Equity Implications of Vehicle Emissions Taxes

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Abstract

This paper considers the equity implications of vehicle emissions taxes by examining the incidence of a tax on hydrocarbons and oxides of nitrogen, two ozone precursors. It uses emissions data from the California Air Resources Board and household vehicle and income data from the U.S. Consumer Expenditure Survey. It incorporates household price-responsiveness that differs across income groups into a consumer surplus measure of tax burden. Since poor vehicle owners spend more on miles as a proportion of their income and drive vehicles that pollute more per mile than those owned by the wealthy, a tax on vehicle emissions is quite regressive. This regressivity, however, is mitigated to some extent by low vehicle ownership rates and high price responsiveness in the lower half of the income distribution. A uniform tax on miles that does not distinguish between dirty and clean vehicles is less regressive than the emissions tax.
I. Introduction

Between 1980 and 2000, vehicle miles traveled ($VMT$) in the United States increased by over 76 percent (FHWA, 2003). This dramatic increase in vehicle use, combined with the surge in popularity of large, inefficient sport-utility vehicles and other light-duty trucks, frustrate attempts to reduce local air pollution. As of August 2003, thirteen metropolitan areas in the United States are classified as extreme or severe ozone nonattainment areas.\(^1\) High ozone levels cause respiratory problems and damage crops and ecosystems.\(^2\)

Faced with these challenges, policymakers seek cost-effective means to attain abatement goals. While command-and-control standards still dominate vehicle pollution policy in the United States, many studies have shown that taxes and other incentives can attain the same amount of pollution reduction at lower cost (see for example Bohm and Russell (1985) and Harrington et al. (1994)). Pollution taxes also generate revenue that can be used to fund government projects or to reduce taxes on labor or investment.

Despite these clear advantages, policymakers often oppose taxes on vehicle pollution or gasoline on the grounds that such taxes will disproportionately burden poor households. Few studies, however, actually estimate the incidence of vehicle emissions policies.\(^3\) This paper estimates the incidence of a tax on vehicles' emissions of hydrocarbons and oxides of nitrogen, two

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\(^1\) See the U.S. Environmental Protection Agency's Green Book Nonattainment listings at http://www.epa.gov/oar/oqps/greenbk.

\(^2\) The transport sector is responsible for about half of the ozone created in the United States. For this and other U.S. transport statistics, visit the federal government's Center for Transportation Analysis homepage at http://www-cta.ornl.gov/cta.

\(^3\) Kahn (1996b) determines the effect of households’ neighborhoods’ median incomes on the likelihood of passing vehicle emissions tests. Dill et al. (1999) consider the incidence of existing California vehicle license fees that are not based on emissions. Other papers analyze the incidence of other pollution taxes. Brännlund and Nordström (forthcoming) and Cornwell and Creedy (1997), for example, examine the incidence of carbon taxes. Poterba (1991) and West and Williams (2002) consider the incidence of a gasoline tax, West (forthcoming) examines taxes on miles and subsidies to new vehicles, and Metcalf (1999) calculates incidence for a variety of environmental taxes but not a tax on vehicle emissions.
ozone precursors. Such a tax would require that authorities be able to measure both emissions per mile and vehicle miles traveled. Since measurement of emissions per mile may be prohibitively costly, I also estimate the incidence of a uniform tax on miles.

This paper makes four main contributions. First, it uses data from the California Air Resources Board to estimate vehicle emissions per mile as a function of vehicle vintage, engine size, import status, and vehicle type (light-duty truck or car). Walls and Hanson (1999) and Sevigny (1998) assign emissions per mile to vehicles in households according only to vehicle vintage. Papers that estimate vehicle emissions functions as complicated as those estimated in this paper do not conduct incidence analysis (see for example Harrington (1997), and Kahn (1996a)).

Second, my analysis includes households that do not own vehicles. Other studies that consider the incidence of vehicle emissions taxes consider only vehicle owners (see Sevigny (1998) and Walls and Hanson (1999)). Measures that ignore households that do not own vehicles will overstate the incidence on income groups with fewer vehicle owners, and understate the incidence on groups with more vehicle owners.

Third, I incorporate households' responses to an emissions tax and a tax on vehicle miles traveled into incidence calculations. I use elasticities of demand for VMT that differ across income groups, obtained from estimation using household data from the 1997 U.S. Consumer Expenditure Survey. Other papers calculate incidence with no price responsiveness or with no income-varying price responsiveness.\textsuperscript{4} They assume away the possibilities that, for example, poorer households are more price-responsive because their spending on miles occupies a larger fraction of their budget, or that wealthier households are more price-responsive because they have more transportation options. To the extent that demand elasticities vary with income, measures that ignore this will overstate the

\textsuperscript{4} Metcalf (1999), Poterba (1991), and Walls and Hanson (1999) calculate incidence assuming no price responsiveness. Sevigny (1998) allows price-responsiveness to differ according to how many vehicles a household owns but not according to income.
incidence on income groups with relatively elastic demand, and understate the incidence on groups
with relatively inelastic demand.

Fourth, incorporation of price responsiveness allows me to use the change in consumer
surplus to calculate the reduction in welfare due to the tax. This measure adds the triangle of
deadweight loss, the Harberger triangle (Harberger (1962)), to the rectangle of tax paid. Ignoring
the deadweight loss triangle biases incidence estimates. For example, if poor households are more
price responsive than wealthy households, they will escape more of the tax than wealthy
households, mitigating regressivity, but their deadweight loss triangles will be larger, exacerbating
regressivity.

The incidence of vehicle emissions taxes depends on the relationships between emissions
per mile, VMT, and income. Thus the income measure used is a critical determinant of incidence.
For the purposes of incidence analysis, an ideal income measure places a money value on material
well-being with which the value of welfare loss from the policy change can be scaled. Consumption
is a better indicator of material well-being than annual income. University students and retired
people, for example, may have very low incomes but high levels of consumption and thus high
material well-being. And working households can maintain levels of well-being in the face of
temporary reductions in income by taking money from savings or by borrowing. In good economic
times, households smooth consumption by saving. For these reasons, and since the Consumer

5 Sevigny (1998) uses annual income. Walls and Hanson (1999) use a measure of lifetime income, which usually
produces incidence estimates more similar to those that use consumption. Poterba (1991), West (forthcoming), and
West and Williams (2002) use consumption to analyze environmental policy incidence but do not consider a vehicle
emissions tax.

6 See Slesnick (2001) for further discussion of differences among income measures. Consumption may be a better
approximation to welfare than income, but it is still an approximation. It is problematic, for example, for households
that cannot smooth consumption by saving or borrowing.
Expenditure Survey contains detailed and accurate data on expenditures, I use total consumption expenditures as my measure of income.

Among vehicle owners, emissions per mile of hydrocarbons and oxides of nitrogen decrease as income increases; poor vehicle-owning households drive vehicles that pollute more than those owned by wealthy households. But a significant proportion of the population owns no vehicles and therefore emits no vehicle pollution.\(^7\) This population is concentrated in the lower third of the income distribution. In addition, poor households are more price responsive than wealthy ones; elasticities of \(VMT\) demand in the poorer deciles of the income distribution are about twice as large as those in the wealthier deciles. While a tax on emissions of HC and NOX is quite regressive, the regressivity is mitigated to some extent by the low vehicle ownership rates and high price responsiveness in the lower half of the income distribution.

Since poor households drive dirtier vehicles than wealthy households, a uniform tax on miles that does not distinguish among vehicles is less regressive than the emissions tax. In the case of vehicle emissions of local pollutants, the pollution control policy that is easier to implement is also less regressive.

Section II provides details on the incidence measures employed in the paper. Section III discusses the data, emissions per mile estimation, and elasticity estimation. Section IV presents the incidence results and Section V concludes.

II. Measuring the Incidence of Emissions Taxes

A household's total emissions of hydrocarbons equals the emissions per mile of HC \((EPM_{HC}^h)\) times vehicle miles traveled \((VMT^h)\). Likewise, total emissions of oxides of nitrogen

\(^7\) Of course, households that do not own vehicles may pollute indirectly by riding diesel-fueled buses or trains fueled by electricity generated by coal-burning power plants.
equals the emissions per mile of NOX ($EPM^h_{NOX}$) times vehicle miles traveled ($VMT^h$). An efficient tax on emissions equals the money value of marginal external damages (MED) per unit of emissions.\(^8\) A tax per gram of hydrocarbons could be assessed by measuring the emissions per mile of hydrocarbons and multiplying by miles traveled, where miles traveled is obtained by comparing current odometer readings with previous readings. The total tax paid by a household ($T^h$) on HC and NOX would equal:

$$T^h = (MED_{HC}EPM^h_{HC} + MED_{NOX}EPM^h_{NOX})VMT^h.$$ 

The tax on emissions is thus equivalent to a vehicle-specific tax on miles.

An ideal measure of the incidence of a tax on vehicle emissions would calculate the general-equilibrium changes in prices that would occur throughout the economy in response to the tax, and then calculate the effects of those price changes on households’ welfare. A tax on vehicle emissions, even if it were assessed only on households, would presumably affect prices of fuel and automobiles and thereby affect many sectors of the economy. Calculating such effects, however, requires a great deal of information, most notably the demand and supply elasticities for all affected industries, and the distribution of ownership of firms in those industries. Thus, for simplicity, I focus on the short-run partial equilibrium incidence of the tax. I assume that in the short run, households respond to the emissions tax by reducing the number of miles they drive, but not by switching to less-polluting vehicles or other modes of transportation.\(^9\) I also assume that the supply of consumer goods is perfectly elastic. This implies that the imposition of the emissions tax does not affect the producer prices of related goods such as fuel and vehicles, and thus the entire burden of

\(^8\) This is the familiar Pigouvian tax, introduced in Pigou (1932).

\(^9\) While we can only speculate about the likely long run effects of a vehicle emissions tax, since wealthier households can more easily afford to replace a dirty car with a less-polluting one and thus avoid more of the tax, we might expect for the emissions tax to be more regressive in the long run.
the tax falls on consumers.\(^{10}\)

Each household faces its own initial price per mile, determined by fuel costs and other variable costs per mile. Each household also faces its own with-tax price per mile, which is the initial price per mile plus \((MED_{hc} EPM_{hc}^h + MED_{nox} EPM_{nox}^h)\). While I assume that MED are the same for all households, emissions per mile are vehicle-specific. In addition, I allow \(VMT\) demand elasticities to vary across income deciles.

I use the change in household consumer surplus to measure the change in household welfare due to the tax. Because I consider short run incidence, where households respond to the emissions tax only by reducing miles, consumer surplus is defined as the change in the area under the household's \(VMT\) demand curve over the quantity purchased, which reflects the effect of changing prices on utility. Assuming a linear \(VMT\) demand curve, the change in consumer surplus for household \(h\) can be expressed:

\[
\Delta CS^h = (MED_{hc} EPM_{hc}^h + MED_{nox} EPM_{nox}^h) VMT_i + \frac{1}{2} (MED_{hc} EPM_{hc}^h + MED_{nox} EPM_{nox}^h) (VMT_i^h - VMT_0^h),
\]

where the first term is \(T^h\), the rectangle of tax paid defined in equation (1), after the household has adjusted miles in response to the tax. The second term is the triangle of deadweight loss, which, with a linear demand for \(VMT\), is one half times the tax per \(VMT\) times the change in \(VMT\) that occurs in response to the tax.\(^{11}\)

For ease of comparison with previous studies, I also calculate the change in household welfare as the tax paid by that household, using equation (2) but omitting the second term. I divide

\(^{10}\) To the extent that gasoline and vehicle suppliers bear part of the burden of the tax, my estimates will overstate the incidence on households that consume gasoline and vehicles, and will understate the incidence on households that own firms that supply gasoline and vehicles. If firm owners are concentrated in the top deciles, this would mean that my estimates would overstate the regressivity of the tax.

\(^{11}\) For detailed discussion of this and related measures of welfare loss, see Willig (1976).
both welfare loss measures by total expenditures to obtain tax burden as a fraction of income.\textsuperscript{12} Comparison of these ratios across deciles allows one to determine which income groups bear more of the burden of a particular tax relative to their incomes.

To compare the overall regressivity of two different tax policies, however, one needs to measure the distribution of the tax burden across all deciles for each policy. Suits (1977) derives just such a measure. The Suits index is traditionally calculated using tax paid as the measure of welfare change. For a given tax policy $T_x$, the Suits index calculated over ten income deciles is:

\[ S_x = 1 - \left[ \frac{\sum_{i=1}^{10} \left[ T_x(y_i) + T_x(y_{i+1}) \right] (y_i - y_{i+1})}{K} \right] / K, \]

where $y_i$ is the accumulated percent of income through decile $i$, $T_x(y_i)$ is the accumulated percent of total tax paid through decile $i$, and $K$ is a constant. Scaling the term in brackets by $K$ and subtracting it from one gives an index similar to the Gini coefficient. The Suits index ranges from -1 for a perfectly regressive tax, to zero for a proportional tax, and to +1 for a perfectly progressive tax.

For ease of comparison with other studies, I present the traditional Suits index using tax paid. I also calculate a Suits index using consumer surplus as the measure of welfare loss. The Suits index equivalent for consumer surplus is obtained by defining $T_x(y_i)$ as the accumulated percent of consumer surplus lost through decile $i$.

\textbf{III. Data, Emissions per Mile Estimation, and Elasticity Estimation}

Determining the incidence of a tax on vehicle emissions requires data on household income, emissions per mile, vehicle miles traveled, and a measure of households' responsiveness to the tax.

\textsuperscript{12} All of these measures ignore the distribution of the external benefits of reduced vehicle pollution and miles driven. Incorporating such benefits would reduce tax burdens for all income groups and might have important distributional effects if the benefits are unevenly distributed across income groups. See Baumol and Oates (1988) and Brooks and Sethi (1997) for general discussion of the distribution of benefits.
This section describes the three main sources of data used here: the U.S. Consumer Expenditure Survey (CEX), the California Air Resources Board Light Duty Surveillance Program (CARB), and the American Chambers of Commerce Researchers Association (ACCRA) cost of living index. It also explains estimation of emissions per mile and estimation of elasticities of $VMT$ with respect to operating costs per mile.

A. Household Data, Operating Costs, and VMT Derivation

The household data consists of 7073 households from the 1997 U.S. Consumer Expenditure Survey that own zero, one, or two vehicles.\footnote{Eighty-two percent of 1997 CEX households own zero, one, or two vehicles (for comparison, the 1995 U.S. Nationwide Personal Transportation Survey lists this number as 81 percent (ORNL (2000))). The CEX data for households with more than two vehicles is very spotty; seventy percent of these households have missing data for engine size or vintage of at least one vehicle. Households with three or more vehicles have higher average expenditures than the households included here; by ignoring them this study focuses on a less-wealthy portion of the income distribution.} Households that own no cars make up 24 percent of the sample, 45 percent own one vehicle, and 31 percent own two vehicles. The CEX includes total expenditures, the amount spent on gasoline, and detailed information on each household’s vehicles. Variables in the vehicle file include year, make, model, number of cylinders, odometer reading, the amount paid for the vehicle, and other characteristics.

I define the operating cost per mile for each vehicle as the price of gasoline divided by fuel efficiency, plus maintenance and tire costs per mile. The ACCRA cost of living index lists for each quarter the average prices of regular, unleaded, national-brand gasoline for over 300 U.S. cities. Since the CEX reports state of residence of each household, but not city, I average the city prices within each state to obtain a state gasoline price for each calendar quarter. Then I assign a gas price to each CEX household based on state of residence and CEX quarter.

Unfortunately, the CEX does not record vehicles' fuel efficiencies. I therefore use data from the California Air Resources Board (CARB) to estimate a regression of miles per gallon ($MPG$) on...
engine size and vehicle vintage.\textsuperscript{14} Smaller or newer vehicles are more fuel efficient. For one-vehicle households, fuel efficiency is calculated directly from the regression results. For two-vehicle households, I calculate the fuel efficiency of each two-car pair by averaging the two cars’ estimated efficiencies.

I then calculate the fuel cost per mile as the price of gasoline divided by fuel efficiency. The ORNL (1998) provides maintenance and tire costs per mile, by vehicle vintage. I add these per mile costs to the fuel cost per mile to obtain operating costs per mile.

The CEX reports one number per household for gasoline expenditures. To obtain \( VMT \) driven per household, I divide the household’s gas expenditure by its gas price to get gallons of gas consumed. Then, I multiply gallons by fuel efficiency to obtain \( VMT \) for the household.\textsuperscript{15}

\textit{B. Emissions per Mile Estimation}

The CEX does not include information on vehicle emissions. I therefore use data from the CARB to estimate emissions per mile (\( EPM \)) as a function of vehicle characteristics. Several studies find that important determinants of vehicle emissions include vintage, cumulative miles (obtained from an odometer reading), engine size, vehicle class (light-duty truck versus car), and import status (that is, manufactured by a U.S. company versus a non-U.S. company) (see for example Bin (2003), Harrington (1997), and Kahn (1996a)). All of these variables are included in both the CEX and the CARB data. Odometer readings, however, are missing for more than 10 percent of the CEX vehicles in my sample. And, since CEX interviewers do not check the odometers of the vehicles but instead rely on the household to accurately report their vehicles' mileage, readings are subject to

\textsuperscript{14} For more detail on these data and results from the \textit{MPG} regression, see West (forthcoming).

\textsuperscript{15} Using total \( VMT \) versus the \( VMT \) in each vehicle ignores the possibility that households respond to changes in the operating cost per mile by driving more in one vehicle and less in another. Green and Hu (1985) find that substitution among vehicles within a household in response to changes to the price per mile is negligible, and so the bias is not likely to be large.
extreme rounding and other measurement error, and so I do not include odometer readings in emissions per mile estimation.  

The CARB contains complete information on 671 vehicles' emissions of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOX) in grams per mile. Lack of good estimates of the value of the health and environmental costs of CO preclude simulation of an emissions tax on CO, however, so I focus on HC and NOX. These pollutants are ozone precursors.

I estimate two regressions, one for HC and the other for NOX, as functions of indicators for the number of cylinders in the engine (four, six, or eight), vintage (older than 1980, 1980 through 1989, and 1990 and newer), interactions between number of cylinder and vintage indicators, an indicator equal to one if the vehicle is a light truck (pick-up truck, van or minivan, or sport-utility vehicle), and an indicator equal to one if the vehicle is an import (made by a non-U.S. manufacturer).

Since the CARB data contain only vehicles from California, the sample is not representative of the U.S. vehicle fleet. I therefore use population weights from the CEX to weight the vehicles in the CARB data so that the data represent the distribution of all combinations of vintage, engine size, vehicle type, and import status in the U.S. vehicle fleet. Examination of the relationship

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16 Inspection of households' reported odometer readings across quarters confirms these measurement error problems; if reported odometer readings were accurate, the data would imply that many households are driving a negative number of miles per quarter.

17 The CARB's Light-Duty Vehicle Surveillance Program, Series 13 and 14, was part of ongoing efforts by the CARB to accumulate vehicle emissions data, to investigate vehicle maintenance practices, and to determine the frequency and effect of tampering with pollution control equipment.

18 An alternative specification might replace the vintage ranges with indicator variables for each year. Some years, however, are very sparsely represented in the CARB.

19 The CARB chose a random sample of all vehicles in California, and then sent requests to owners of such vehicles within a 25-mile radius of the CARB office in El Monte, California. The final sample includes only those who responded.
between emissions per mile of HC and NOX revealed that a semilog specification best fits the data.\textsuperscript{20} I estimate the regressions using weighted ordinary least squares.

Table 1 contains results from this estimation. In the HC regression, 6-cylinder interaction terms and import are not statistically significant; all other coefficients are significant at the 5 percent level or better. In the NOX regression, the 6-cylinder-1980s-vintage interaction term, truck, and import are not statistically significant. The 6-cylinder indicator is significant at the 10 percent level and all other coefficients are significant at the 5 percent level or better.

Older and larger vehicles pollute more HC and NOX per mile than newer and smaller vehicles. The average 6-cylinder vehicle emits 43 percent more HC and 6.6 percent more NOX per mile than a 4-cylinder vehicle. The average 8-cylinder vehicle emits 4.5 times more HC and 1.2 times more NOX than the average 4-cylinder vehicle. Controlling for other factors, 1980s vintage vehicles emit 54 percent less HC and 25 percent less NOX than vehicles older than 1980, while 1990s vehicles emit 87.3 percent less HC and 77 percent less NOX than vehicles older than 1980.

These results make sense in the context of U.S. vehicle emissions policies. Newer vehicles are subject to more stringent emissions per mile standards than are older vehicles. And, since pollution-control equipment deteriorates with time, even cars that face stringent off-the-assembly-line standards emit more as they age. This is compounded for larger cars with lower fuel efficiencies; cars that burn more gas per mile and have broken pollution control equipment emit more per mile than smaller cars with equipment in the same condition (Harrington (1997)).

Until 1994, standards for light-duty trucks (including minivans and sport-utility vehicles) were less stringent than for cars. The regression results show that they emit 39 percent more

\textsuperscript{20} Tests of Box-Cox specifications do not reject the null hypothesis of a semilog specification and this specification results in the highest $R^2$ values.
hydrocarbons per mile than cars. Light-duty trucks also appear to emit more oxides of nitrogen than cars, though this is not a statistically significant effect.

I predict emissions per mile of HC and NOX for each vehicle in the CEX household data. Households with one vehicle are assigned the emissions per mile of their one vehicle, while two-vehicle households are assigned the average HC and the average NOX of their two vehicles. Households that own no vehicles are assigned zero values for emissions per mile.

Table 2a summarizes the data on household total expenditures, car ownership, $VMT$, and emissions per mile, by decile, for the full sample of households that own zero, one, or two vehicles. Decile 1 contains the poorest households and decile 10 the richest. Hydrocarbon and oxides of nitrogen emissions per mile both peak in the seventh decile. Low emissions per mile figures in the lower deciles of the full sample are due to low vehicle ownership rates in those deciles. Less than 40 percent of households in the lowest expenditure deciles own at least one vehicle; that number is about 57 percent for the second decile.

Table 2b shows the summary statistics for vehicle owners only. Emissions per mile are significantly higher in the lower deciles of vehicle owners than in the higher deciles; poor households that own vehicles own dirtier vehicles than wealthy vehicle owners.

C. $VMT$ Elasticity Estimation

A tax on vehicle emissions is equivalent to a vehicle-specific tax per mile. In the short run, households respond to such an increase in vehicle operating costs by reducing the number of miles they drive. If households in different income groups respond differently to the tax, this difference in elasticities will affect incidence calculations.

The joint nature of the demands for vehicles and miles complicates estimation of $VMT$ demand elasticities. An unobserved household characteristic that affects the utility of miles driven
in a particular vehicle is likely to affect both its probability of selection and its intensity of use. For example, a large household may gain more enjoyment from driving in a spacious vehicle. The household may also have to drive children to more activities, and so they may drive more miles. Moreover, factors that affect the intensity of use will affect the probability of choosing particular vehicle bundles. A person that lives in a region with long commutes drives more miles and may be more likely to choose a vehicle bundle that has low operating costs. Cases such as these imply that the residuals in a miles regression are correlated with vehicle choice indicators. Unless one controls for the endogeneity of vehicle choice in the determination of miles traveled, operating cost elasticity estimates will be biased.

West (forthcoming) provides such unbiased elasticity estimates. That study estimates a model of the joint determination of miles driven and vehicle attributes in two stages. The first stage estimates a nested logit on the choice between owning zero, one, or two vehicles, and within these vehicle number categories, the vintage and engine size of each vehicle. This discrete choice model includes variables that might affect a household’s vehicle choice, including total expenditures, gender, family size, whether the household owns a home or lives in a large metropolitan area, and the number of earners and potential drivers in the household.

The second stage estimates a regression of vehicle miles traveled as a function of vehicle operating cost per mile, indicators for vehicle choice, total expenditures, interactions between total expenditures and vehicle operating costs, and demographic characteristics. To correct for the endogeneity of the vehicle choice indicators, West (forthcoming) employs the conditional expectation correction approach introduced by Dubin and McFadden (1984). This method corrects for the bias due to the fact that the vehicle-choice indicators are correlated with the error term. This is a sample-selection correction along the lines of that presented in Heckman (1979); the VMT regression is therefore estimated on vehicle-owners only.
Results from this second stage can be used to calculate many different measures of the elasticity of demand for \( VMT \) with respect to operating costs, all conditional on vehicle choice. The regression results, for example, can be used to calculate this elasticity evaluated at sample means of miles, operating costs per mile, and total expenditures. This elasticity equals \( -.87 \).\(^{21}\)

This estimate, however, conceals two critical characteristics of miles demand that vary across the income distribution. First, as shown in Table 2a, a large proportion of lower income households do not own vehicles and therefore drive no miles. In the lower half of the income distribution, as expenditures increase, spending on miles as a proportion of total expenditures also increases.

Second, lower income households are more responsive to price changes than are high income households. For the full sample, \( VMT \) elasticities range from \(-1.51 \) in the poorest decile to \(-.75 \) in decile 8. Elasticities for vehicle owners tend to be slightly smaller than full sample elasticities. Because of how income and operating costs are defined, these elasticities are not strictly comparable to estimates from previous studies. However, they are generally larger in absolute value than others.\(^{22}\)

IV. Incidence Calculations

This section discusses results of incidence calculations for two taxes designed to reduce vehicle pollution. The first is the vehicle emissions tax, equivalent to a vehicle-specific tax on miles. While this tax may be the most efficient way to reduce vehicle pollution, its measurement

\(^{21}\) The expenditure elasticity of demand for \( VMT \) calculated at sample means is .02. This estimate is smaller than estimates from other studies and implies that a tax on miles would be quite regressive (for other income elasticity estimates, see Archibald and Gillingham (1981), Hensher et al. (1992), and Mannering and Winston (1985)).

\(^{22}\) For example, Walls et al. (1994) has \( VMT \) price elasticity estimates that range from -0.120 to -0.583. Berkowitz et al. (1990) estimate a \( VMT \) price elasticity of -0.21. Similarly, Mannering and Winston (1985) find a \( VMT \) price elasticity of -0.228, and Hensher et al.’s (1992) results range from -0.28 to -0.39. Sevigny’s (1998) \( VMT \) estimates are the only ones that are in the same neighborhood those used here; they range from -0.85 to -0.94.
requirements may render it prohibitively costly—it would require the taxing authority to measure both emissions per mile and vehicle miles traveled. I therefore also analyze the effects of a uniform tax on miles, set so that the revenue it generates equals that generated by the emissions tax. It would require the taxing authority to measure only \( VMT \) but would not differentiate between dirtier and cleaner vehicles.\(^{23}\)


*Vehicle Emissions Tax*

As mentioned in Section II, the efficient tax on emissions equals the marginal external damages per unit of emissions. Because I consider two pollutants, HC and NOX, I need estimates of the MED of each. Small and Kazimi (1995) calculates the dollar value of damages due to increases in mortality and morbidity rates caused by NOX and volatile organic compounds (VOC). Hydrocarbons are the main component of VOC. Like Small and Kazimi, I ignore the distinctions between VOC and HC because these differences are "small for petroleum based motor vehicle emissions" (Small and Kazimi (1995): p. 8). Their estimates for the health damages per ton of VOCs and per ton of NOX are $2,920 and $10,670 in 1992 dollars. Translating these estimates into dollars per gram and inflating to year 1997 dollars using the Consumer Price Index yields $0.003 per gram of HC and $0.012 per gram of NOX. Multiplying these MED per gram by HC per mile and NOX per mile yields an average vehicle-specific \( VMT \) tax of about one cent ($0.01) per mile.\(^{24}\)

Each household faces its own vehicle-specific \( VMT \) tax and responds by reducing \( VMT \). The first two panels of Table 3 present incidence estimates for the full sample of both vehicle owners and households that do not own vehicles. The left-most panel shows results assuming that all

\(^{23}\) For all simulations, I assume that the taxing authority discards the tax revenue. For incidence analysis of a gasoline tax whose revenues are used to reduce a labor tax, see West and Williams (2002). For analysis of a carbon tax whose revenues are used to reduce a variety of taxes, see Brännlund and Nordström (forthcoming).

\(^{24}\) These measures of MED do not include the value of lost crops or damaged ecosystems. Since HC and NOX per mile follow very similar distributions across deciles, however, changes in MED of each pollutant do not have significant effects on incidence results.
households have the same degree of price responsiveness, while the middle panel shows results allowing price responsiveness to differ by income group. Tax burden, for both the tax paid and the consumer surplus measures of welfare loss as percentage of total expenditures, peaks in decile three of the full sample.

Suits indexes indicate that the emissions tax is quite regressive. The traditional Suits index using elasticities calculated at sample means is –0.197. Allowing elasticities to vary across deciles results in a less regressive Suits index of –0.182; poor households are more price responsive than wealthy households and therefore avoid more of the tax by reducing $VMT$ by a greater proportion. Because of this greater price responsiveness, however, poor households' triangles of deadweight loss are larger than those of wealthy households. This results in Suits Index equivalents for consumer surplus that are more regressive than the traditional Suits indexes based on tax paid.

As a comparison, the Suits index for the taxes considered by Suits (1977) ranged from –0.17 to 0.36, so the emissions tax is more regressive than the most regressive tax (the payroll tax) considered in that study. My estimates of the traditional Suits index, however, are less regressive than those found in the two studies that consider the incidence of a tax on vehicle emissions. Sevigny (1998) reports a traditional Suits index of –0.226 and that in Walls and Hanson (1999) is –0.24. The fact that their results are more regressive is not surprising given that they consider vehicle owners only and do not incorporate price responsiveness that varies across deciles.

Indeed, consider the results for an emissions tax on vehicle owners only, presented in the third panel of Table 3. Ratios of tax paid and consumer surplus losses to total expenditures are highest in the lowest decile and decrease substantially as total expenditures increase. Resulting Suits indexes for emissions taxes are thus more regressive among vehicle owners only.

*Uniform VMT Tax*
A uniform tax on \( VMT \) would not be efficient because it would penalize driving in clean vehicles as much as driving in dirty vehicles. Taxing authorities would also face possible cheating on the part of households, who might roll back their odometers before taking their vehicles in for readings. This tax, however, would require less information than an emissions tax and still reduce pollution by reducing miles driven.

In order to simulate a uniform \( VMT \) tax rate that is similar in magnitude to the household-specific emissions tax rate, I find and simulate uniform \( VMT \) tax rates that generate the same amount of revenue as the emissions taxes. These \( VMT \) tax rates differ depending on whether the full sample or the vehicle-owners only sample is used, and whether the sample-mean elasticity or decile-specific elasticities are used. They all fall between $0.013 and $0.015 per mile.

Table 4 reports the results from this simulation. Since poor households drive dirtier vehicles than wealthy households, a uniform tax on \( VMT \) that does not distinguish among vehicles is less regressive than the emissions tax. Suits index equivalents for consumer surplus for the full sample using the elasticity evaluated at sample means and decile-specific elasticities are –0.153 and –0.149, respectively. In the case of vehicle emissions of local pollutants, the pollution control policy that is easier to implement is also less regressive.

V. Conclusion

This paper combines data on emissions per mile from the California Air Resources Board and household level vehicle and income data from the U.S. Consumer Expenditure Survey to calculate the incidence of a tax on vehicle emissions. Incidence calculations allow for household price responsiveness to differ across income groups and include both households that own vehicles and those that do not. It compares the incidence of an emissions tax with that of imposing a uniform miles tax.
While this paper focuses on hydrocarbons and oxides of nitrogen, two ground-level ozone precursors, it would be fruitful to analyze the incidence of a vehicle emissions tax that includes the marginal external costs of global warming gases such as carbon dioxide. Since emissions of carbon dioxide are proportional to fuel use, we might expect the incidence of a carbon tax to resemble that of a gasoline tax, a tax that is less regressive than the emissions tax considered here.

The analysis undertaken here is short-run and partial equilibrium in nature. Future research might consider the partial equilibrium incidence of vehicle pollution taxes in the long run, where households respond to the emissions tax not only by reducing the number of miles they drive but also by switching to newer, smaller, better-maintained, or hybrid vehicles. Other research might conduct incidence analysis in a general equilibrium context wherein increases in vehicle operating costs affect producer prices of fuel, vehicles, and other sectors of the economy.

I assume that the government tax revenue generated by an emissions tax is discarded. Environmental tax reforms—measures that use pollution tax revenue to reduce taxes on employment or investment—are now common in Europe. Denmark, Finland, Germany, Italy, the Netherlands, Norway, Sweden, and the United Kingdom have all implemented such reforms (Hoerner and Bosquet (2001)). Such reforms have also been proposed in state legislatures in the United States (Hoerner and Erickson (2000)). Future research could apply methods used to conduct incidence analysis of environmental tax reforms wherein revenue is used to reduce other taxes (see for example Metcalf (1999) and Brännlund and Nordström (forthcoming)), to reforms involving vehicle emissions taxes.

A tax on vehicle emissions is quite regressive, more regressive than the most regressive U.S. labor tax (the payroll tax). This is due to the fact that poor vehicle owners spend more on miles as a proportion of their income and drive vehicles that pollute more per mile than vehicles owned by the wealthy. Low vehicle ownership rates and high price responsiveness in the lower half of the income
distribution, however, mitigates this regressivity to some extent. On the other hand, while high-price responsiveness reduces taxes paid by poor households, it increases deadweight losses among poor households and checks the mitigating effect. Overall, however, the results of this analysis suggest that a tax on vehicle emissions is less regressive than previously thought.

A uniform tax on miles that does not distinguish between dirty and clean vehicles is less regressive than the emissions tax. If choosing between an emissions tax and a miles tax, policymakers should weigh the greater efficiency gains of an emissions tax with the lower implementation costs and more favorable distributional consequences of a miles tax.
References


Table 1: Emissions per Mile Regressions*

<table>
<thead>
<tr>
<th></th>
<th>$\ln(\text{HC})$ (grams per mile)</th>
<th>$\ln(\text{NOX})$ (grams per mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 1 if cylinders = 6</td>
<td>0.643 (0.321)</td>
<td>0.449 (0.261)</td>
</tr>
<tr>
<td>= 1 if cylinders = 8</td>
<td>2.001 (0.220)</td>
<td>1.241 (0.195)</td>
</tr>
<tr>
<td>= 1 if 1980s vintage</td>
<td>0.490 (0.191)</td>
<td>0.453 (0.173)</td>
</tr>
<tr>
<td>= 1 if 1990s vintage</td>
<td>-0.665 (0.185)</td>
<td>-0.487 (0.199)</td>
</tr>
<tr>
<td>= (6-cylinders X 1980s)</td>
<td>-0.267 (0.352)</td>
<td>-0.243 (0.284)</td>
</tr>
<tr>
<td>= (6-cylinders X 1990s)</td>
<td>-0.387 (0.348)</td>
<td>-0.629 (0.304)</td>
</tr>
<tr>
<td>= (8-cylinders X 1980s)</td>
<td>-1.154 (0.299)</td>
<td>-0.729 (0.246)</td>
</tr>
<tr>
<td>= (8-cylinders X 1990s)</td>
<td>-1.819 (0.300)</td>
<td>-1.440 (0.309)</td>
</tr>
<tr>
<td>= 1 if light-duty truck</td>
<td>0.385 (0.152)</td>
<td>0.143 (0.095)</td>
</tr>
<tr>
<td>= 1 if import</td>
<td>0.005 (0.136)</td>
<td>0.083 (0.120)</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.904 (0.194)</td>
<td>-0.482 (0.177)</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>671</td>
<td>671</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.36</td>
<td>0.28</td>
</tr>
</tbody>
</table>

* HC is hydrocarbons; NOX is oxides of nitrogen. Estimation is weighted OLS. Robust standard errors are in parentheses. The omitted vehicle is a 4-cylinder, older than 1980-vintage, domestic car.
Table 2a: Mean Income, \( VMT \), Emissions per Mile and Vehicle Ownership Percentages by Decile*
(Full Sample)

<table>
<thead>
<tr>
<th>Decile</th>
<th>Income (Total Quarterly Expenditures $ 1997)</th>
<th>Vehicle Miles Traveled (( VMT ))</th>
<th>HC (grams/mile)</th>
<th>NOX (grams/mile)</th>
<th>Percentage of households that own at least one vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1383.80</td>
<td>675</td>
<td>0.51</td>
<td>0.49</td>
<td>39.46</td>
</tr>
<tr>
<td>2</td>
<td>2384.19</td>
<td>1212</td>
<td>0.70</td>
<td>0.66</td>
<td>57.43</td>
</tr>
<tr>
<td>3</td>
<td>3148.51</td>
<td>1713</td>
<td>0.81</td>
<td>0.75</td>
<td>65.77</td>
</tr>
<tr>
<td>4</td>
<td>3872.68</td>
<td>2106</td>
<td>0.80</td>
<td>0.78</td>
<td>74.54</td>
</tr>
<tr>
<td>5</td>
<td>4662.93</td>
<td>2506</td>
<td>0.86</td>
<td>0.82</td>
<td>81.21</td>
</tr>
<tr>
<td>6</td>
<td>5582.14</td>
<td>2936</td>
<td>0.89</td>
<td>0.84</td>
<td>82.60</td>
</tr>
<tr>
<td>7</td>
<td>6726.75</td>
<td>3388</td>
<td>0.90</td>
<td>0.84</td>
<td>86.02</td>
</tr>
<tr>
<td>8</td>
<td>8309.97</td>
<td>3907</td>
<td>0.86</td>
<td>0.84</td>
<td>89.25</td>
</tr>
<tr>
<td>9</td>
<td>10832.03</td>
<td>4009</td>
<td>0.84</td>
<td>0.81</td>
<td>89.67</td>
</tr>
<tr>
<td>10</td>
<td>19223.34</td>
<td>4618</td>
<td>0.75</td>
<td>0.74</td>
<td>89.41</td>
</tr>
</tbody>
</table>

* HC is hydrocarbons; NOX is oxides of nitrogen. Decile 1 is the poorest, decile 10 is the richest. The sample includes households that own zero, one, or two vehicles. The total number of households is 7073. Figures are means unless otherwise noted.
Table 2b: Income, \(VMT\), and Emissions per Mile by Decile* 
( Vehicle Owners Only) 

<table>
<thead>
<tr>
<th>Decile</th>
<th>Income (Total Quarterly Expenditures $ 1997)</th>
<th>Vehicle Miles Traveled ((VMT))</th>
<th>HC (grams/mile)</th>
<th>NOX (grams/mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1955.08</td>
<td>1825</td>
<td>1.25</td>
<td>1.19</td>
</tr>
<tr>
<td>2</td>
<td>3118.31</td>
<td>2527</td>
<td>1.26</td>
<td>1.17</td>
</tr>
<tr>
<td>3</td>
<td>3944.13</td>
<td>2794</td>
<td>1.07</td>
<td>1.04</td>
</tr>
<tr>
<td>4</td>
<td>4726.50</td>
<td>3087</td>
<td>1.09</td>
<td>1.03</td>
</tr>
<tr>
<td>5</td>
<td>5573.63</td>
<td>3453</td>
<td>1.05</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>6534.29</td>
<td>3855</td>
<td>1.04</td>
<td>0.98</td>
</tr>
<tr>
<td>7</td>
<td>7733.90</td>
<td>4109</td>
<td>1.00</td>
<td>0.96</td>
</tr>
<tr>
<td>8</td>
<td>9395.23</td>
<td>4292</td>
<td>0.96</td>
<td>0.93</td>
</tr>
<tr>
<td>9</td>
<td>11906.65</td>
<td>4644</td>
<td>0.95</td>
<td>0.90</td>
</tr>
<tr>
<td>10</td>
<td>20515.85</td>
<td>5250</td>
<td>0.81</td>
<td>0.80</td>
</tr>
</tbody>
</table>

* HC is hydrocarbons; NOX is oxides of nitrogen. Decile 1 is the poorest, decile 10 is the richest. The sample includes households that own one or two vehicles (5343 total). Figures are means.
Table 3: Vehicle Emissions Tax Incidence*

<table>
<thead>
<tr>
<th>Decile</th>
<th>Elasticity at Sample Means</th>
<th>Tax/Total Expenditures</th>
<th>ΔCS/Total Expenditures</th>
<th>Decile-Specific Elasticities</th>
<th>Tax/Total Expenditures</th>
<th>ΔCS/Total Expenditures</th>
<th>Decile-Specific Elasticities</th>
<th>Tax/Total Expenditures</th>
<th>ΔCS/Total Expenditures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.87</td>
<td>0.69</td>
<td>0.79</td>
<td>-1.51</td>
<td>0.57</td>
<td>0.73</td>
<td>-1.46</td>
<td>1.24</td>
<td>1.53</td>
</tr>
<tr>
<td>2</td>
<td>-0.87</td>
<td>0.68</td>
<td>0.76</td>
<td>-1.31</td>
<td>0.61</td>
<td>0.73</td>
<td>-1.09</td>
<td>1.10</td>
<td>1.28</td>
</tr>
<tr>
<td>3</td>
<td>-0.87</td>
<td>0.72</td>
<td>0.81</td>
<td>-1.06</td>
<td>0.68</td>
<td>0.79</td>
<td>-1.02</td>
<td>0.86</td>
<td>0.98</td>
</tr>
<tr>
<td>4</td>
<td>-0.87</td>
<td>0.64</td>
<td>0.71</td>
<td>-1.01</td>
<td>0.62</td>
<td>0.70</td>
<td>-0.94</td>
<td>0.80</td>
<td>0.90</td>
</tr>
<tr>
<td>5</td>
<td>-0.87</td>
<td>0.64</td>
<td>0.71</td>
<td>-0.95</td>
<td>0.63</td>
<td>0.70</td>
<td>-0.86</td>
<td>0.74</td>
<td>0.83</td>
</tr>
<tr>
<td>6</td>
<td>-0.87</td>
<td>0.64</td>
<td>0.71</td>
<td>-0.84</td>
<td>0.64</td>
<td>0.72</td>
<td>-0.79</td>
<td>0.77</td>
<td>0.85</td>
</tr>
<tr>
<td>7</td>
<td>-0.87</td>
<td>0.60</td>
<td>0.66</td>
<td>-0.78</td>
<td>0.61</td>
<td>0.67</td>
<td>-0.78</td>
<td>0.64</td>
<td>0.70</td>
</tr>
<tr>
<td>8</td>
<td>-0.87</td>
<td>0.56</td>
<td>0.62</td>
<td>-0.75</td>
<td>0.57</td>
<td>0.62</td>
<td>-0.77</td>
<td>0.57</td>
<td>0.62</td>
</tr>
<tr>
<td>9</td>
<td>-0.87</td>
<td>0.41</td>
<td>0.45</td>
<td>-0.78</td>
<td>0.42</td>
<td>0.46</td>
<td>-0.77</td>
<td>0.46</td>
<td>0.50</td>
</tr>
<tr>
<td>10</td>
<td>-0.87</td>
<td>0.28</td>
<td>0.31</td>
<td>-0.83</td>
<td>0.28</td>
<td>0.31</td>
<td>-0.84</td>
<td>0.29</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Suits Index = -0.197
Suits Index Equivalent for Consumer Surplus = -0.202

Suits Index = -0.182
Suits Index Equivalent for Consumer Surplus = -0.195

Suits Index = -0.243
Suits Index Equivalent for Consumer Surplus = -0.285

* ΔCS is the change in consumer surplus defined in equation (2). Elasticities are taken from West (forthcoming). Tax/Total Expenditures and ΔCS/Total Expenditures are means for each decile.
Table 4: Uniform VMT Tax Incidence*

<table>
<thead>
<tr>
<th>Decile</th>
<th>Full Sample</th>
<th>Vehicle Owners Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elasticity at Sample Means</td>
<td>Tax/Total Expenditures</td>
</tr>
<tr>
<td>1</td>
<td>-0.87</td>
<td>0.54</td>
</tr>
<tr>
<td>2</td>
<td>-0.87</td>
<td>0.59</td>
</tr>
<tr>
<td>3</td>
<td>-0.87</td>
<td>0.63</td>
</tr>
<tr>
<td>4</td>
<td>-0.87</td>
<td>0.63</td>
</tr>
<tr>
<td>5</td>
<td>-0.87</td>
<td>0.63</td>
</tr>
<tr>
<td>6</td>
<td>-0.87</td>
<td>0.62</td>
</tr>
<tr>
<td>7</td>
<td>-0.87</td>
<td>0.60</td>
</tr>
<tr>
<td>8</td>
<td>-0.87</td>
<td>0.56</td>
</tr>
<tr>
<td>9</td>
<td>-0.87</td>
<td>0.44</td>
</tr>
<tr>
<td>10</td>
<td>-0.87</td>
<td>0.32</td>
</tr>
</tbody>
</table>

*Suits Index = -0.153
Suits Index Equivalent for Consumer Surplus = -0.153

*Suits Index = -0.144
Suits Index Equivalent for Consumer Surplus = -0.149

*Suits Index = -0.203
Suits Index Equivalent for Consumer Surplus = -0.237

* ΔCS is the change in consumer surplus defined in equation (2). Elasticities are taken from West (forthcoming). Tax/Total Expenditures and ΔCS/Total Expenditures are means for each decile.