline use by 10 percent. The resulting welfare gain is $5.9 billion, and tax revenues increase by 180 percent, from $56 billion to $157 billion.

In the high global warming case, the optimal gasoline tax rises to $1.88/gallon, and welfare gains are almost three times as large (as both the height and the base of the shaded triangle in Figure 4 increase). However, the corrective tax *falls* to $1.14/gallon if there is a preexisting CO_2 cap-and-trade policy (or a Pigouvian CO_2 tax that fully internalizes global warming damages).

In the (future) case with (binding) preexisting fuel economy regulations, the corrective tax rises to $2.01/gallon. Here the mileage-related externalities—local pollution, congestion, and accidents—each contribute about 80 percent more to the corrective tax than they do in the benchmark case. This is because the reduction in mileage associated with a given reduction in gasoline use is now higher, for two reasons. First, an assumed 67 percent (rather than 50 percent) of the marginal reduction in fuel use comes from reduced driving. Second, the distance traveled per gallon of gasoline is about a third higher than in the benchmark case.

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[13] For the cases with preexisting fuel economy standards, and preexisting mileage taxes, we scale back initial gasoline use accordingly, using (3), and with the mileage tax converted to its fuel tax equivalent.

Finally, with a preexisting tax that fully corrects all of the mileage-related externalities, the corrective gasoline tax falls dramatically to $0.19/gallon, or about half its current rate. In this case, the tax reflects global warming and oil dependence externalities only.

4. The Fiscal Rationale for Gasoline Taxes

Gasoline taxes (or any corrective tax or regulation for that matter) interact with distortions in the economy created by the broader tax system, and these interactions should be taken into account to obtain an unbiased assessment of the welfare effects, and optimal level, of the tax. Here we represent the broader tax system by collapsing it into a single tax of t_L on labor income, which reflects the wedge between the gross wage (which we normalize to unity) and the net wage received by households. The gross wage reflects the value marginal product of labor, and the net wage reflects the marginal cost of labor supply in terms of forgone time in nonmarket activities. Changes in labor supply induced by fuel taxes therefore induce welfare effects equal to the change multiplied by t_L. We first discuss adjustments to the corrective gasoline tax to account for broader fiscal interactions and then provide some sense of the empirical importance of these adjustments.

A. Fiscal Adjustments to the Corrective Gasoline Tax

As discussed in the literature on environmental tax shifts (e.g., Goulder 1995), broader fiscal interactions take two forms.

First is the *tax interaction effect*. This is the efficiency loss in the labor market that results when a new product tax drives up the general consumer price level, thereby reducing the real household wage and discouraging labor supply. Of course, the proportionate impact of the product tax on economy-wide labor supply will be extremely small. However, the resulting efficiency loss may still substantially change the overall welfare effect of the tax, given the huge size of the labor market in the economy, and the large wedge that results from federal and state income taxes, payroll taxes, and sales taxes.[14]

Second is the *revenue-recycling effect*. In the literature this is usually taken to reflect the efficiency gain from recycling environmental tax revenues in broader income tax reductions. Alternatively, however, revenues from higher fuel taxes might be used to fund highway spending or, more generally, public goods, transfer payments, or deficit reduction.

[14] That is, the welfare change rectangle in the labor market has a small base but a large height.

There is no need to repeat here the derivations for fiscal adjustments to corrective taxes from other papers that integrate models of externalities into general equilibrium models with prior tax distortions. Instead, we simply start with the following formula derived in Parry et al. (2009):

$$(5) \qquad t_G^* = t_G^C + \delta\left\{G\left(-\frac{dt_G}{dG}\right) - t_G^*\right\} - (1+\delta)t_L\frac{\partial L}{\partial p_G}\left(-\frac{dt_G}{dG}\right)$$

In this expression, δ is the efficiency gain associated with an extra dollar of government revenue (see below), and * denotes an optimal (as opposed to corrective) tax.

In equation (5), the first adjustment to the corrective tax is the revenue-recycling effect. It equals the product of δ and the extra revenue per gallon reduction in gasoline induced by the higher fuel tax. The second adjustment is the tax interaction effect. This includes the change in labor supply from a marginal increase in the gasoline price, multiplied by the increase in gasoline tax, per gallon reduction in gasoline. This labor supply change is multiplied by the labor tax wedge and also by $1+\delta$, to account for the efficiency cost of lost labor tax revenues.

Some manipulation gives, after decomposing the labor supply effect using the Slutsky equation, and using the Slutsky symmetry property (Parry et al. 2009):

$$(6) \qquad t_G^* = t_G^C + \delta\left\{\frac{p_G + t_G^*}{(-\eta_G)} - t_G^*\right\} - \frac{(1+\delta)t_L(p_G + t_G^*)(\eta_{Gl}^{comp} + \eta_{LI})}{(1-t_L)(-\eta_G)}$$

η_{Gl}^{comp} is the (compensated) cross-price elasticity of gasoline use with respect to the household wage or price of leisure and $\eta_{LI} < 0$ is the income elasticity of labor supply.

Suppose for now that extra revenues are used to cut labor taxes. In this case, δ is the efficiency cost of raising an extra dollar of revenue through labor taxes, or the efficiency cost from an incremental increase in t_L divided by the marginal increase in revenue. Thus:

$$(7) \qquad \delta = \frac{-t_L\dfrac{\partial L}{\partial t_L}}{\dfrac{\partial(t_L L)}{\partial t_L}} = \frac{\dfrac{t_L}{1-t_L}\varepsilon_L}{1-\dfrac{t_L}{1-t_L}\varepsilon_L}, \quad \varepsilon_L = \frac{\partial L}{\partial(1-t_L)}\frac{1-t_L}{L} = \varepsilon_L^{comp} + \eta_{LI}$$

where ε_L is the uncompensated labor supply elasticity. This is related to the compensated labor supply elasticity, ε_L^{comp}, and the income elasticity of labor supply, via the Slutsky equation.

B. Quantitative Importance of Fiscal Linkages

Although there is considerable dispersion in empirical estimates, a plausible benchmark assumption is that ε_L = 0.2 (e.g., Blundell and MacCurdy 1999). This value represents an average over labor supply responses due to changes in average hours worked per employee, and labor force participation rates, across male and female workers. We use a standard value of 0.4 for the labor tax wedge, representing a compromise between the average tax rate (which affects the participation margin) and the marginal tax rate (which affects the hours on the job margin). Our values imply δ = \$0.15. This corresponds to a value of 1.15 for the *marginal cost of public funds* (equal to 1+ δ). Note that δ is defined here relative to when revenue is not recycled, and therefore the behavioral responses underlying δ are uncompensated. In contrast, for example, if we were raising income taxes and returning revenue in lump-sum transfers to households, efficiency effects would depend in part on the compensated labor supply elasticity, implying a larger value for δ. This larger value corresponds to the *marginal excess burden of taxation*, as commonly defined.

If gasoline exhibits the same degree of substitution with leisure as consumption goods in general, then $\eta_{Gl}^{comp} = \varepsilon_L^{comp}$, that is, gasoline changes in the same proportion to aggregate consumption, or labor supply, following a compensated increase in the price of leisure (Parry et al. 2009). From manipulating (6) and (7), we can easily show $t_G^* = t_G^C/(1+\delta)$. In this case, using our value for δ, the optimal tax is about 15 percent smaller than the corrective tax. This downward adjustment reflects the balance between the externality benefit per gallon of gasoline reduced and the efficiency cost per gallon reduced, where the latter is the tax per gallon, times 1+δ, to account for the erosion of the base of the gasoline tax (which must be offset by higher labor taxes).

If all auto passenger travel were work related, it might be reasonable to assume gasoline is an average substitute for leisure, as travel would change in rough proportion to hours worked (or total consumption) following a change in the price of leisure. However, evidence in West and Williams (2007) suggests that gasoline is a relatively weak substitute for leisure (i.e., $\eta_{Gl}^{comp} < \varepsilon_L^{comp}$), a plausible explanation being that a large portion of passenger-vehicle trips are leisure-related rather than work-related. Based on West and Williams (2007), we set $\eta_{Gl}^{comp} + \eta_{LI} = 0.1$. With this assumption, the optimal gasoline tax rises to \$1.71/gallon or about 40 percent more than the corrective tax (from equations (6), (7) and the benchmark value for t_G^C).

However, the U.S. fiscal system distorts not only factor markets but also the allocation of spending across ordinary consumption and tax-favored goods, like owner-occupied housing and employer-provided medical insurance. Although the tax-favored sector is small relative to the labor market, it is relatively more responsive to income tax changes than labor supply. This means that the efficiency costs of higher income taxes caused by exacerbating distortions in the pattern of spending can still be significant relative to efficiency costs in factor markets. Based on empirical evidence, Parry (2002) suggests that the efficiency gain from recycling a dollar of revenue in income tax reductions (relative to not recycling the dollar) might be on the order of $0.30 rather than $0.15. If so, the optimal gasoline tax rises dramatically because the revenue-recycling effect is doubled. As indicated in Figure 5, which is obtained from equation (6) with alternative values for δ in both the revenue-recycling and tax interaction components, the optimal gasoline tax rises above $3/gallon.

On the other hand, additional fuel tax revenue might be used to fund highway maintenance and expansion projects. It is difficult to put a general figure on the marginal value of highway spending, given that it will be highly project specific and that transportation agencies do not routinely conduct economic valuations of projects. In fact, a longstanding concern has been the lack of pressure for efficient allocation of highway spending, given that federal grants to states (which account for more than half of federal highway spending) are largely allocated in proportion to vehicle miles rather than degree of congestion or road quality. Empirical estimates of the social rate of return to highway spending are typically within a range of 0–30 percent (TRB 2006, Ch. 3). If the social discount rate is 5 percent, this would imply δ is between about 0.05 and 0.25 for highway spending.[15] As indicated in Figure 5, this would imply an optimal gasoline tax of anywhere between about $0.50 and $2.50/gallon.

More generally, extra revenues might fund (nontransport-related) public spending or deficit reduction, though without more specifics, it is difficult to know how efficiency gains would compare with those from cutting distortionary taxes.[16] The general point here is that optimal gasoline taxes are very sensitive to alternative forms of revenue recycling: if revenues are not used to increase efficiency, the case for higher fuel taxes is considerably undermined. Correspondingly, annualized welfare gains from optimizing the gasoline tax vary enormously under alternative revenue-recycling options, from close to zero to more than $30 billion (Figure 5).

[15] The benefit of highway spending, $1+\delta$, is (1+the rate of return on spending)/(1+the social discount rate).

[16] For pure transfer spending, according to Parry et al. (2009) there is an efficiency loss of 7 cents per dollar of revenue recycled ($\delta = -0.07$). This is because labor supply falls slightly as higher household income increases the demand for leisure (a normal good), thereby exacerbating the labor tax distortion.

One caveat here is that the baseline against which the policy change should be measured is not always clear. For example, fuel tax revenues may fund a spending project that would have gone ahead anyway, even without the fuel tax increase. In this case, fuel tax revenues effectively substitute for an increase in other distortionary taxes, rather than fund extra spending.

5. Optimal Taxes on Diesel for Heavy Trucks

A. Conceptual Framework

The corrective tax on diesel fuel consumed by heavy-duty trucks (i.e., single-unit and combination, commercial trucks) is given by[17]

(8) $$t_D^C = e_D + (\beta^T / g_D)\left\{e_M^T - t_M^T - \gamma \cdot (e_M - t_M + (e_G - t_G)/g)\right\}$$

Here, subscript D refers to diesel rather than gasoline: g_D is diesel consumption per truck mile and e_D is external costs per gallon of diesel. Superscript T refers to trucks rather than light-duty vehicles: β^T is the portion of the marginal, price-induced, reduction in diesel that comes from reduced truck mileage; e_M^T is external costs per truck mile; and t_M^T is a possible tax per truck mile.

γ is the increase in automobile miles per unit reduction in truck miles. $\gamma > 0$ to the extent that travel speeds on congested roads increase as they are vacated by trucks (Calthrop et al. 2007). If $\gamma = 0$, the corrective diesel tax would be essentially analogous to the corrective gasoline tax, with parameters related to heavy truck characteristics. One exception to this is that local emissions for trucks vary (approximately) in proportion to fuel use rather than mileage because emissions standards are defined relative to engine capacity (specifically, grams per brake horsepower-hour) rather than mileage. In addition, road damage is a significant mileage-related externality for heavy trucks, and to lesser extent, so is noise.

To the extent that $\gamma > 0$, the corrective diesel tax is adjusted downward, to account for the induced increase in (fuel- and mileage-related) auto externalities. The latter are defined net of any auto mileage tolls and gasoline taxes. Net auto externalities are expressed in \$/auto mile, then converted into \$/gallon of diesel (via dividing by g_D), and scaled back by the portion of the

[17] The formula below is adapted from Parry (2008), after aggregating his analysis, which distinguishes truck mileage by region and vehicle type.

reduction in diesel use that comes from reduced truck mileage, as opposed to increased fuel economy.[18]

We assume analogous functional forms for truck mileage and fuel/mile as in (3) and assume that γ is constant.

Finally, the general presumption is that freight is an average substitute for leisure because essentially all heavy-truck trips are work-related and are therefore likely to exhibit a similar degree of substitution with leisure compared with goods in general (e.g., Diamond and Mirrlees 1971). Thus, we compute the overall optimal tax using the analogous expression to (6), with $\eta_{Gl}^{comp} = \varepsilon_L^{comp}$.

B. Parameters

Combusting a gallon of diesel produces about 16 percent more CO_2 than combusting a gallon of gasoline,[19] and therefore we adopt a (conservative) value of $0.10/gallon for global warming damages from diesel (using a higher value, or zero to reflect a preexisting cap-and-trade program, would have comparable effects to those discussed above for gasoline taxes). We use the same placeholder value as above, $0.10/gallon, for oil dependence costs.

Based on a source-apportionment study for year 2000 by the U.S. Environmental Protection Agency, FHWA (2000, Table 13) puts local air pollution costs from heavy trucks at about $0.40/gallon. We make two adjustments to this figure. First, we multiply by 4.15/2.7, which is the ratio of the VSL for local pollution assumed above to the VSL in FWHA (2000). Second, we multiply by 0.6 to account for the decline in heavy-truck emission rates (see BTS 2008, Table 4.38). The resulting air pollution cost is $0.36/gallon.

Based on FHWA (2000), marginal congestion costs are assumed to be twice as large as for automobiles, or $0.09/truck-mile. Trucks take up more road space and drive more slowly than autos, though a partly offsetting factor is that a greater share of nationwide truck mileage occurs under free-flow conditions (in rural areas and at off-peak hours) than for autos.

Marginal accident costs are assumed to be 83 percent of those for autos, or $0.029/mile, based on FHWA (2000). Although, for given speeds at impact, trucks have far greater damage

[18] In principle, higher gasoline taxes might lead, through a fall in road congestion, to a proportionate increase in truck mileage. However, given that trucks account for a relatively small share of highway traffic, this feedback effect likely makes very little difference to the optimal gasoline tax.
[19] See http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

potential than cars, an offsetting factor is that trucks are traveling at slower speeds and crash less often, in part because they are driven by professionals.

Road damage externalities for heavy trucks have been assessed in studies that apportion road maintenance expenditures to different vehicle classes, and noise costs have been estimated based on hedonic studies measuring how proximity to highways affects property values. We assume external costs of $0.055/mile and $0.015/mile respectively based on FHWA (2000), after updating to 2007 using the consumer price index.

We assume the same pretax price of diesel as for gasoline, an initial tax of $0.44/gallon, initial truck fuel consumption of 38 billion gallons, and fuel economy of 6 mpg.[20] Although the limited evidence available suggests that diesel fuel elasticities are in the same ballpark as gasoline price elasticities (Dahl 1993, 122–23; Small and Winston 1999, Table 2.2), we might expect the fuel economy elasticity to be smaller for diesel, since technological opportunities for improving fuel economy are more limited for trucks than for cars given the high power requirements necessary to move freight (EIA 1998). We assume a diesel price elasticity of –0.25, with 40 and 60 percent, respectively, due to the responsiveness of fuel economy and mileage.

As regards the feedback effect on auto externalities, about 55 percent of truck travel occurs in rural areas (FHWA 2000), where congestion is minimal, and therefore a reduction in truck driving would have little impact on encouraging more auto travel. For typical urban roads, a reasonable rule of thumb appears to be that roughly 70 percent of reduced truck congestion would be offset by extra auto travel (Cervero and Hansen 2002; Calthrop et al. 2007). We assume, nationwide, that 31 percent (70 percent times 0.45) of any reduction in congestion from trucks would be offset by extra auto travel. We double this, based on the assumption that two car miles is equivalent to one truck mile in terms of congestion, to obtain $\gamma = 0.62$ (Santos and Fraser 2006). If diesel taxes were increased substantially, it is highly likely that gasoline taxes would go up in tandem. Therefore, in computing the auto feedback effect in (8), we use the corrective gasoline tax (and fuel economy at that tax), though we also note the implications of assuming the current gasoline tax.

C. Optimal Tax Estimates

We begin with the corrective portion of the optimal diesel tax, as summarized in Table 2. Even though all parameters, aside from global warming and oil dependence externalities, are

[20] From www.eia.gov, FHWA (2003), Table MF-121T, and BTS (2008), Tables 4.13 and 4.14.

notably (if not substantially) different, overall the corrective tax is very close to that for gasoline—$1.15/gallon compared with $1.23/gallon.

On the one hand, road damage and noise combined contribute $0.26/gallon to the corrective diesel tax (versus zero to the corrective gasoline tax), and the contribution of local pollution is higher for diesel, since emissions vary with all fuel reductions rather than just the portion from reduced mileage.

On the other hand, congestion contributes $0.33/gallon to the corrective diesel tax compared with $0.52/gallon for gasoline. Congestion per mile is twice as large for trucks as for autos, and a larger portion of the tax-induced reduction in diesel is assumed to come from reduced vehicle mileage. However, these factors are more than offset by the much lower fuel economy of trucks, which implies that a gallon reduction in diesel fuel is associated with a much smaller reduction in vehicle miles than a gallon reduction in gasoline. For the same reason, accidents play a smaller role in the corrective diesel tax. Moreover, accident costs per truck mile are roughly the same (rather than twice as large) as for an auto mile. The auto feedback effect shaves a further $0.10/gallon off the corrective diesel tax. This effect would be $0.18 if evaluated at the current, rather than corrective, gasoline tax.

Given our assumptions, the proportionate improvement in vehicle fuel economy and the proportionate reduction in fuel use from optimizing fuel taxes are smaller for diesel than for gasoline. Moreover, current diesel fuel consumption is only 27 percent of that for gasoline. For these reasons, welfare gains under benchmark parameters—ignoring fiscal linkages—are $1.3 billion per year from raising diesel taxes to their corrective level, compared with $5.9 billion for the analogous gasoline tax reform.

A final point from Table 2 is that if mileage-related externalities were fully internalized through vehicle tolls, the corrective diesel tax would be $0.56/gallon (this assumes that auto externalities are fully internalized, thereby eliminating the auto feedback effect).

Figure 6 underscores the critical role of broader fiscal interactions for the diesel tax (under baseline parameters). If the efficiency gain per dollar of recycled revenue is $0.15, the optimal diesel tax is $1.06, or moderately lower than the corrective tax. Thus, the net adjustment for fiscal interactions is in the opposite direction to that for the gasoline tax, reflecting the assumption that diesel is an average, rather than a relatively weak, leisure substitute. On the other hand, if the efficiency gain from revenue recycling is $0.30 per dollar (e.g., because income taxes distort spending patterns in addition to the labor market), the optimal diesel fuel tax can rise to $3/gallon. Conversely, if revenue recycling does not increase efficiency, the optimal diesel tax not only falls below its current level but essentially falls to zero. In this case the efficiency loss from the tax interaction effect is large enough to offset the entire efficiency gain from externality mitigation!

6. Conclusion

At first glance, there appears to be a strong efficiency case for substantially increasing taxes on highway fuels—to more than $1/gallon—at least for the foreseeable future, before other (more efficient) policies to largely internalize mileage-related externalities (e.g., peak-period road pricing) are widely implemented. This presumes efficient use of additional fuel tax revenues. Ideally, from an efficiency perspective, such revenues would finance reductions in distortionary income taxes, in which case the argument for higher fuel taxes is even stronger. On the other hand, the case for higher taxes is more qualified if there is some risk that revenues will not be used productively.

Our discussion ignores the distributional impact of higher fuel taxes. Studies suggest that gasoline taxes are regressive, though less so if income is measured on a lifetime rather than annual basis (e.g., Poterba 1991; West and Williams 2004). One approach to addressing these concerns is to make adjustments to the broader tax and benefit system. Williams (2009) finds that the distributional effects of gasoline taxes can be approximately offset through such adjustments, with modest overall implications for the optimal gasoline tax.

Substantially higher fuel taxes appear to have little political traction at present, though it is not difficult to think of examples of policy reforms that, at some earlier date, seemed impossible to implement (e.g., industry deregulation or the use of market-based instruments for pollution control). At any rate, the economist’s role is to inform policymakers about the potential net benefits from overcoming obstacles to more efficient policy.

Finally, over the long haul, the development of new technologies is critical for any effort to wean motorists off conventional fuels. Does this mean we should implement even stiffer fuel taxes? Perhaps not. A common view among economists seems to be that innovation incentives are more efficiently addressed through supplementary technology policies than by raising energy taxes above levels warranted on externality and fiscal grounds (e.g., Fischer and Newell 2007; Goulder and Schneider 1999). These additional measures might include funding for basic research, inducements for applied private sector R&D, and possible interventions at the technology deployment stage, though more research is needed on the appropriate stringency and design of such supplementary measures.

References

Blundell, Richard and MaCurdy, Thomas, 1999. “Labor Supply: A Review of Alternative Approaches.” In Ashenfelter, O., and D. Card, (eds.), *Handbook of Labor Economics*, New York, Elsevier.

Bordoff, Jason E. and Pascal J. Noel, 2008. *Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity*. The Hamilton Project, the Brookings Institution, Washington, DC.

BTS, 2008. *National Transportation Statistics 2008*. Bureau of Transportation Statistics, US Department of Transportation, Washington, DC.

Brown, Stephen P. A. and Hillard G. Huntington, 2009. “Reassessing the Oil Security Premium.” Working paper, Resources for the Future and Stanford University.

Calthrop, E., de Borger, B., Proost, S., 2007. “Externalities and Partial Tax Reform: Does it Make Sense to Tax Road Freight (but not Passenger) Transport?” *Journal of Regional Science* 47: 721–752.

CEA, 2009. *Economic Report to the President*. Council of Economic Advisors, Washington, DC.

Cervero, R., Hansen, M., 2002. “Induced Travel Demand and Induced Transport Investment: A Simultaneous Equation Analysis.” *Journal of Transport Economics and Policy* 36, 469–490.

Dahl, Carol, 1993. “A Survey of Energy Demand Elasticities in Support of the Development of the NEMS.” Report prepared for the US Department of Energy.

Diamond, Peter A., and James Mirrlees, 1971. “Optimal Taxation and Public Production I: Production Efficiency and II: Tax Rules.” *American Economic Review* 61: 8-27 and 261-278.

EIA, 1998. *Impacts of the Kyoto Protocol on US Energy Markets and Economic Activity*. Energy Information Administration, US Department of Energy, Washington, DC.

FHWA, 2007. *Highway Statistics 2007*. Federal Highway Administration, US Department of Transportation, Washington DC.

FHWA, 2003. *Highway Statistics 2003*. Federal Highway Administration, US Department of Transportation, Washington, DC.

FHWA, 2000. *Addendum to the 1997 Federal Highway Cost Allocation Study Final Report*. US Federal Highway Administration, Department of Transportation, Washington, D.C.

Fischer, Carolyn and Richard G. Newell, 2007. "Environmental and Technology Policies for Climate Mitigation" *Journal of Environmental Economics and Management*, forthcoming.

Fischer, Carolyn, Winston Harrington, and Ian W.H. Parry, 2007. "Should Corporate Average Fuel Economy (CAFE) Standards be Tightened?" *Energy Journal* 28: 1-29, 2007.

Goulder, Lawrence H., 1995. "Environmental Taxation and the 'Double Dividend': A Reader's Guide." *International Tax and Public Finance* 2: 157-183.

Goulder, Lawrence H. and Stephen H. Schneider, 1999. "Induced Technological Change and the Attractiveness of CO_2 Emissions Abatement Policies." *Resource and Energy Economics* 21:211-53.

Greenberg, Allen, 2009. "Designing Pay-Per-Mile Auto Insurance Regulatory Incentives." *Transportation Research Part D* 14: 437-445.

Heal, Geoffrey, 2009. "Climate Economics: A Meta-Review and Some Suggestions for Future Research." *Review of Environmental Economics and Policy* 3: 4–21.

OECD, 2009. *Energy Prices and Taxes: Quarterly Statistics*, First Quarter, 2009. Organization for Economic Cooperation and Development, Paris.

Leiby, Paul N., 2007. *Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*. Oakridge National Laboratory, ORNL-TM-2007-028.

Li, Shanjun, 2009. "Traffic Safety and Vehicle Choice: Quantifying the Effects of the Arms Race on American Roads." Discussion paper 09-33, Resources for the Future, Washington, DC.

Nordhaus, William D., 2007. "A Review of the Stern Review on the Economics of Climate Change." *Journal of Economic Literature* 45: 686–702.

———. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press.

———. 2009. "An Analysis of Weitzman's Dismal Theorem." Working paper, Yale University.

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

Parry, Ian W.H., 2002. "Tax Deductions and the Marginal Welfare Cost of Taxation." *International Tax and Public Finance* 9: 531-551.

Parry, Ian W.H., 2008. "How Should Heavy-Duty Trucks be Taxed?" *Journal of Urban Economics* 63: 651-668.

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.

Parry, Ian W.H., Ramanan Laxminarayan, and Sarah E. West, 2009. "Fiscal and Externality Rationales for Alcohol Taxes." *B.E. Journal of Economic Analysis & Policy* (Contributions) 9, Article 29, 1-45.

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

Santos, Georgina and Gordon Fraser, 2006. "Road Pricing: Lessons from London." *Economic Policy* 21: 264-310.

Schrank, David, and Timothy Lomax. 2009. *The 2009 Urban Mobility Report*. College Station: Texas Transportation Institute, Texas A&M University.

Small, Kenneth A., 2009. "Energy Policies for Passenger Transportation: A Comparison of Costs and Effectiveness." Working paper, University of California, Irvine.

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 Erik Verhoef, 2007. *The Economics of Urban Transportation*. New York: Routledge.

Small, Kenneth A. and Clifford Winston, 1999. "The Demand for Transportation: Models and Applications." In J.A. Gómez-Ibáñez, W. Tye and C. Winston (eds.), *Transportation Policy and Economics: A Handbook in Honor of John R. Meyer*. Brookings Institution, Washington, DC

Stern, Nicholas, 2007. *The Economics of Climate Change*. Cambridge University Press, Cambridge, U.K.

TRB. 2006. *The Fuel Tax and Alternatives for Transportation Funding*. Transportation Research Board, Special Report, no. 285. National Academy Press, Washington, DC.

Weitzman, Martin, L. 2009. "On Modeling and Interpreting the Economics of Catastrophic Climate Change." *Review of Economics and Statistics* 91: 1–19.

West, Sarah and Roberton C. Williams, 2004. “Estimates from a Consumer Demand System: Implications for the Incidence of Environmental Taxes.” *Journal of Environmental Economics and Management* 47: 535-558.

West, Sarah and Roberton C. Williams, 2007. “Optimal Taxation and Cross-Price Effects on Labor Supply: Estimates of the Optimal Gas Tax.” *Journal of Public Economics* 91: 593-617.

White, Michelle, 2004. “The ‘Arms Race’ on American Roads: The Effect of SUV’s and Pickup

Trucks on Traffic Safety.” *Journal of Law and Economics* XLVII: 333–356.

Williams, Roberton C. III, 2009. “An Estimate of the Second-Best Optimal Gasoline Tax Considering Both Efficiency and Equity.” Working paper, University of Maryland.

Appendix: Analytical Derivations

Deriving Equation (2): The corrective gasoline tax. The optimal tax is derived using a standard two-step procedure. First, we solve the household optimization problem in (1), where externalities, and government variables, are taken as given. This yields the first order conditions:

$$\text{(A1)} \qquad \frac{u_m}{v} = \lambda(p_G + t_G)g \;, u_v = \lambda\left[(p_G + t_G)gm + c\right], -c'(g) = (p_G + t_G)m \,, \quad u_X = \lambda p_X$$

The second step is to totally differentiate the household's indirect utility function, which is simply equivalent to the expression in (1), with respect to the gasoline tax. In this step, economy-wide changes in externalities and the government transfer are taken into account. Using the first order conditions in (A1) to eliminate terms in dm/dt_G, dv/dt_G, dg/dt_G, and dX/dt_G, the total differential is given by:

$$\text{(A2)} \qquad u_{E_G} E'_G \frac{dG}{dt_G} + u_{E_M} E'_M \frac{dM}{dt_G} + \lambda\left\{\frac{dGOV}{dt_G} - G\right\}$$

The government budget constraint, equating spending with gasoline tax revenue, is $GOV = t_G G$. Totally differentiating this expression gives:

$$\text{(A3)} \qquad \frac{dGOV}{dt_G} = G + t_G \frac{dG}{dt_G}$$

From differentiating the expression for gasoline use in (1b):

$$\text{(A4)} \qquad \frac{dG}{dt_G} = g \frac{dM}{dt_G} + M \frac{dg}{dt_G}$$

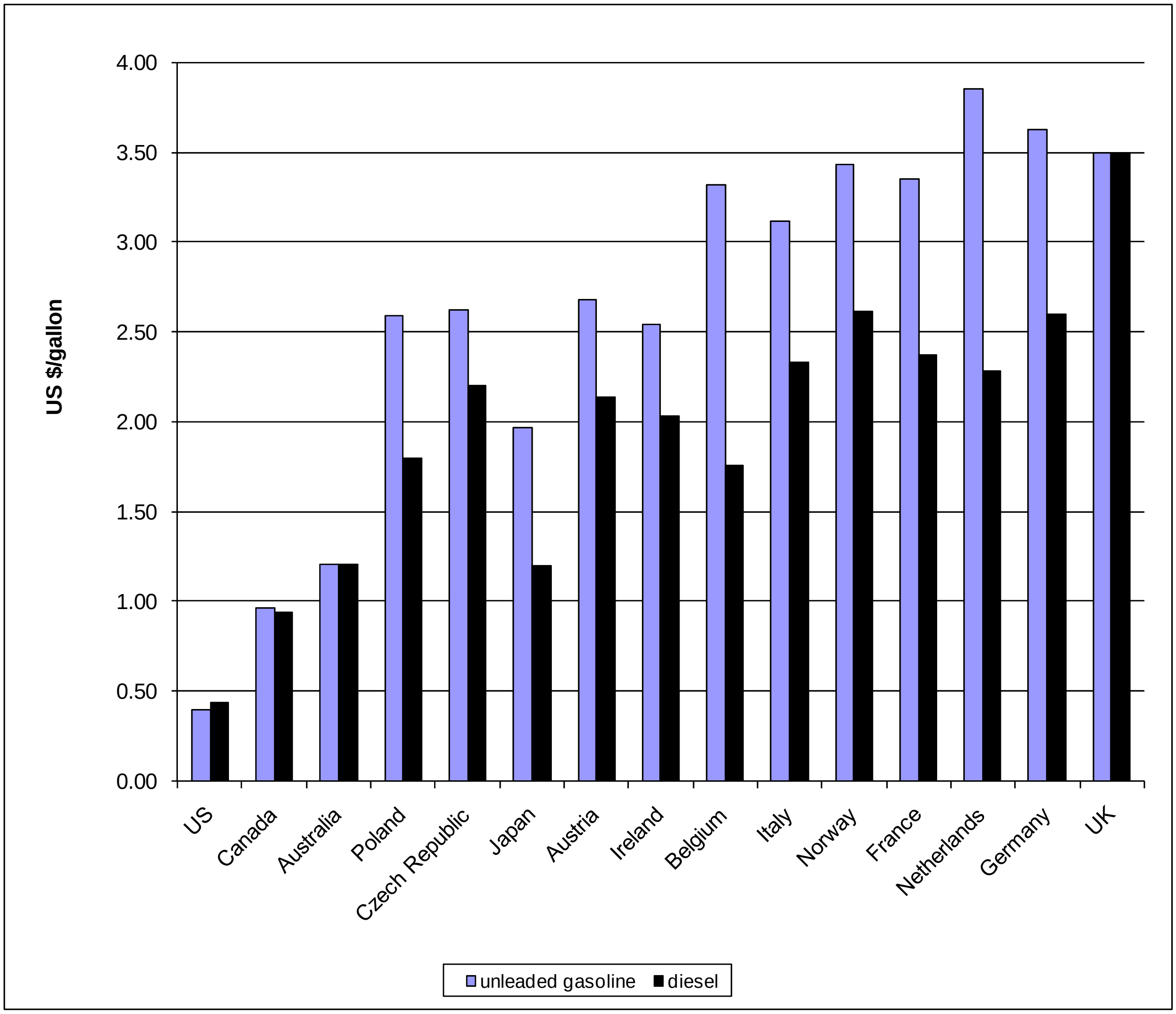
Equating (A2) to zero, to obtain the corrective tax, and substituting (A3), gives:

$$\text{(A5)} \qquad t_G^C = -\frac{u_{E_G}}{\lambda} E'_G - \frac{u_{E_M}}{\lambda} E'_M \frac{dM/dt_G}{dG/dt_G}$$

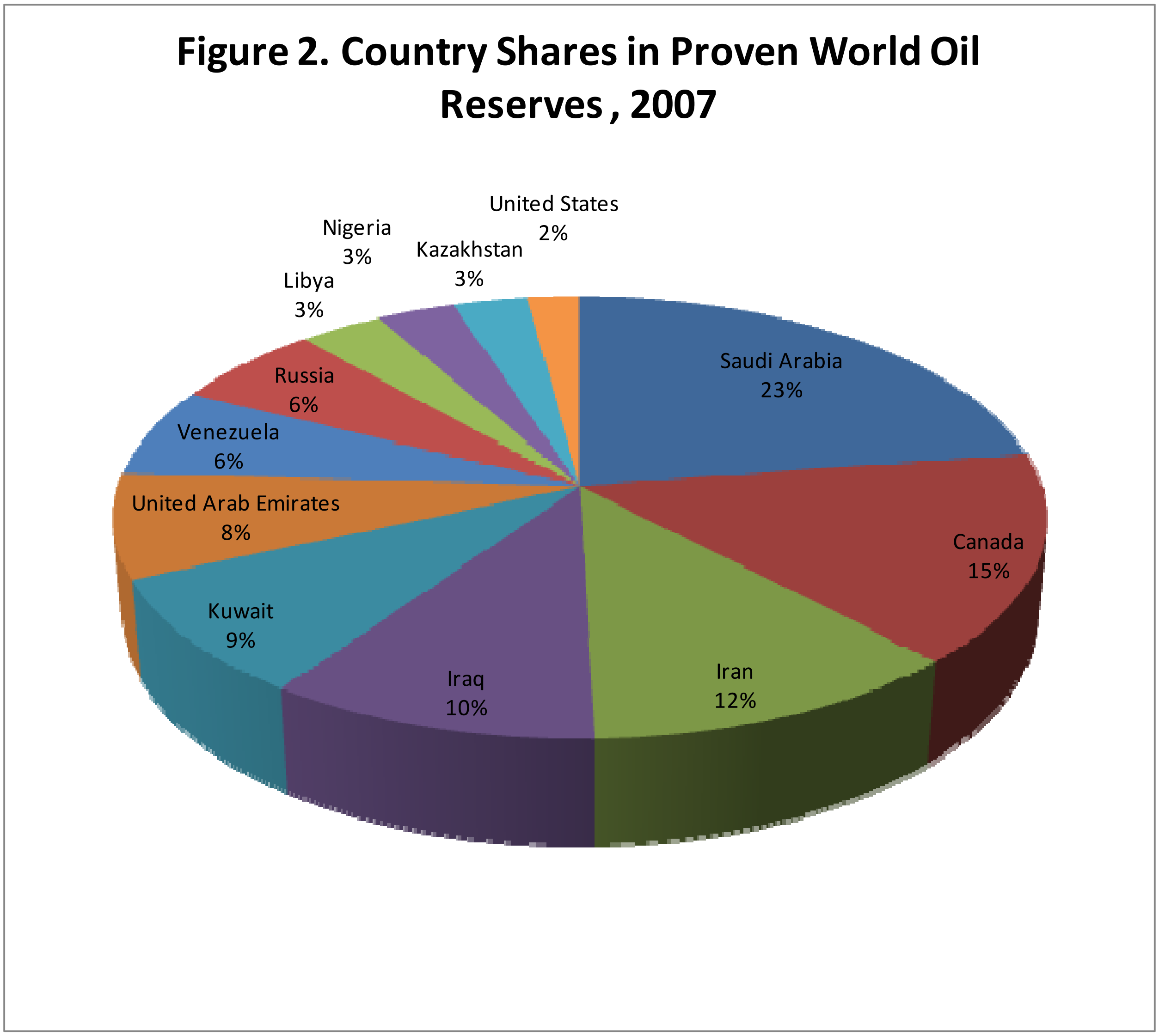
Substituting expressions in (2b) in (A5), gives the corrective tax formula in (2a), with β defined in (2c).

Figures and Tables

Figure 1. Taxation of Motor Fuels: Selected Countries (2008)

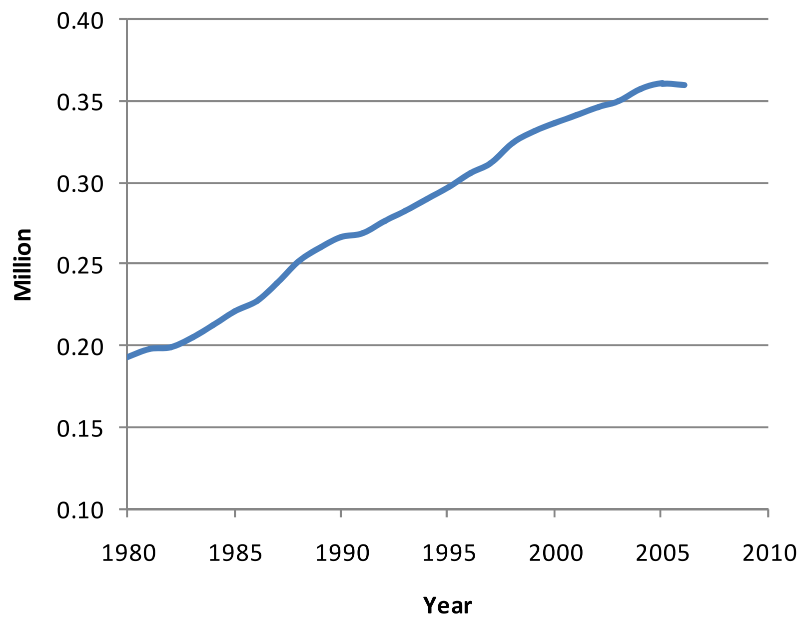


Source: OECD (2009).



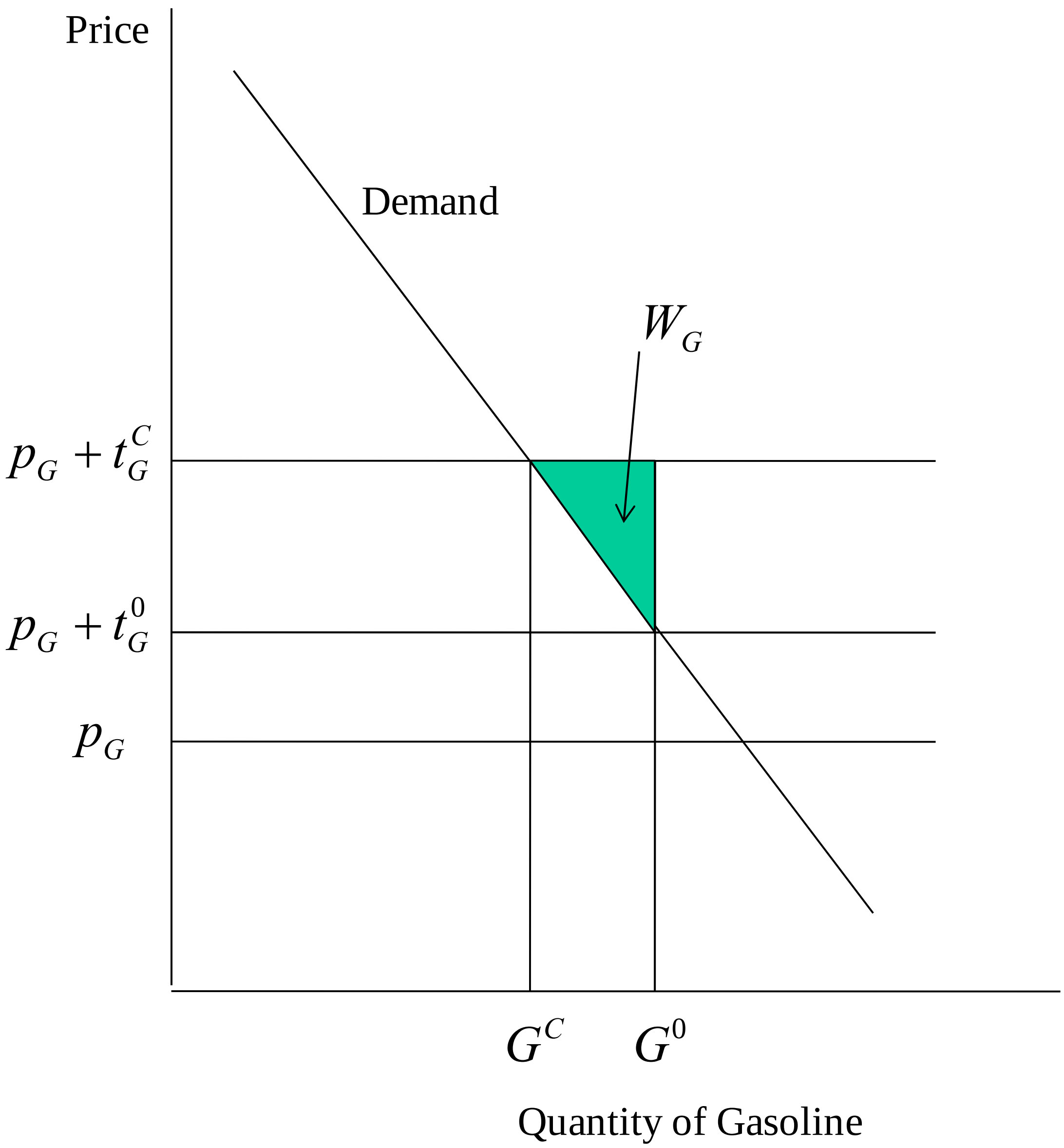
Source: *Oil and Gas Journal*, January 2008.
Note: Canadian figure includes 150 billion barrels from oil sands.

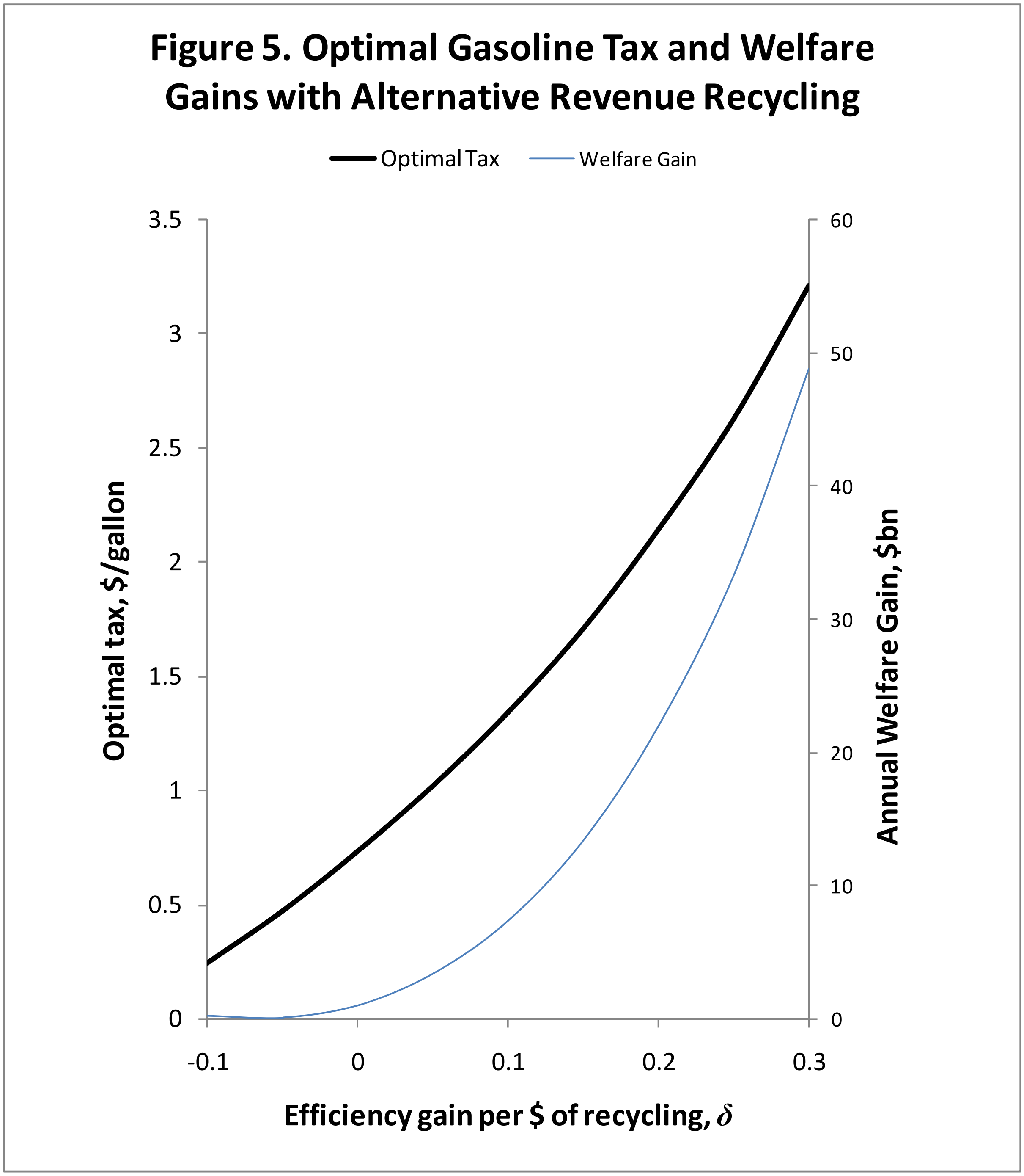
Figure 3. Vehicle Miles of Travel per Lane Mile of Capacity, 1980-2007



Source: FHWA (2007), Table 4.2.1.
Note: Figure includes mileage from light and heavy vehicles.

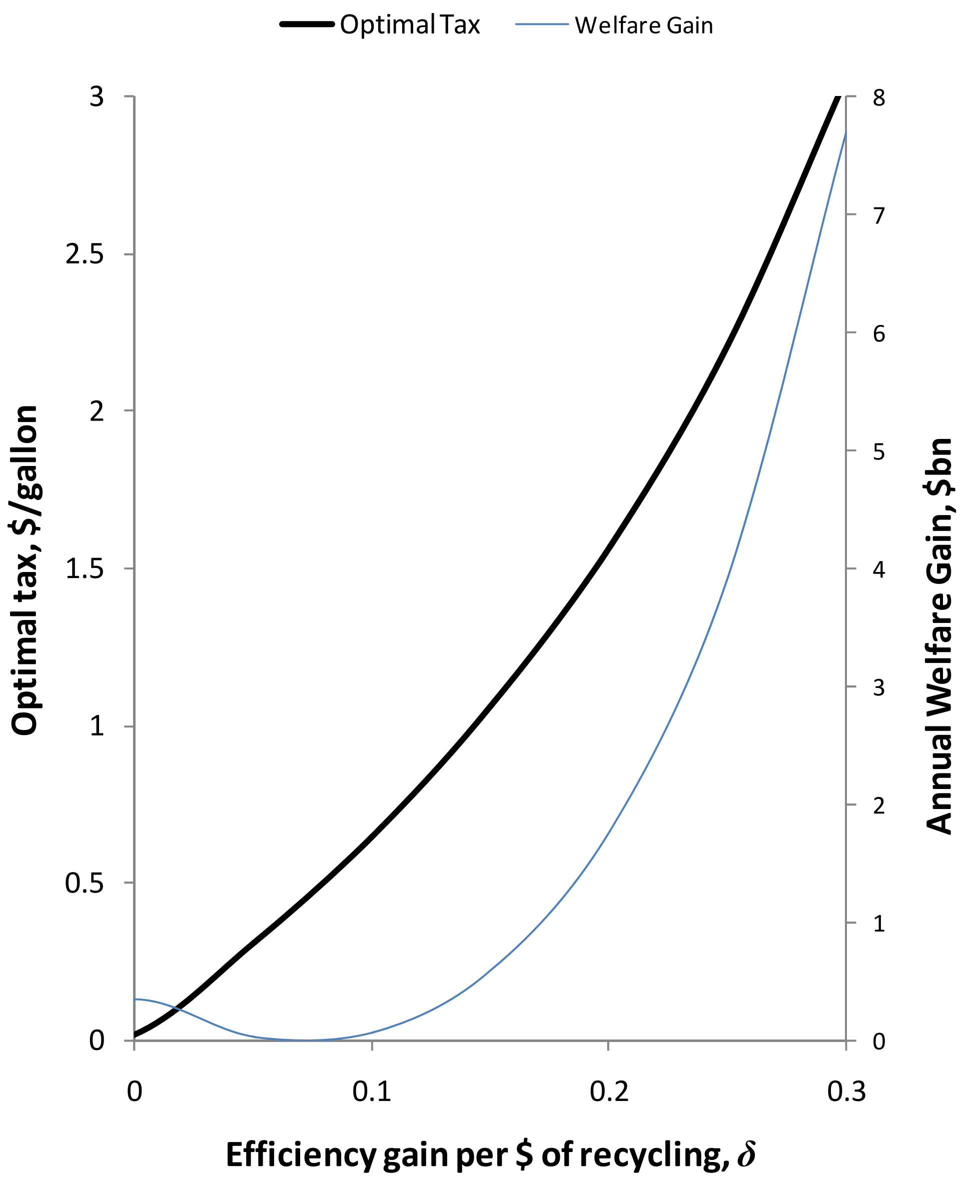
Figure 4. Welfare Gain from Corrective Tax





Note: Efficiency gain is defined relative to withholding revenues from the economy and therefore depends on uncompensated behavioral responses.

Figure 6. Optimal Diesel Tax and Welfare Gains with Alternative Revenue Recycling



Note: Efficiency gain is defined relative to withholding revenues from the economy and therefore depends on uncompensated behavioral responses.

Table 1. Calculations of the Corrective Gasoline Tax
(Year 2007 $)

Benchmark case		
Corrective tax, $/gallon		**1.23**
Contribution from		
global warming	0.09	
oil dependence	0.10	
local pollution	0.12	
congestion	0.52	
accidents	0.41	
Miles/gallon at corrective tax		23.2
Proportionate reduction in gasoline use		0.10
Welfare gain, $ billion[a]		5.9
Proportionate increase in tax revenue		2.8
High global warming damages		
Corrective tax, $/gallon		**1.88**
Miles/gallon at corrective tax		24.0
Proportionate reduction in gasoline use		0.16
Welfare gain, $ billion[a]		16.6
With pre-existing climate policy		
Corrective tax, $/gallon		**1.14**
Binding fuel economy regulations		
Corrective tax, $/gallon		**2.01**
Miles/gallon at corrective tax		30.4
Proportionate reduction in gasoline use		0.17
Welfare gain, $ billion[a]		12.3
With pre-existing corrective mileage tax		
Corrective tax, $/gallon		**0.19**
Proportionate reduction in gasoline use		-0.03
Welfare gain, $ billion[a]		0.43

Notes: [a] Ignores welfare effects from broader fiscal linkages.

Sources: See discussion in text

Table 2. Calculations of the Corrective Diesel Tax
(Year 2000$)

Benchmark case		
Corrective tax, $/gallon		**1.15**
Contribution from		
global warming	0.10	
oil dependence	0.10	
local pollution	0.36	
congestion	0.33	
accidents	0.11	
road damage	0.20	
noise	0.06	
auto feedback effect	-0.10	
Miles/gallon at corrective tax		6.1
Proportionate reduction in diesel use		0.06
Welfare gain, $ billion[a]		1.3
Proportionate increase in tax revenue		2.8
With pre-existing corrective mileage tax		
Corrective tax, $/gallon		**0.56**
Proportionate reduction in diesel use		0.01
Welfare gain, $ billion[a]		0.26

Notes: [a] Ignores welfare effects from broader fiscal linkages.

Sources: See discussion in text