# The Distributional Impacts of a VMT-Gas Tax Swap

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## Abstract

More stringent fuel economy standards and increased market penetration of electric vehicles (EVs) present challenges to federal policy makers who historically have relied on motor vehicle fuel excise taxes to fund highway projects.  This paper considers the distributional implications of a federal tax swap where a new vehicle miles travelled (VMT) tax is used to finance a reduction in the federal excise tax on gasoline.  Whether the tax shift is progressive (relative to the pivot point) or not depends on the sign of the income elasticity of demand for fuel intensity.   If it is negative (higher-income households demand more fuel efficient cars), then the tax shift is progressive around the pivot point.  Conversely, if it is positive, then the tax shift is regressive around the pivot point.  Where the pivot point occurs and how progressive a shift occurs is an empirical matter.

Using data from the 2017 National Household Travel Survey (NHTS), I find that the income elasticity of fuel intensity is negative and that this revenue-neutral tax swap to be mildly progressive for all household incomes below $200,000.   This is driven, in part, by the fact that higher income households are more likely to drive hybrid and electric vehicles and to own newer vehicles which, due to increasingly stringent fuel economy standards, tend to be more fuel efficient.  How the progressivity of a tax swap changes as fuel economy standards are raised and EV market penetration increases depends on who purchases EVs and more efficient vehicles.  Federal policy will likely play a role in influencing the future distribution of EV ownership.  In addition, I find the tax swap benefits rural drivers and has no appreciable differential impacts on Black and Hispanic households.

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**I.       Introduction**

Electric Vehicles (EVs) are increasingly popular and a major focus for policy makers as they consider ways to decarbonize the transportation sector.  Auto makers are getting on board as well.  General Motors has announced that it will roll out 30 EV models globally by 2025 as part of its plan to move to an "all-electric future."[1]  One fiscal concern with the shift from the internal combustion engine (ICE) to electric engines is its impact on motor vehicle fuel excise tax collections at the federal and state level.  The federal excise tax has historically been the major source of funding for the Highway Trust Fund.  But increased fuel economy in ICEs (see Figure 1) combined with the political challenges of raising the federal fuel excise tax rate has led to shortfalls in revenue for the trust fund.  Greater penetration of EVs in the marketplace only exacerbates the problem (Figure 2).  Federal motor transportation excise tax revenue is expected to be unchanged in nominal terms between 2017 and 2026; in real terms, the revenue is falling at the rate of between 1 and 2 percent per year (Figure 3).[2]

One possible solution is to shift from a gas tax to a vehicle-miles-traveled (VMT) tax.  Besides addressing the problem of a shrinking tax base for the current fuel excise tax, a VMT tax is better aligned with the externalities created by driving.  Research by Parry and Small (2005) shows that the bulk of damages related to personal vehicle gasoline consumption are driving-related damages (congestion, accident externalities) rather than fuel-related pollution.   Two states, Utah and Oregon, have dipped their toes in the water.  Oregon, for example, launched a voluntary pilot VMT tax in 2015 and is debating a mandatory VMT tax on new vehicles with a fuel economy of 30 MPG or higher to go into effect in 2026 (Duncan, 2021).

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[1] See GM announcement at https://www.gm.com/electric-vehicles.html, accessed Oct. 7, 2021.
[2] Transportation excise tax revenue from Table 2.4 of the Historical Tables in Office of Management and Budget (2021).

Opponents of a VMT tax raise several objections.  First, a VMT tax requires collecting information on miles traveled; this raises privacy and data security concerns for many.  Related are the administrative and compliance costs of collecting this information, sending out tax bills, and ensuring payment of the tax.  The American Transportation Research Institute (2021) estimates that the administrative costs of a national VMT could exceed $20 billion annually.

Environmentalists have also raised concerns.  A VMT tax that replaced a motor vehicles fuel excise tax would remove an implicit subsidy to electric and hybrid vehicles and thereby discourage the greater electrification of the vehicle fleet.  While true, this simply reflects the fact that we have multiple externalities at work – in particular, driving-related congestion and greenhouse gas emissions.  The Tinbergen Rule suggests the need for as many policy instruments as there are policy targets.  A VMT tax would address the congestion externality while a carbon tax or a subsidy to EVs would be a way to address the climate externality.

Finally, there are fairness concerns.  A VMT tax would be regressive, it is argued, and would unfairly burden low-income and rural drivers.  As a recent Grist article notes, "Like the gas tax, and like sales taxes in general, a VMT tax would be regressive if applied uniformly across income brackets: It would take a larger percentage of income from low earners than it would take from high earners… A VMT tax would also be likely to disadvantage rural communities, as well as communities of color generally" (Mahoney, 2021).

This paper addresses this fairness concern.  I analyze the distributional impact of a revenue-neutral tax swap where a VMT tax is implemented with revenues used to lower (or eliminate) the excise tax on motor vehicle fuels.  I focus on personal transportation rather than commercial transportation and trucking.  Light duty vehicles accounted for 89 percent of vehicle miles traveled in 2018, according to the Federal Highway Administration's *Highway Statistics 2018* (Table VM-1).  Some of this vehicle use

is for commercial purposes; one estimate is that household-based VMT accounts for 77 percent of total VMT.[3]  In addition, it is not clear how to apportion commercial diesel tax burdens to households.

The next section of this paper surveys the literature on the distributional impact of VMT taxes. In a subsequent theory section, I demonstrate that a revenue-neutral tax swap that used VMT tax revenues to replace some portion of gas tax revenues is progressive if the income elasticity of the demand for fuel intensity (fuel consumption per mile traveled) is negative.   The following section presents regressions on the household demand for vehicle fuel intensity using data from the National Household Travel Survey (NHTS).  Results indicate that the income elasticity of demand for fuel intensity is about -0.02 indicating that a VMT-Gas tax swap should be modestly progressive.

I then test the theory by calculating the change in tax burden from a revenue-neutral VMT-Gas tax swap using the NHTS data and find that the swap is modestly progressive.  This result holds using both an annual income measure and an approach that proxies for permanent or lifetime income.  Next, I consider a simulation where fuel economy standards are increased by 40 percent and EV market penetration rises to 15 percent, reflecting the Biden Administration's initiatives to tighten fuel economy standards and incentivize greater purchases of EVs.  In this counterfactual world, the VMT-gas tax swap is significantly more progressive.  Finally, I present results showing that rural areas of the country benefit from the tax swap.  While rural drivers drive more miles than urban drivers, they also drive less fuel efficient vehicles.  Vehicles with low fuel efficiency gain from the switch from a gas tax to a VMT tax and, in the case of rural versus urban drivers, the gains from saving on gas taxes more than offsets the new tax based on vehicle miles traveled.    Moreover, there do not appear to be any racial or ethnic differences in the impact of the tax swap.  A concluding section suggests policy implications and suggestions for further research.

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[3]  Figure 1-1 in *2017 NHTS Data User Guide*, available at
https://nhts.ornl.gov/assets/NHTS2017_UsersGuide_04232019_1.pdf.

## II.      Background

While a number of papers have assessed various policies involving hybrid and electric vehicles as well as optimal tax rates for a VMT tax (see, for example, Davis and Sallee (2019), Zhao and Mattauch (2021), and Rapson and Muehlegger (2021)), few recent papers have looked at the distributional implications of a shift from a gas tax to a VMT tax.  McMullen et al. (2010) simulates a tax swap for Oregon drivers based on data from the 2001 National Household Travel Survey (NHTS).  They find the tax swap to be regressive.  It is not clear that their study's results will hold up today given the overall increase in vehicle fuel economy and the increased market penetration of hybrid, plug-in hybrid, and electric vehicles (see Figures 1 and 2).   Another study by Langer et al. (2017) compares and contrasts the efficiency and political grounds.  While not a tax swap analysis, their paper provides evidence to support a VMT-gas tax swap on efficiency grounds.[4]  Weatherford (2012) notes several early papers that have compared VMT and gas taxes and concludes that the research "has not arrived at a strong consensus regarding whether [VMT taxes] would be more or less regressive  than the [fuel] tax" (p. 23).  He notes that the studies he surveys find that rural drivers would benefit from the tax swap while urban drivers would not.  In his own research using data from the 2001 and 2009 NHTS, Weatherford finds a VMT-gas tax swap would be distributionally neutral.  He finds that it would reduce the tax burden for rural drivers while increasing the burden for urban drivers.  As noted above, EV and PHEV market penetration and fuel economy have both increased significantly between 2009 and 2017, suggesting the value of revisiting this question with more recent data.  In the empirical analysis below, I'll use the 2017 NHTS, the most recent year of this survey.

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[4] They also carry out a distributional analysis of sorts, but it compares a VMT tax with differentiated rates between urban and rural drivers with a uniform gasoline tax.  It is not clear if it the tax swap or differentiated rate structure for the VMT tax that drives their results.

### III.     Theory

Individuals derive utility from travel $(M)$, measured in vehicle miles traveled and a vector of vehicle attributes $(A)$, one of which is fuel intensity $(E)$, measured in gallons per 1000 miles traveled.[5] Maximizing utility subject to a budget constraint yields demand equations for these three driving-related goods:

$$M = M(p_M, Y, X_M)$$

(1)
$$E = E(p_F, Y, A, X_E)$$

$$A = A(p_A, Y, X_A)$$

where $Y$ is income, $p_M, p_F,$ and $p_A$ are the price of driving a mile, the price of fuel, and the price of vehicle attributes, respectively and $X_M, X_E,$ and $X_A$ are other variables that affect miles driven $(M)$, fuel intensity $(E)$, and other vehicle attributes $(A)$.[6] The price of driving a mile is defined as

(2)
$$p_M = p_F E + t_M,$$

where the price of fuel is tax inclusive and $t_M$ is the VMT tax rate (currently zero).[7]

Below, I argue that a key parameter for determining the distributional impact of a VMT-Gas Tax swap is the income elasticity of demand for fuel intensity (e.g. the impact of income on the demand for fuel efficient vehicles). When considering that elasticity, I want to allow for the fact that changes in income affect the demand for fuel intensity directly but also indirectly through changes in demand for various vehicle attributes that, in turn, can affect fuel intensity. For example, as income rises, drivers might wish heavier and roomier cars, cars that will likely be more fuel intensive. To capture these

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[5] With some modification, this approach follows Small and Van Dender (2007).
[6] Variables that affect miles driven could include geography and occupation, for example. Fuel intensity is affected both by consumer preferences as well as federal fuel economy regulations. Other vehicle attributes could be affected by family size and driving conditions, among other factors.
[7] The relevant price per mile is a marginal price and also includes the depreciation and repair costs per mile driven. Excluding these additional costs will not affect my results as none of my analysis requires a percentage change in price but rather the absolute price change. A tax swap changes the tax-inclusive price of fuel and the VMT tax rate but has no effect on these other elements of the price per mile.

indirect impacts of income on fuel intensity, I substitute the vehicle attributes equation into the fuel

intensity equation and obtain the following system:

$$M = M(p_M, Y, X_M)$$

(3)

$$\hat{E} = \hat{E}(p_F, p_A, Y, X_E, X_A).$$

The relevant income elasticity of fuel intensity for considering the distributional impact of this tax swap

is the percentage change in $\hat{E}$ due to a one percent change in income.

The demand for gasoline is a derived demand from the demand for VMT and fuel intensity:

(4)
$$F = M \cdot \hat{E}$$

and income elasticities are related as

(5)
$$\eta_F = \eta_{\hat{E}} + \eta_M.$$

Define driving-related tax revenue as $R = t_M M + t_F F$ where the first term is the VMT tax and

the second term is gasoline excise revenue. I will consider a policy change where the VMT tax rate is

increased (from zero) and the tax rate on gasoline reduced to keep total revenue constant:

(6)
$$\frac{dR}{dt_M}\bigg|_{t_M=0} = \sum_i \frac{dR_i}{dt_M} = \sum_i \left( M_i + \frac{dt_F}{dt_M}\left[F_i + t_F \frac{\partial F_i}{\partial t_F}\right]\right) = 0,$$

where $i$ is indexing over households.[8] The term $\frac{dt_F}{dt_M}$ measures the revenue-neutral change in the gas tax

rate relative to the new VMT tax rate. This term is constant across all individuals and, presumably, is

negative starting from a zero tax rate on VMT. Call this term $\delta$. I can rewrite equation 6 as

(6')
$$\frac{dR}{dt_M} = \sum_i \frac{dR_i}{dt_M} = \sum_i \left( M_i + \delta F_i\left[1 + \frac{t_F}{p_F}\frac{p_F}{F_i}\frac{\partial F_i}{\partial t_F}\right]\right) = 0,$$

or

(7)
$$\frac{dR}{dt_M} = \sum_i \frac{dR_i}{dt_M} = \sum_i \left( M_i - \frac{F_i}{\bar{\hat{E}}}\right) = 0$$

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[8] Households may own more than one vehicle. The term $dR_i$ is the change in tax revenue per vehicle. In the
distributional analysis, I'll sum revenue changes over vehicles to the household level.

where

(8)
$$\bar{E} = \frac{-1}{\delta(1 + \theta_F \varepsilon_{FF})},$$

$\theta_F$ is the excise tax rate divided by the tax-inclusive price of fuel, and $\varepsilon_{FF}$ is the own price elasticity of demand for fuel. The term in the denominator is positive so long as an increase in the tax on gasoline increases gas tax revenue (i.e., no Laffer effect). I will assume that condition holds. Since $\delta < 0$, $\bar{E} > 0$. Note that $\bar{E}$ does not vary across individuals (assuming a constant own price elasticity of demand for fuel). The term $\bar{E}$ is a threshold value of fuel intensity. Vehicles with fuel intensity above $\bar{E}$ will experience a decrease in tax payments due to the tax swap while vehicles with fuel intensity below $\bar{E}$ will experience a tax increase:

$$\frac{dR_i}{dt_M} > 0 \text{ for } E_i < \bar{E}$$

and

$$\frac{dR_i}{dt_M} < 0 \text{ for } E_i > \bar{E}.$$

In words, drivers with low fuel economy cars $(E_i > \bar{E})$ pay less in driving-related taxes with this tax shift while drivers with high fuel economy cars $(E_i < \bar{E})$ pay more. Whether the tax shift is progressive (relative to the pivot point) or not depends on the sign of the income elasticity of demand for fuel intensity $(\eta_E)$. If it is negative (higher-income households demand more fuel efficient cars), then the tax shift is progressive around the pivot point. Conversely, if it is positive, then the tax shift is regressive around the pivot point.

While information relative to the pivot point is useful, it does not tell us anything about global progressivity. A tax is progressive (regressive) if the average tax rate, defined as the tax payment

relative to some measure of income, rises (falls) with income.[9]  Most studies find the current gas tax to

be regressive (see, for example, West and Williams, 2004).[10]  Whether the gas tax is regressive or not is,

to a large degree, irrelevant for the question at hand.  What matters is the *relative* regressivity of each

tax.  To assess the impact of a VMT-gas tax swap, we need to measure the change in the average tax

rate (ATR) as the reform is implemented.  It will be convenient in the derivation below to replace $\bar{E}$ with

its inverse, $\psi = 1/_{\bar{E}}$.  The term $\psi$ is the threshold now measured in miles per gallon.  Vehicles with fuel

economy greater than $\psi$ experience an increase in tax payments with the tax swap while vehicles with

fuel economy less than $\psi$ experience a decrease in tax payments.

With that change in notation, the change in the average tax rate due to the tax swap is given by:

(9)
$$\frac{dATR_i}{dt_M} = \frac{d\frac{R_i}{Y_i}}{dt_M} = \frac{M_i - \psi F_i}{Y_i}.$$

Whether the tax swap is progressive or not depends on the sign of the derivative of the change in the

ATR with respect to the reform as income changes:

$$\frac{\partial\left(\frac{dATR_i}{dt_M}\right)}{\partial Y} \begin{cases} > 0 & progressive \\ < 0 & regressive \end{cases}$$

A formula for this derivative is given by

(10)
$$\frac{\partial\left(\frac{dATR_i}{dt_M}\right)}{\partial Y} = \frac{M_i - \psi F_i}{Y_i^2}\left\{(\eta_M - 1) - \left(\frac{\psi F_i}{M_i - \psi F_i}\right)\eta_E\right\}.$$

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[9] How one measures income is a long-standing topic of study in economics.  A snapshot measure of income may misrepresent the taxpayer's true resources.  Economists have used various proxies for lifetime or permanent income.  See Fullerton and Metcalf (2002) for more on this issue.

[10]  Studies using lifetime income proxies (e.g. current consumption as in Poterba, 1991) find much less regressivity.  Teixidó and Verde (2017), however, argue that findings such as Poterba's ignore important wealth effects that mask regressivity.

Consider first those households with high fuel intensity vehicles $(M_i - \psi F_i < 0)$. The sign of the derivative in equation (1) depends on the signs of the two terms in curly braces. Based on the analysis of Small and Van Dender (2007), the income elasticity of VMT is less than 0.6 and so the first term, $(\eta_M - 1)$, is negative.[11] If $\eta_E < 0$, the change in the average tax rate rises with income:

$$(10') \qquad \frac{\partial \left( \frac{dATR_i}{dt_M} \right)}{\partial Y} = \underbrace{\frac{M_i - \psi F_i}{Y_i^2}}_{<0} \left\{ \underbrace{(\eta_M - 1)}_{<0} - \underbrace{\left( \frac{\psi F_i}{M_i - \psi F_i} \right)}_{<0} \underbrace{\eta_E}_{<0} \right\} > 0.$$

The tax reform is strictly progressive over the range of fuel intensity such that the average tax rate is falling. Conversely, if $\eta_E > 0$, the sign depends on the relative magnitude of the two terms in the braces. For high fuel intensity cars (high value of $E_i$), the first term will dominate and the derivative will be positive. As $E_i$ approaches $\bar{E}$, the second term will dominate and the sign of this derivative will become negative.

Now consider those cars with low fuel intensity $(M_i - \psi F_i > 0)$.[12] If $\eta_E < 0$, the sign of the derivative is ambiguous:

$$(10'') \qquad \frac{\partial \left( \frac{dATR_i}{dt_M} \right)}{\partial Y} = \underbrace{\frac{M_i - \psi F_i}{Y_i^2}}_{>0} \left\{ \underbrace{(\eta_M - 1)}_{<0} - \underbrace{\left( \frac{\psi F_i}{M_i - \psi F_i} \right)}_{>0} \underbrace{\eta_E}_{<0} \right\}.$$

For values of $E_i$ close to $\bar{E}$, the denominator of the fraction in the curly braces is close to zero and the second term dominates. In that case

$$\frac{\partial \left( \frac{dATR_i}{dt_M} \right)}{\partial Y} > 0, \qquad \text{for } E_i \text{ near } \bar{E}.$$

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[11] See appendix for calculations.
[12] These cars are low intensity regardless of miles driven or fuel consumed because the inequality, $M_i - \psi F_i > 0$, can be rewritten as $E_i < \bar{E}$.

But as fuel economy grows, the second term in the curly braces gets smaller and at some point the first term dominates in which case the change in the average tax rate begins to fall with income. EVs are at the limit where $E_i = F_i = 0$ and

$$\frac{\partial \left( \frac{dATR_i}{dt_M} \right)}{\partial Y} = \frac{M_i}{Y_i^2}(\eta_M - 1) < 0.$$

There is no incentive to increase fuel efficiency further to avoid gasoline consumption since it has already been driven to zero. Driving increases with income but at a slower rate so that the average tax rate falls.

If $\eta_E > 0$, the derivative then is negative. The change in the average tax rate falls with income. Figure 4 sums up the results for the two different cases (positive or negative income elasticity of fuel intensity). If the income elasticity is negative, the change in the ATR is negative at low levels of income but approaches zero. At the point where the change in the ATR equals zero, the slope of the curve is positive. Eventually the curve peaks and the change in the ATR for higher values of income begins to fall. If the income elasticity of fuel intensity is positive, the change in the ATR is positive at low levels of income but falls towards zero. At the point where the change in ATR equals zero, the slope is still negative. The change in the ATR eventually reaches a minimum and then begins to rise as income grows.

Figure 4 makes the point that the VMT-gas tax swap is progressive over some portion of the income range if the income elasticity of fuel intensity is negative. Conversely, it is regressive over some portion if the elasticity is positive. Where the turning point occurs, however, and what proportion of households are in the progressive or regressive range is an empirical question. The next section addresses this issue by estimating the income elasticity of fuel intensity.

**III.      Estimating the Income Elasticity of Fuel Intensity**

For the empirical analysis in this paper, I use data from the 2017 National Household Travel Survey (NHTS), the most recent wave of this survey.  The NHTS is a stratified random sample of households in all fifty states and asks questions about travel behavior and all modes of travel.  The survey was conducted from March 2016 through May 2017.  It collects information about the household, all residents of the household, all motor vehicles owned, and detailed information about trips taken during a designated 24 hour period.[13]  The survey is designed to collect information about daily travel, whether for commuting, errands, vacation, or other household trips.  According to the User's Guide, household-based travel in light-duty vehicles accounted for 77 percent of vehicle miles traveled (VMT).

Data are reported in several files: household, person, vehicle, and trip.  There are 129,696 households included in the survey and  256,115 vehicles included in the vehicles file.  Households are included in the sample whether they own motor vehicles or not.  Of the 129,696 households surveyed, 6,249 do not own vehicles (4.8 percent of households).  All households that own vehicles are included in the vehicles data file.  I use data from the vehicles file.  For the distributional analysis (described below), I aggregate vehicles up to the household level to calculate total miles driven and fuel consumed.

In the analysis, I restrict attention to light-duty vehicles (cars, vans, SUVs, pickup, and other trucks), reducing the sample by 12,209 observations.[14]   I also drop households with more than 5 vehicles (following Levinson, 2019) or households with missing income as well as vehicles with no annual mileage reported or whose mileage has been flagged by NHTS as an outlier.  Finally, I drop vehicles in

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[13] Detailed information about the 2017 NHTS is available at https://nhts.ornl.gov/.

[14] Other trucks are defined in the User Guide Glossary as "all trucks other than pickup trucks (e.g., dump trucks, trailer trucks, etc.)."  Note that they are all privately owned.  I include these 1,414 vehicles as analysis of the trip data indicate that 83 percent of the trips made with these vehicles are non-work related (variable whytrp1s).

the top and bottom 0.5 percentile of annual mileage. The final sample has 208,167 vehicles (see Table 1). For the distributional analysis there are 113,434 households (see Table 3).

Details on construction of the annual average mileage, fuel consumption, and fuel intensity for the vehicles is reported in an appendix to this paper. Summary statistics for these variables are included in Table 2. Overall, the average fuel intensity is 49.1 gallons per 1000 miles (20.4 miles per gallon), ranging from 0 to 167. The average VMT is 10,517 miles and average fuel consumption is 507 gallons per vehicle per year. While the maximum fuel consumption in the data set is over 5000 gallons, this is a significant outlier. The 99$^{th}$ percentile of fuel consumption is 1,758 gallons. Cars make up just half of the vehicles in the data. They have lower average fuel intensity (42.0 gallons per 1000 miles) but are driven roughly the same distance. Vans, accounting for 5 percent of the vehicles, use more fuel per mile and are driven slightly more than vehicles on average. As a result, they use about 17 percent more fuel than vehicles on average. Sport Utility Vehicles (SUVs) account for one-quarter of the vehicle stock in the dataset and, like vans, use more fuel and are driven slightly more than vehicles on average. Finally, pickup trucks account for a little under one-fifth of the vehicles and use considerably more fuel (64.3 gallons per 1000 miles) but are driven a bit less than vehicles overall.

Table 3 reports summary statistics on the 113,434 households with vehicles that are included in the analysis. The NHTS reports income by bins. I set household income equal to the midpoint of each of the 11 bins and equal to $300,000 for the top bin ($200,000 or more). Mean household income with my constructed measure is $81,189. In the analysis below, I use both my constructed income variable and the income bins for distributional analyses. The average household size is just over 2.5. A little over one-third of the homes have children in them. Most adults drive in a household and two-thirds of the households are in owner-occupied housing.

Driving depends on density patterns in the area. I include a number of controls including whether the household is in an urban area as well as whether the block in which the household resides

is an urban or rural block group (other possible block group types are second city, suburban, and small

town).[15]  I also have a measure of population density for the household's block group.  Having multiple

measures of urban density accounts in a more flexible way for the various driving patterns different

households might experience.

Finally, I include information at the household level on vehicles.  The average fuel intensity of

household vehicles (weighted by vehicle miles traveled) is 48 gallons per 1000 miles (21 miles per gallon)

and the average household driving is just under 20,000 miles a year with average fuel consumption of

934 gallons.

Table 4 presents results from a regression of fuel intensity on household income and other

variables.  Regressions (1) and (2) are OLS regressions with and without additional household control

variables.  The next two regressions add state level fixed effects to control for unobserved state

variables that could be correlated with income and the demand for fuel intensity.[16]   In all cases, the

coefficient on the log of household income is negative and statistically significant.  Adding state fixed

effects modestly reduces the magnitude of the semi-elasticity.  Adding additional control variables

nearly doubles the estimated semi-elasticity.  Using the fourth regression in Table 4, the elasticity of fuel

intensity with respect to income at the mean value of fuel intensity is -0.020.   A ten percent increase in

income decreases fuel intensity by 0.2 percent or 0.1 gallons per 1000 miles.  Income does appear to

affect the demand for fuel intensity, but the effect is modest.

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[15] Block groups comprise 600 to 3,000 people and are the smallest geographic units tabulated in sample data.
Urban areas are larger geographic clusters with 2,500 or more people (depending on the type of urban area).   See
https://www.census.gov/content/dam/Census/data/developers/geoareaconcepts.pdf for more on census
designations.
[16] I also have run regressions at the household level where I regress various measures of household fuel intensity
on income and other variables.   The fuel intensity measures include an average over household owned vehicles,
VMT weighted average fuel intensity, and fuel intensity of the vehicle with maximum VMT.  In all cases the
estimated coefficient on the income variable is negative and statistically significant.

Figure 5 shows the impact of income on fuel intensity by graphing the estimated coefficients for income bins along with 95 percent confidence intervals from a regression of vehicle fuel intensity on income bin indicators along with other covariates, specifically the covariates included in the regression in Table 4, column 4.  The regression shows that fuel intensity declines with income though the difference in fuel intensity between the bottom and top of the income distribution is small – on the order of 3 to 4 gallons per 1000 miles (less than 10 percent of average fuel intensity).  Summing up, the evidence from the regressions indicates that higher-income households drive more fuel-efficient vehicles.

My results stand in contrast to those of Levinson (2019).  He finds a positive relation between income and fuel intensity using the 2009 NHTS in a regression where he does not control for any vehicle attributes (Table 5, column 2 in his paper).  Our papers differ in the measure of fuel economy used in the analysis.  Levinson used the EPA measure of fuel economy while I use the Energy Information Agency (EIA) measure which adjusts the EPA measure for real-world driving conditions and vehicle use (see the appendix for more on the difference between these measures).  When replicating Levinson's regression in Table 5, column 2 of his paper, I find that the coefficient on income becomes negative and statistically significant if EIA's fuel economy measure is used rather than the EPA measure.[17]

Using data from the Massachusetts Vehicle Census, Lu (2021) finds, in contrast to my results, that fuel intensity rises with income whether other vehicle attributes are controlled for in the regression or not (Table 2).  His data, however, are for motor vehicles in Massachusetts only and for model years 2011-2012 and there are few EVs or PHEVs in his dataset.  As noted in Figure 2 below, these vehicles are only starting to enter the marketplace in 2011.[18]

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[17] I am grateful to Arik Levinson for sharing his data and STATA code with me.
[18] I also ran the regression in Table 4 after dropping all EVs and PHEVs.  The coefficients on income become smaller in magnitude but continue to be negative and statistically significant.  There may be more significant differences between vehicles owned by Massachusetts drivers when compared to the national average.

While it might be imagined that higher-income households prefer more fuel intensive vehicles, the data suggest two countervailing forces. First, EV, PHEV, and hybrid vehicle ownership is positively correlated with income (albeit only modestly) either unconditionally or after controlling for the other household attributes included in Table 4.[19] Even setting aside hybrid or EV ownership, higher-income households tend to own newer vehicles which, in turn, consume less fuel on average (in no small part due to more stringent fuel economy standards). A regression of fuel intensity on vehicle age indicates that cars consume roughly one more gallon of fuel per 1,000 miles for each year of age.[20]

Given the results in this section, I would expect the VMT-Gas tax swap to be progressive over most of the income distribution (see top panel of Figure 4). In the next section, I turn to that empirical analysis.

## IV.      Distributional impacts of the tax reform

A theoretically rigorous measure of the welfare impact of a VMT-gas tax swap would measure the equivalent (or compensating) variation at the household level and then compare across income levels. To do this, I would need to assume a functional form for utility (or equivalently the expenditure function). However, it is not necessary to do that. As I argue in the appendix, the welfare impact for household $i$ ($\Delta W_i$) is reasonably well approximated by the change in tax burden:

(5)                                           $\Delta W_i \cong -dR_i = -(t_M M_i + dt_F F_i)$

where $R_i$ is tax revenue for household $I$ from fuel and VMT taxes, $M_i$ is miles driven for household $i$, $F_i$ is fuel consumption for household $i$, and $t_M > 0$ is the revenue-neutral VMT tax rate for a given reduction in the gasoline excise tax rate $(dt_F < 0)$. I will report the change in tax revenue as the measure of the

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[19] Unconditional correlation coefficients range from .04 to .06.
[20] A simple quadratic regression of fuel intensity $(\hat{E})$ on vehicle age in years $(A)$ and age squared yields $\hat{E} = 39.5 + 1.32A - .023A^2$, with all p-values essentially zero. At the median vehicle age (9 years), fuel intensity (gallons per 1000 miles) increases at the rate of 0.9 per year.

welfare change for each household. While this underestimates the impact of the tax swap on individual households, it should not impart any bias to the distributional impact across income groups.

I calculate this measure of the change in welfare at the household level after first estimating the revenue-neutral VMT tax rate for a ten cent per gallon reduction in the gasoline excise tax rate.  A ten cent reduction in the gas tax reduces gas prices for drivers in the 2017 NHTS by 4 percent on average. Offsetting this price decrease is the tax on VMT.  In the appendix, I argue that the demand for fuel efficiency and vehicle miles traveled should change by less than 1 percent and so can be ignored in the simulation.  Ignoring changes in driving behavior or fuel intensity, the revenue-neutral VMT tax rate is 0.48 cents per mile.  This lowers the price of driving per mile by 4 percent on average.  On average the VMT-gas tax swap collects $93 in VMT taxes per household while simultaneously lowering gas tax payments by the same amount.  The standard deviation of the household change in tax payments is $23 and the change in tax payments ranges from a reduction of $388 per household per year to an increase of $192.

Any distributional analysis where households are ranked by annual income suffers from the well-known measurement problem that annual income may differ significantly from a measure of permanent or lifetime income.  Measurement error is also an issue, especially in lower income deciles where expenditures commonly exceed reported income.  A measure of permanent or lifetime income more accurately captures welfare differences across households (e.g. Friedman, 1957).  In their seminal work on measuring the U.S. tax burden, Pechman and Okner (1974) address the problem of high consumption to income ratios in lower income deciles by excluding the bottom half of the lowest income decile from their distributional analysis.  Their approach was followed by subsequent researchers before economists explored either using current consumption as a proxy for lifetime income (e.g. Poterba, 1991) on the argument that households do consumption smoothing over their lifetime, or explicitly measured lifetime income and taxes (e.g. Fullerton and Rogers, 1993).

I take two approaches to this problem of approximating household welfare by annual income. My first approach is to use annual income but exclude those households for whom gasoline expenditures exceed fifty percent of household income. This is admittedly an arbitrary cut-off, but distributional results are not appreciably affected by the choice of cut-off. Of the 113,307 households from the 2017 NHTS included in the welfare analysis, 534 households have gas expenditures in excess of fifty percent of household income – less than one-half of one percent of the sample. Of these households, 93 percent are in the lowest income group (household income less than $10,000) and the remaining 7 percent have income below $25,000.

Using annual income has its drawbacks but does accord with how most policy-related distributional analyses are done in Washington DC. As an alternative (or supplementary approach), I limit my analysis to households with household heads between the ages of 40 and 60. The logic here is that annual income most significantly diverges from a lifetime income measure for those starting out in life and, perhaps, making significant human capital investments and for those who have (mostly) exited the workforce and are drawing down personal savings and pensions in retirement.

1.    *Annual Income Distributional Analysis*

Figure 6 graphs the estimated coefficients from a regression of the change in tax payments on indicator variables for the income bins. The lowest income bin (less than $10,000) is excluded so the coefficient estimates represent the estimated difference between the bin in question and the lowest income bin. Two things stand out in this table. First, the average change in tax payments is initially negative in the lower income groups but rises nearly monotonically across the income groups. Second, the average change in tax payments is quite modest – ranging from a little more than a one dollar decline for the second lowest income group to a little more than a two dollar increase in the highest

income group.[21]  This range corresponds to approximately 6 percent of the average fuel tax, pre-reform. I also ran a regression of the change in tax payments on my constructed income variable.  The estimated change in tax payments per one log point change in log income equals 0.665 and has a p-value of less than one percent.

While the average change in taxes is quite small, there is heterogeneity within the income groups.  Figure 7 shows what percentage of households pay more in taxes and Figure 8 shows what percentage pay at least $50 more in taxes.  Roughly half the households in each income group pay more in taxes, with the percentage rising slightly with income.  Few households (less than 5 percent) pay $50 or more in additional taxes as a result of the tax swap.  The percentage is under one percent for the lowest income group and rises to just over four percent for the highest income group.

*2.        Lifetime Income Distributional Analysis*

Next I report results for households with heads of household between the ages of 40 and 60 as a way to address the problem that annual income may not be a good measure of lifetime income for households starting careers or entering retirement.  Limiting households in this way removes some of the difference between income on which consumption decisions are being made and measured income. It does not address possible transitory income fluctuations, but it would be difficult with the NHTS to deal with that issue given the single snapshot of income for households.

While household members age 5 and older ("persons" for the purposes of the survey and this paper) are tracked in the NHTS, there is no identifier for head of household.  There can be as many as 13 persons in a single household though over 80 percent of households have only 2 people in them. Looking at the age distribution for the various person identifiers (personid), it is plausible to expect that most heads of household are being identified as person 1 or 2.  The interquartile range and median age

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[21] These are all changes relative to the lowest income group.  When running the regression with indicator variables for all income groups (but no intercept), the estimated coefficient on the lowest income group is very close to zero.

for person 1 is 45 to 69 with a median age of 59 while for person 2 is 39 to 66 with a median of 55. For

every other person (3 – 13), the 75$^{th}$ percentile age is less than 25. For each household I record the age

of person 1 and person 2 and create a lifetime income index variable based on one of three criteria: 1)

the older person is between the ages of 40 and 60; 2) the younger person is between the ages of 40 and

60; and 3) both are between the ages of 40 and 60.[22] I report results using the first lifetime income

index to select households for the analysis.[23]

Figure 9 shows the change in tax payments by income group relative to the lowest income group

(income less than $10,000). The same upward-sloping pattern occurs as in Figure 6 though the range

between the first and last income group is now larger. The percentage of households with welfare

decreases of $50 or more looks similar (Figure 10 compared to Figure 8). A regression of the change in

tax payments on my constructed income variable yields an estimated coefficient on the log income

variable of 1.034 (p value less than .01). If anything, the tax swap looks slightly more progressive than

when all households are included in the analysis, a result commonly found in analyses of excise taxes

when lifetime rather than annual income measures are used.

In summary, whether one uses all households or limits households to an age group likely to be

near the peak of their lifetime earnings potential, a VMT-Gas Tax swap appears to be modestly

progressive. But the actual changes in welfare are quite small for nearly all households. This reflects the

reality that personal driving gasoline taxes are a modest fraction of most households' income and that a

VMT tax would also have small impacts on most households. Given average household driving of

roughly 20,000 miles per year, a VMT tax set at one-half penny per mile would raise about $100 per

household on average. This would be offset by a decline in the gasoline tax that, on average, would also

equal about $100.

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[22] If there is only one person in the household, I simply use the age of that person.
[23] Results are very similar no matter which criterion I use for selecting households. Results are available upon request.

*3.* *Distributional Analysis Assuming More Stringent Fuel Economy Standards and Greater EV Penetration*

The analysis above is based on alternative fuel market penetration as of 2017. Innovation in the EV, PHEV, and Hybrid market is rapid and, as noted, major automobile manufacturers are committed to accelerating the shift to non-gasoline powered vehicles. At the same time, fuel economy standards for internal combustion engine powered vehicles continue to rise. The distributional implications of a VMT-gas tax swap will likely look very different as more EVs, PHEVs, and more fuel efficient vehicles penetrate the market.

To assess the distributional implications of this alternative market structure, I assume EVs and PHEVs comprise 15 percent of the vehicle fleet and, following Langer, et al. (2017), increase fuel economy by 40 percent. The latter is consistent with the more stringent fuel economy standards initially put forward by the Obama Administration and subsequently reinforced by the Biden Administration.[24] Who owns the EVs and PHEVs will depend importantly on federal policies to incentivize the purchase of these vehicles. If future policies are similar to previous policies (e.g. the use of non-refundable personal income tax credits), then it is likely that EV and PHEV ownership will concentrate in higher-income household groups. But it is possible that federal policy will focus on incentivizing ownership by middle-income households.

Rather than try to predict future EV policies, I report results from two counterfactual simulations. In the first simulation, I convert the newest vehicles in the NHTS data set to EVs until EVs comprise 15 percent of the market. Since higher-income households tend to buy newer cars, this will weight EV ownership towards higher-income households and reflects a distribution of ownership where federal policy disproportionately incentivizes higher-income households to purchase EVs. In the second

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[24] In April 2022, the Biden Administration released new fuel economy standards for model years 2024 – 2026 which would increase fuel economy by over 28 percent between model years 2023 and 2026. See the NHTSA press release at https://www.nhtsa.gov/press-releases/usdot-announces-new-vehicle-fuel-economy-standards-model-year-2024-2026, accessed May 9, 2022.

simulation, I randomly select vehicles from households in the 25th to 75th percentiles to convert to EVs until 15 percent of all vehicles are EVs.  This reflects a policy scenario that targets EV ownership among households in the middle of the income distribution.  While these are admittedly crude approaches to simulating auto manufacturer and household responses to policy, they make the point that the distributional impact of a future VMT-Gas Tax swap will depend importantly on federal policy to incentivize EV production and purchases.

With either of these approaches, I assume households own the same number of vehicles and simply shift vehicles from internal combustion to either EV or PHEV.  Higher fuel economy standards lower the price of driving per mile.  This, in turn, can lead to more driving – a phenomenon known as rebound.  A central estimate of the rebound effect is 10 percent (Gillingham, 2018),  meaning 10 percent of the fuel savings from higher fuel economy standards is lost due to increased driving.  Given a 40 percent increase in fuel economy, this implies vehicles are driven 4 percent more miles (see Appendix).  I increase vehicle miles traveled by 4 percent for all vehicles and, based on the higher fuel economy standards, recompute gasoline consumption.[25]

Figure 11 presents results from the first simulation where increased EV ownership is based on the age of vehicles owned by households.  All internal combustion vehicles from model year 2015 through 2017 are now assumed to be EVs and a sufficient number of model year 2014 vehicles (randomly chosen) are assumed to be EVs.  Because EVs account for a greater share of the vehicle stock and internal combustion engine vehicles are more fuel efficient, a ten cent per gallon reduction in the gas tax reduces average household gas tax payments by $59 a year.  Changes in household tax payments

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[25] I also increase VMT by 4 percent for EVs and PHEVs.  The literature on rebound for EVs is sparse.  Davis (2019) actually finds that EVs are driven less than gasoline powered vehicles.  But, as he acknowledges, this difference could be driven by sample selection among purchasers.  Bauer (2018), in contrast, finds a modest increase in driving among Norwegian drivers.

range from -$328 a year to $314 a year.  This overstates the typical variation as 95 percent of the households have changes between -$52 and $73.

The effect of income on the change in tax payments is over four times as large now, reflecting in large measure the importance of income for driving EV and PHEV market penetration.  The change in tax payments is negative for households in the income bins below $25,000 and the tax payments become positive and increasing with higher incomes (top panel).  While the average change in tax payments ranged between -$2 and +$4 before, now it ranges between -$3 and +$15 per household.[26]  Now as many as fifteen percent of households see an increase in taxes of at least $50 (Figure 12).  While not shown here, the change in the average tax rate is monotonically increasing with income through all but the top income group.  However, even with the higher fuel economy and market penetration of EVs and PHEVs, the average tax rate change is modest ranging from -0.05 percentage points for the lowest income group to roughly +0.005 percentage points for households with income above $150,000.

If EV policy concentrates new EV ownership in middle-income groups, then – not surprisingly – the burden of the tax swap is felt most keenly by middle-income households (see Figure 13).  Households in income groups below the 25th percentile and above the 75th percentile benefit from the tax swap while households in the middle of the distribution see their tax payments go up, on average, between $10 and $15 per household.   Similarly, households with tax increases of $50 or more annually are concentrated in the middle of the income distribution (Figure 14).

These simulations are necessarily artificial but illustrate the interplay between federal policies to support EV ownership and the distributional implications of a VMT-Gas Tax swap.  At the end of the day, owners of EVs are going to pay more in taxes with such a tax swap.  This would likely be welfare improving on efficiency grounds; whether it is welfare enhancing on equity grounds will depend on who

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[26] While the change in tax payments changes by as much as $300 or more (in either direction), the average change is much smaller.

buys those vehicles.  Note as well that federal policies to encourage greater EV ownership and fuel

efficiency strengthens the fiscal case for reform of the motor fuel excise tax.  Federal (and state) motor

vehicle fuel excise tax revenues are going to drop at a rapid rate as we electrify the transportation fleet.

**V.      Other Distributional Considerations**

Policy makers care about more than the income-related distributional impacts of tax reform.  In

this section, I consider two other distributional aspects of interest: 1) the regional impacts of the tax

swap; and 2) impacts across racial and ethnic groups.  Table 5 presents regressions on the change in tax

payment that include indicators for eight of the nine Census divisions (New England is the omitted

division).  While there is some variation, it is modest.  Every census division pays less in taxes under the

reform than does New England.  The Pacific region is closest in impact to New England; the Mountain

states (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming) have the largest

decline ($8.15 per household on average) followed by the West South Central division (Arkansas,

Louisiana, Oklahoma, and Texas) at $7.20.   Table 6 shows results from regressions with an indicator for

the household being in a rural area.  Households in rural areas pay $7 less in taxes on average than do

households in urban areas.  This reflects the fact that vehicles in rural areas tend to have lower fuel

economy (20.0 miles per gallon) than vehicles in urban areas (22.3 miles per gallon).  Vehicles in rural

areas are driven more but only by 5.6 percent on average relative to vehicles in urban areas.  With

higher fuel intensity (higher by 11.5 percent), rural drivers benefit from the reduction in the gas tax that

more than offsets the new VMT tax – all relative to urban drivers.

Differences across racial or ethnic lines are less pronounced.  Households where the survey

respondent is Black or African American pay on average $.44 less in taxes than other respondents (Table

7) and I can't reject a zero difference at any reasonable level of statistical significance.  Similarly,

households with a Hispanic survey respondent pay on average $.28 less in taxes than other households

(Table 8) but, again, I can't reject a zero difference at any reasonable level of statistical significance.

VI.     **Conclusion**

The increasing electrification of the transportation fleet calls into question the ability of the

current motor vehicle fuel excise tax (gasoline and diesel) to raise sufficient funding for the Highway

Trust Fund.  One possible solution to the problem is to shift from a tax on fuel consumption to a vehicle

miles traveled (VMT) tax.  Advances in technology make this administratively practicable though there

are concerns about privacy.  While there might be concern that the tax shift might dampen consumer

demand for fuel efficient vehicles as well as electric and plug-in hybrid vehicles, I've argued that the tax

shift is unlikely to have an appreciable impact on this margin.   Moreover, the twin externalities of

congestion and petroleum-related pollution suggest the need for multiple instruments (Tinbergen Rule).

A VMT tax combined with a carbon tax or a subsidy to plug-in hybrids and electric vehicles would be one

possible approach to the package of externalities.[27]

Another concern is whether the tax swap might exacerbate the current regressive nature of fuel

taxes.  This paper demonstrates that this latter problem should not be an issue.  A VMT-gas tax swap is

shown to be modestly progressive over much of the income distribution.  Regional variation is also

modest with drivers in rural communities likely to benefit from the tax swap.

On fiscal grounds, the case for such a tax swap grows as the vehicle fleet is increasingly

electrified.  Whether this greater market penetration enhances or blunts the progressivity of the reform

depends on who is motivated by policy to buy EVs.  With the rapidly increasing share of EVs and PHEVs

in the marketplace, further analysis to explore how this higher share affects the distributional impact of

a VMT-gas tax swap would be useful.  The analysis here could be refined in a number of ways, including

allowing for vehicle heterogeneity within households in EV take-up rates based on likely federal and

state policies to encourage EV manufacturing and purchases.  Sensitivity analysis with different

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[27] Given the innovation required to increase driving range in EVs at low cost, one could argue that there is a third
externality of a positive information externality as innovation occurs to increase range at low cost.

assumptions about EV market penetration as well as improvements in fleet fuel economy would also be valuable.

In the end, personal fuel consumption as a share of income is quite modest for most drivers. A VMT-gas tax swap entails a modest change in tax collections. But optics matter and the progressive nature of the tax swap should be heartening to proponents of this tax reform.

Table 1.  2017 NHTS Vehicles Sample

| | |
|---|---|
| Initial Sample Size | 256,115 |
| Drop RVs, motorcycles, etc. | -12,209 |
| Drop if more than 5 vehicles | -8,628 |
| Drop if household income missing | -7,493 |
| drop if annual VMT missing | -1,061 |
| drop if annual VMT outliers (NHTS) | -16,455 |
| drop upper and lower 0.5% tail of VMT | -2,102 |
| Remaining Sample | 208,167 |

Table 2.  Vehicle Summary Statistics

| | All Vehicles | Cars | Vans | SUVs | Pickup Trucks |
|---|---|---|---|---|---|
| Fuel Intensity (gallons per 1000 miles) | 49.1 (12.7) | 42 (8.9) | 53.3 (8.1) | 52.7 (10.4) | 64.3 (10.3) |
| Fuel Economy (miles per gallon) | 20.4 | 23.8 | 18.8 | 19.0 | 15.6 |
| Vehicle Miles Travelled | 10,517 (7,109) | 10,261 (7,086) | 11,246 (7,144) | 11,426 (7,053) | 9,674 (7,049) |
| Fuel Consumption | 508 (370) | 421 (298) | 595 (406) | 594 (383) | 618 (463) |
| Number of Observations | 208,167 | 104,889 | 11,302 | 52,860 | 38,515 |
| This table reports the mean values of fuel intensity, vehicle miles traveled, and fuel consumption along with standard deviations in parentheses.  Fuel economy (miles per gallon) is also reported for the mean values of fuel intensity. | | | | | |

Table 3. Household Summary Statistics

| Variable | Mean | Std. Dev |
|---|---|---|
| Household Income | 81,189 | 70,376 |
| Household Size | 2.56 | 1.36 |
| Number of Adults | 1.95 | 0.80 |
| Number of Drivers | 1.85 | 0.78 |
| Number of Workers | 1.26 | 0.92 |
| Homeowner | 0.68 | 0.47 |
| Children in Home | 0.36 | 0.48 |
| Urban Area | 0.82 | 0.39 |
| Urban Block | 0.37 | 0.48 |
| Rural Block | 0.19 | 0.39 |
| Population Density (100 per square mile) | 49.7 | 64.8 |
| Number of Vehicles | 2.04 | 1.02 |
| HH Average Fuel Intensity | 47.87 | 10.23 |
| HH Total Mileage | 19,347 | 13,915 |
| HH Total Fuel Consumption | 933.6 | 724.8 |
| Summary statistics over 113,434 households with vehicles in the NHTS. Average fuel intensity weighted by vehicle miles travelled. | | |

Table 4.  Fuel Intensity Regressions

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Ln(HH Income) | -0.701 (0.035)** | -1.103 (0.038)** | -0.551 (0.034)** | -1.021 (0.037)** |
| Household Size | | 1.263 (0.055)** | | 1.208 (0.054)** |
| Number of Adults | | -1.001 (0.092)** | | -0.869 (0.091)** |
| Number of Drivers | | -1.361 (0.089)** | | -1.391 (0.088)** |
| Number of Workers | | -0.660 (0.039)** | | -0.642 (0.039)** |
| Homeowner | | 1.143 (0.079)** | | 1.165 (0.079)** |
| Children in Home | | -0.854 (0.114)** | | -0.855 (0.113)** |
| Urban Area | | -1.166 (0.107)** | | -1.377 (0.105)** |
| Urban Block | | 0.284 (0.080)** | | -0.044 (0.081) |
| Rural Block | | 1.667 (0.107)** | | 1.802 (0.105)** |
| Population Density | | -0.000 (0.000)** | | -0.000 (0.000)** |
| Number of Vehicles | | 2.570 (0.037)** | | 2.483 (0.037)** |
| Intercept | 57.180 (0.383)** | 58.013 (0.405)** | 55.508 (0.381)** | 57.295 (0.405)** |
| $R^2$ | 0.00 | 0.07 | 0.02 | 0.08 |
| N | 208,167 | 207,961 | 208,167 | 207,961 |
| *State Fixed Effects?* | No | No | Yes | Yes |

Dependent Variable: gallons per 1000 miles.  Standard errors in parentheses clustered at the household level.

** - p value equal to 0.01 or less

Table 5.  Regional Variation in Tax Payments

| | |
|---|---|
| Middle Atlantic | -0.870 |
| | (0.565) |
| East North Central | -5.020** |
| | (0.570) |
| West North Central | -6.673** |
| | (0.630) |
| South Atlantic | -5.997** |
| | (0.555) |
| East South Central | -7.105** |
| | (0.850) |
| West South Central | -7.205** |
| | (0.556) |
| Mountain | -8.150** |
| | (0.629) |
| Pacific | -1.719** |
| | (0.555) |
| | |
| Observations | 112,774 |
| R-squared | 0.014 |

Dependent Variable: change in tax payments.  Regional coefficient estimates are all relative to New England. Standard errors in parentheses.
** $p<0.01$, * $p<0.05$

### Table 6. Rural/Urban Variation in Tax Payments

| | |
|---|---|
| Rural Indicator | -7.675*** |
| | (0.155) |
| | |
| Observations | 112,774 |
| R-squared | 0.21 |

Dependent Variable: change in tax payments.
Standard errors in parentheses.
*** p<0.01

### Table 7. Race Variation in Tax Payments

| | |
|---|---|
| Black or African American Household Head | -0.435 |
| | (0.268) |
| | |
| Observations | 112,774 |
| R-squared | 0.000 |

Dependent Variable: change in tax payments.
Standard errors in parentheses.
*** p<0.01

### Table 8. Hispanic Variation in Tax Payments

| | |
|---|---|
| Hispanic Household Head | -0.284 |
| | (0.261) |
| Observations | |
| R-squared | 112,774 |

Dependent Variable: change in tax payments.
Standard errors in parentheses.
*** p<0.01

Figure 1.  Fuel Economy Standards
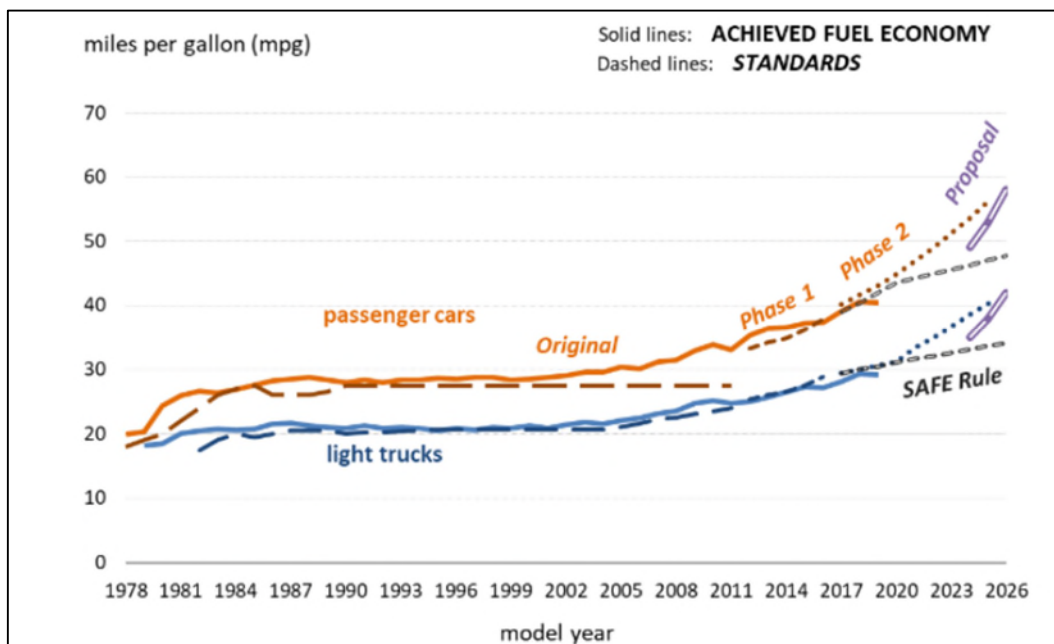


Source: Congressional Research Service (2021)

Figure 2.  Market Penetration of Electric and Hybrid Vehicles by Model Year
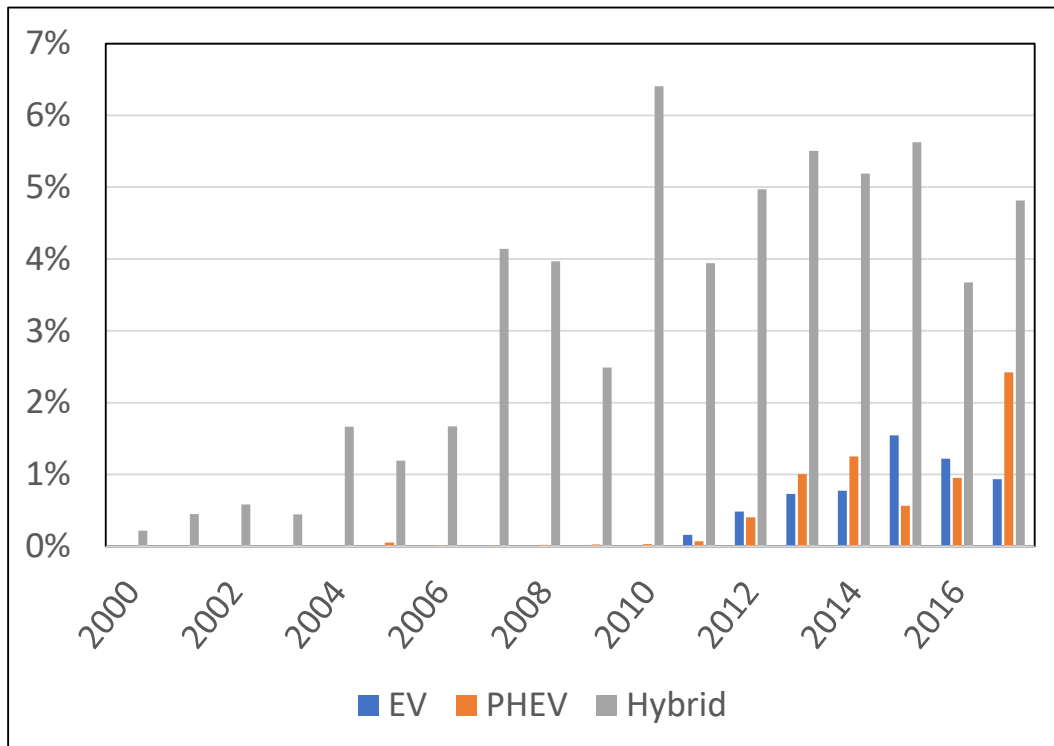


Source: Author's Calculation from 2017 NHTS Data

Figure 3.  Federal Motor Vehicle Fuel Revenue
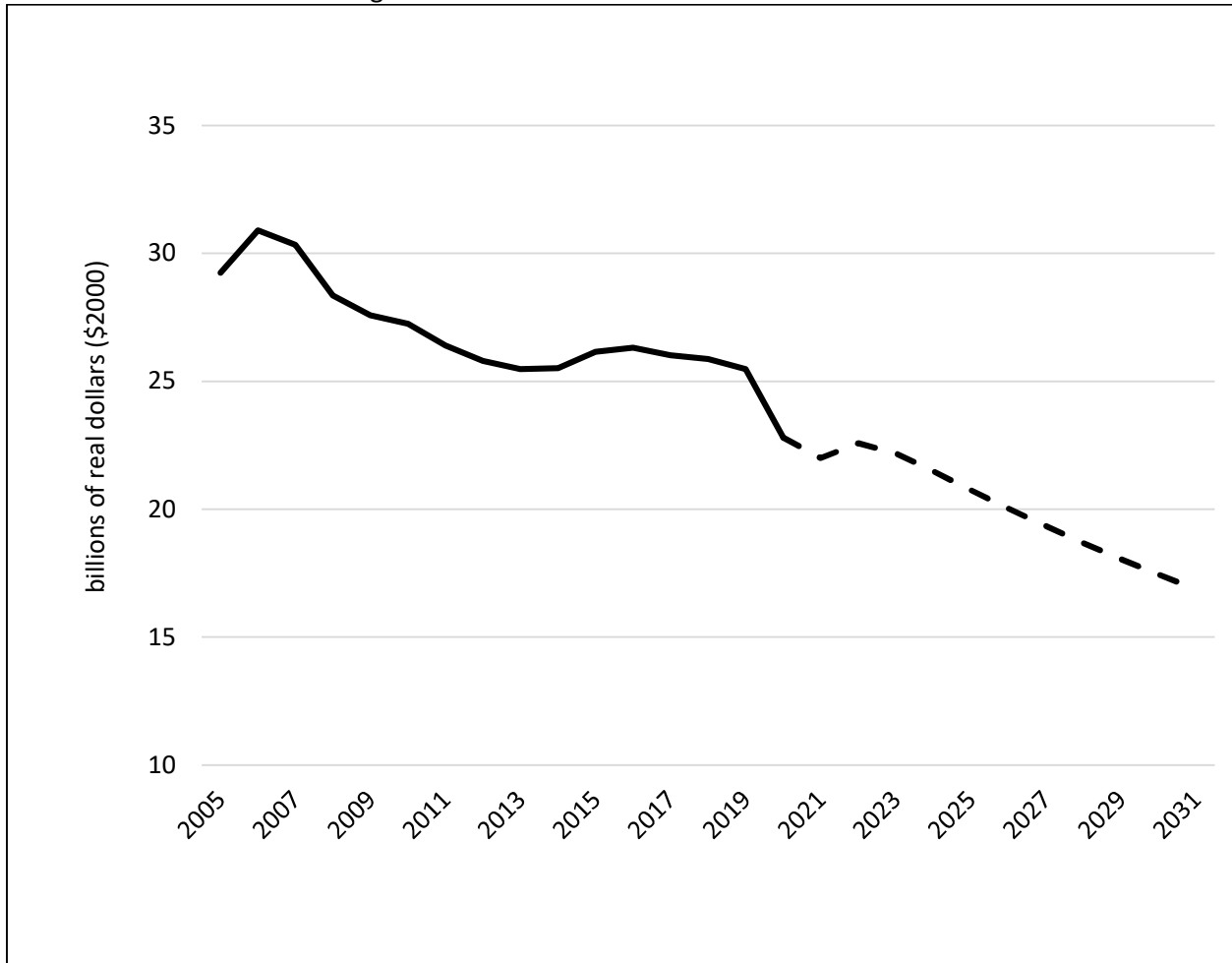
Historic data from IRS in solid line; revenue projections from CBO in dashed line.  Includes federal excise tax revenue from diesel, gasoline, and kerosene sales
Source: IRS Statistics of Income, CBO Revenue Projections, Table 5

Figure 4. Relation of the Change in the Average Tax Rate
and the Income Elasticity of Fuel Intensity



$\frac{dATR}{dt_M}$

$\eta_E < 0$

0

*Income*

$\frac{dATR}{dt_M}$

$\eta_E > 0$

0
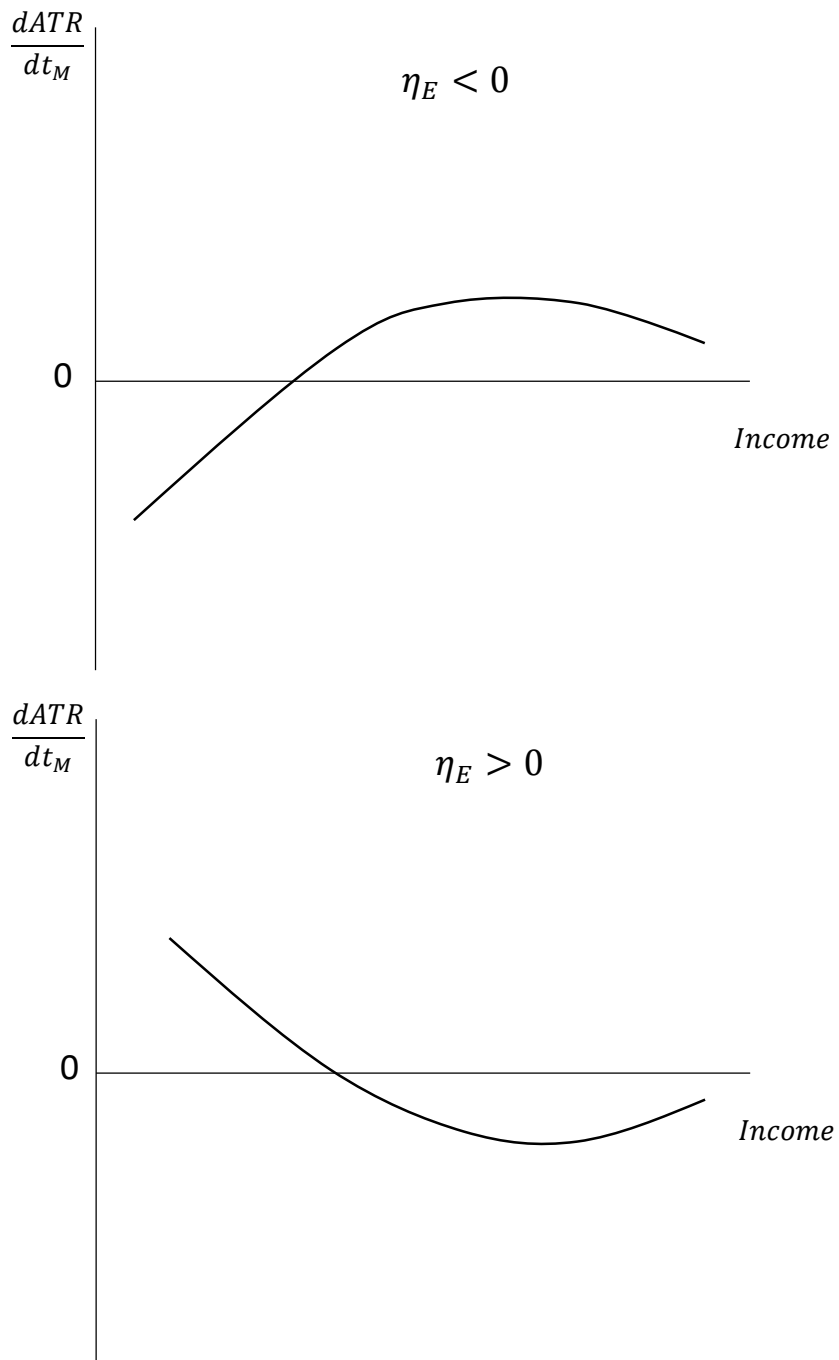
*Income*

Figure 5. Impact of Household Income on Fuel Intensity
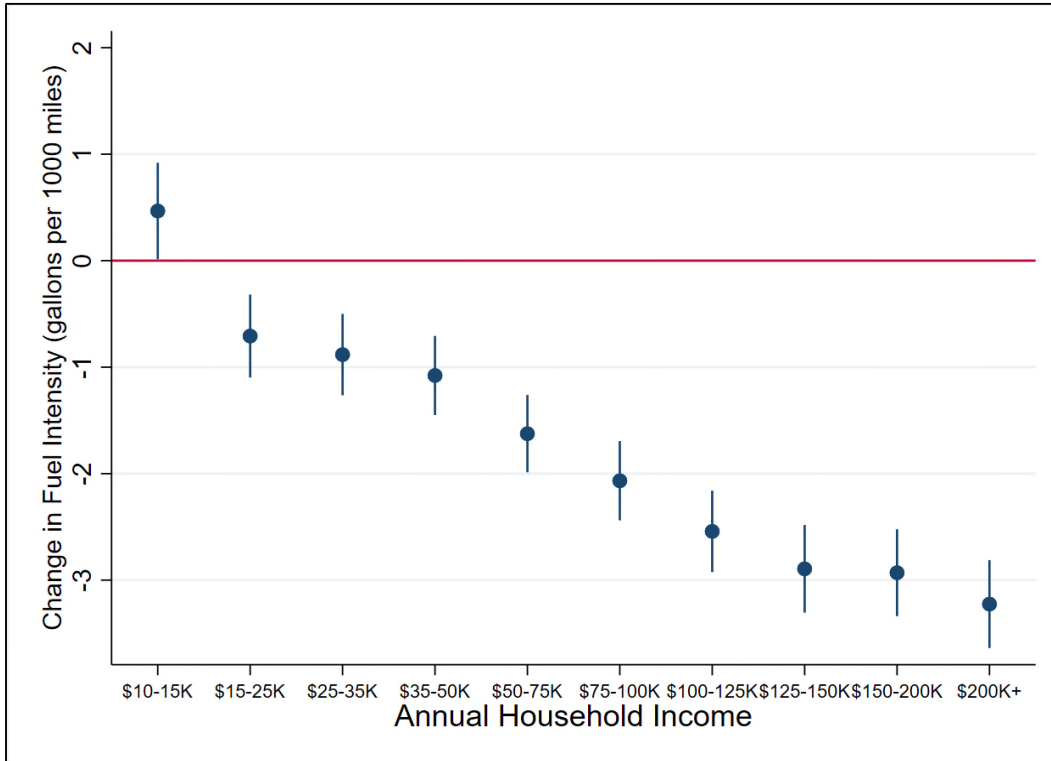


Lowest income group (income less than $10,000). Regression includes other covariates included in Table 4, column (4). 95 percent confidence intervals graphed. Standard errors clustered at the household level.

Figure 6. Impact of Household Income on Change in Tax Payments
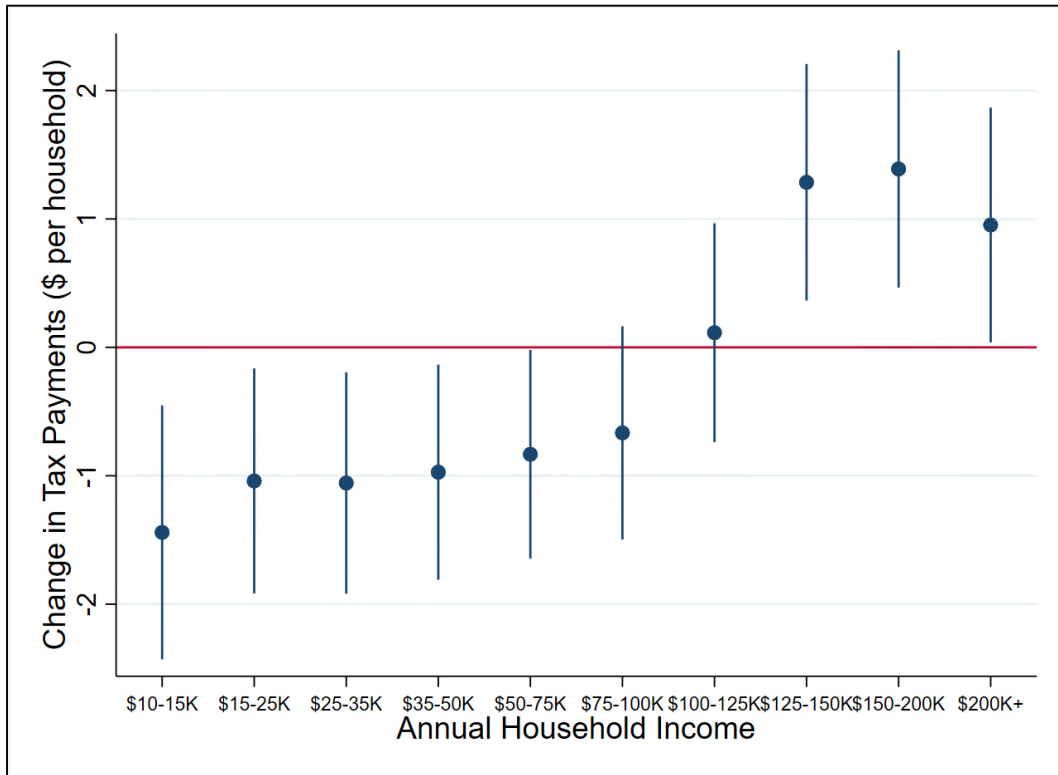


Lowest income group (less than $10,000) omitted. 95 percent confidence intervals graphed.
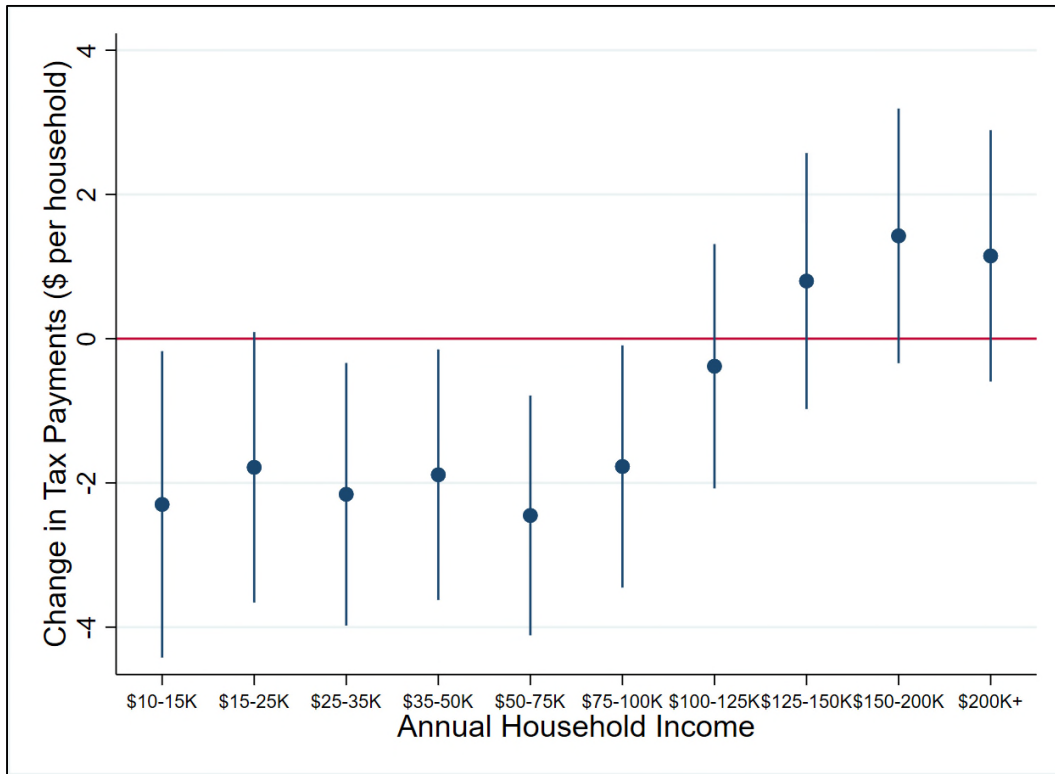
Figure 7.  Percentage of Households with Tax Payment Increase
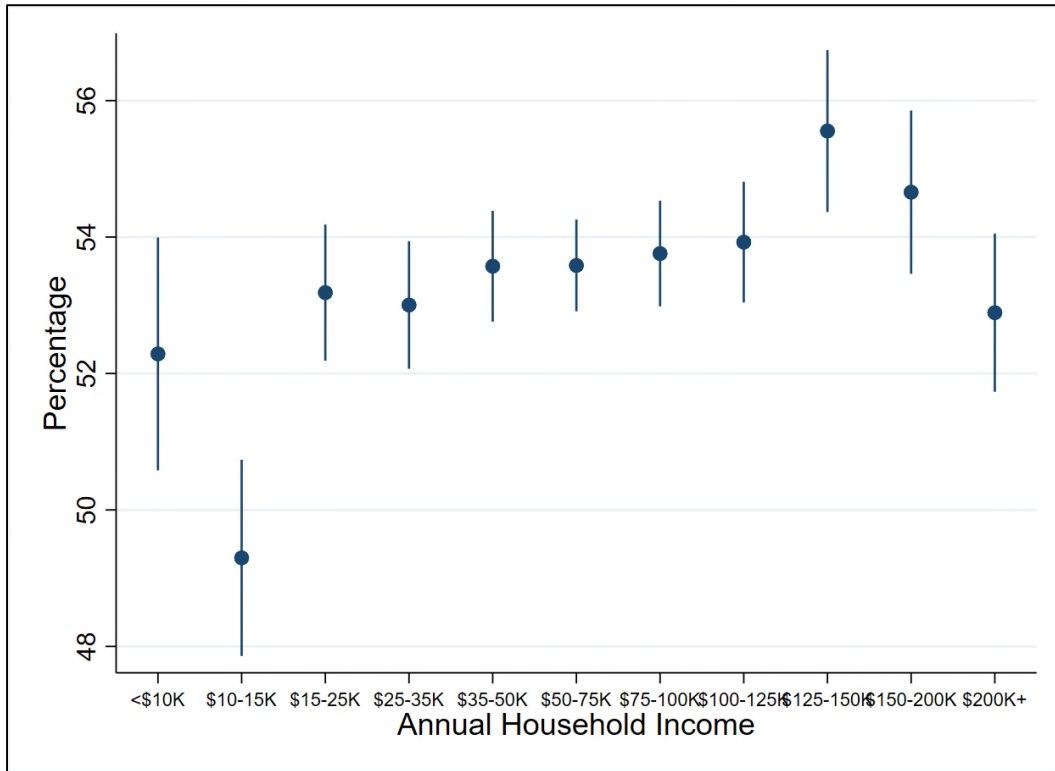


95 percent confidence intervals graphed.

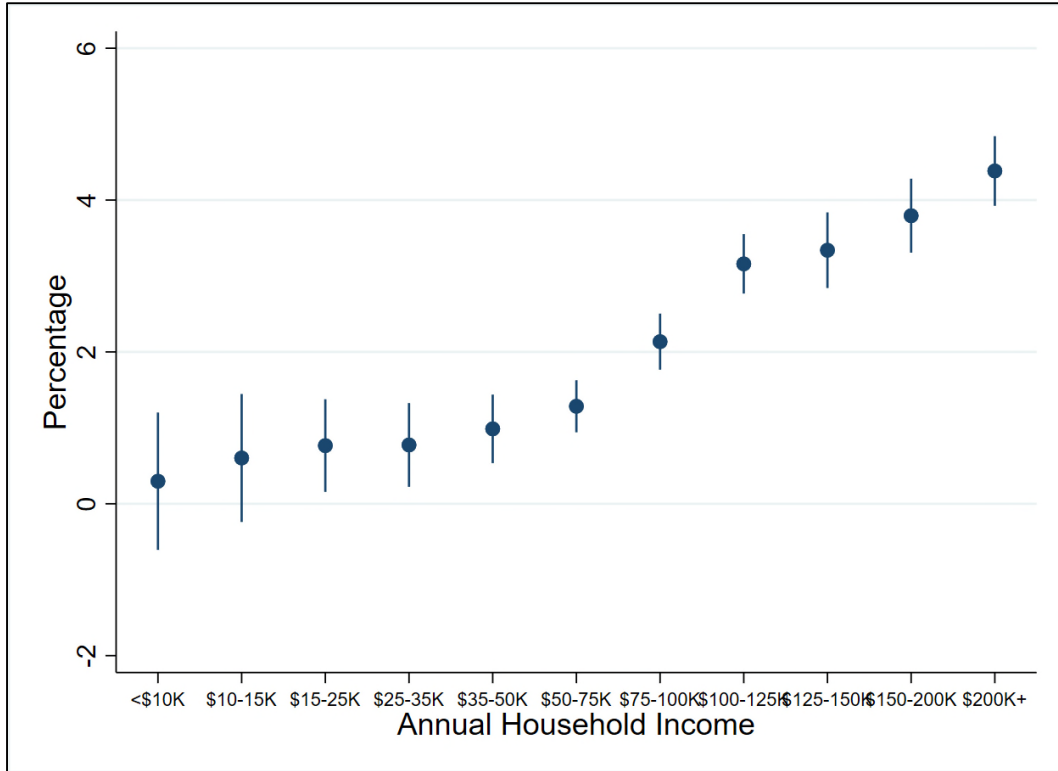Figure 8:  Percentage of Households with Tax Increase of $50 or More
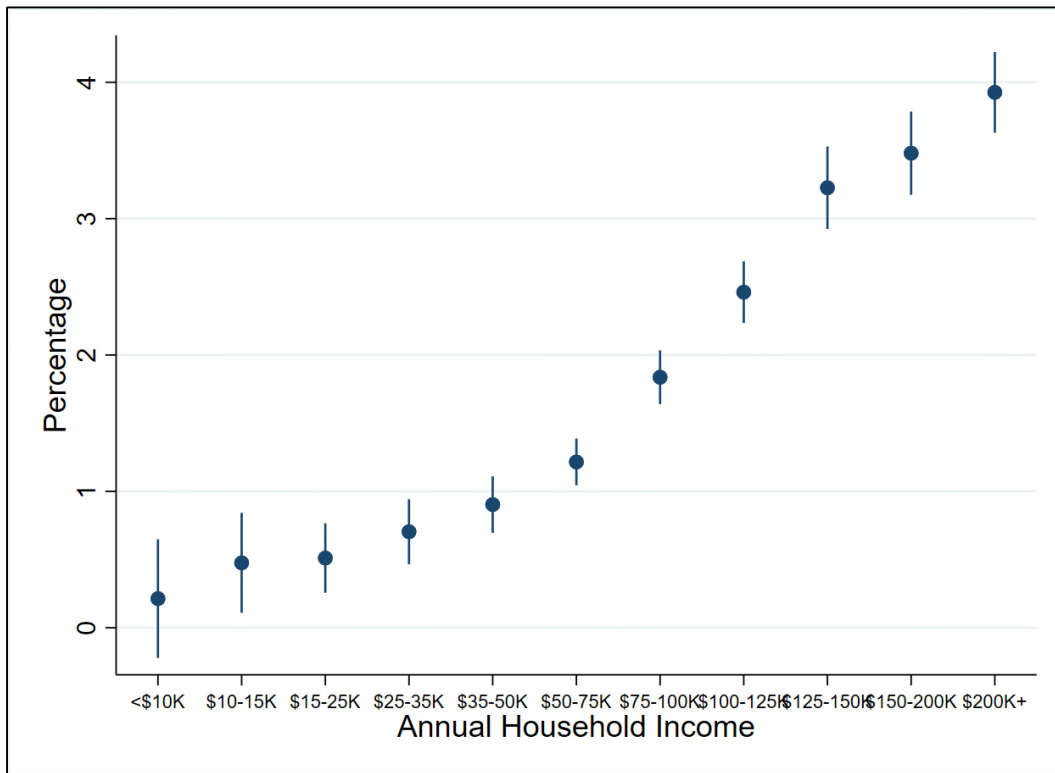


95 percent confidence intervals graphed.

Figure 9. Change in Tax Payments: Lifetime Income Analysis



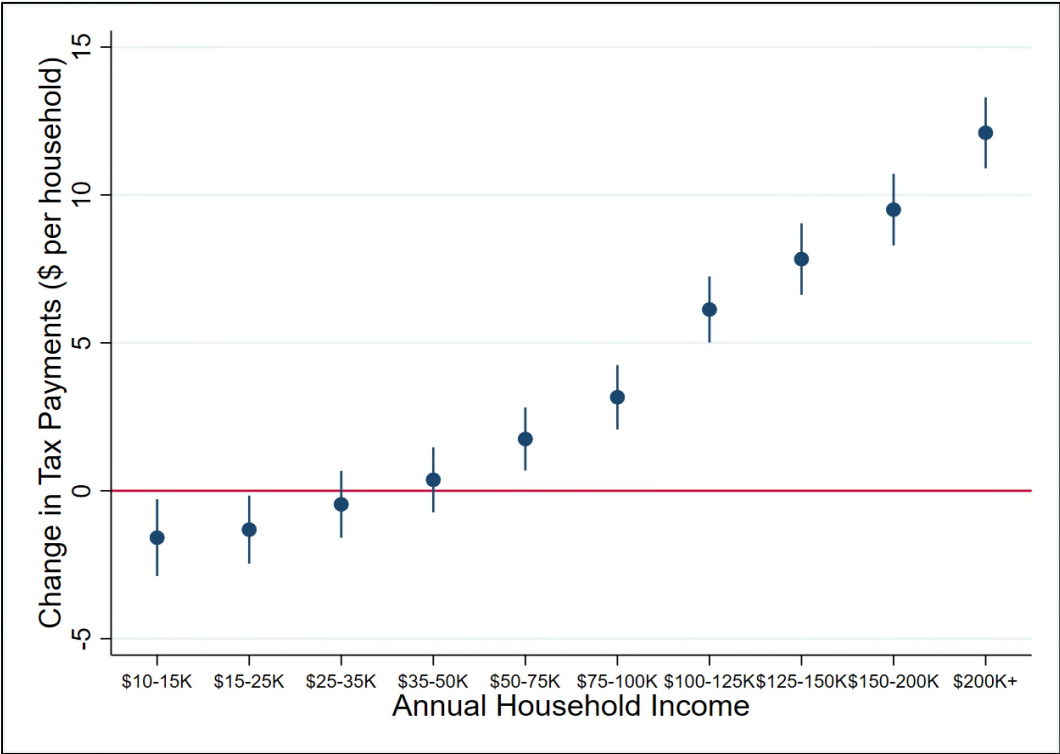Lowest income group (less than $10,000) omitted. 95 percent confidence intervals graphed.

Figure 10. Percentage of Households with Tax Increase of $50 or More: Lifetime Income Analysis



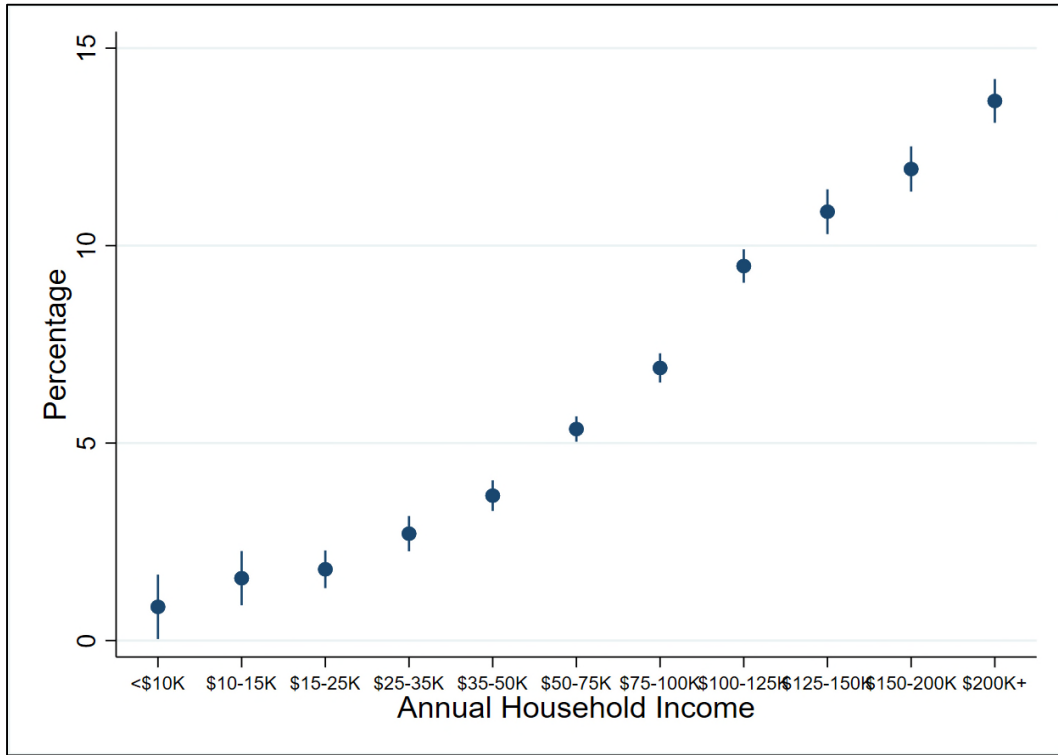95 percent confidence intervals graphed.

Figure 11.  Change in Tax Payments: Simulation with Higher Fuel Economy and
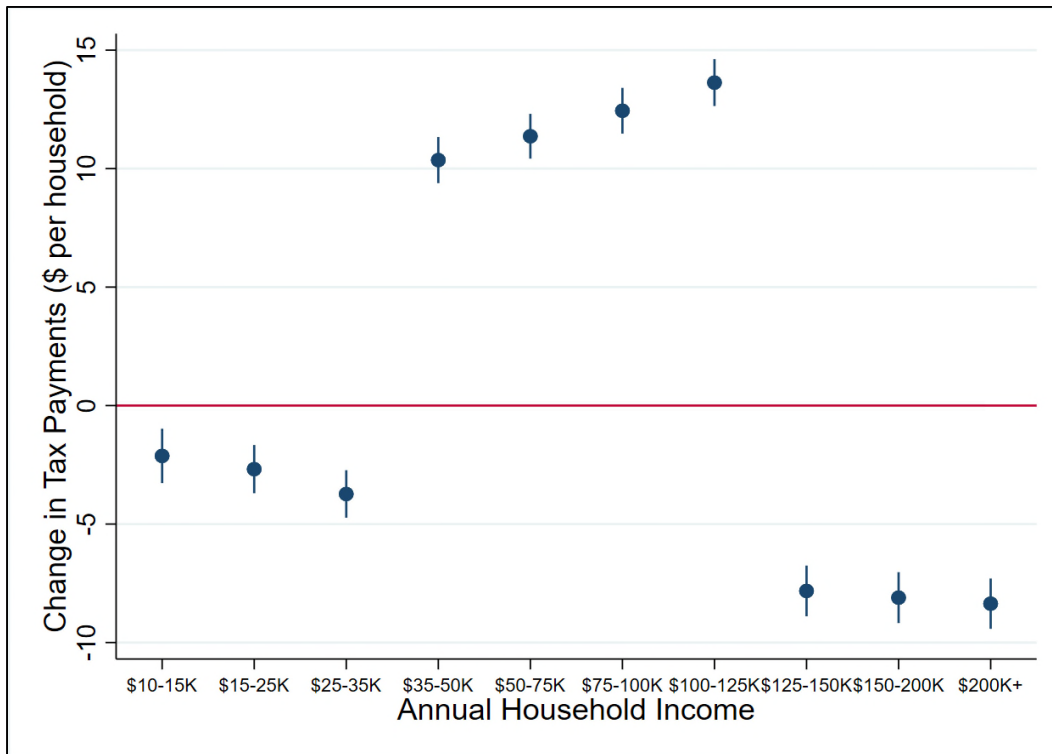Market Penetration of EVs and PHEVs: Version 1



Lowest income group (less than $10,000) omitted.  95 percent confidence intervals graphed.

Figure 12. Percentage of Households with Tax Increase of $50 or More: Version 1



95 percent confidence intervals graphed.

Figure 13.  Change in Tax Payments: Simulation with Higher Fuel Economy and Market Penetration of EVs and PHEVs: Version 2



Lowest income group (less than $10,000) omitted.  95 percent confidence intervals graphed.

Figure 14.  Percentage of Households with Tax Increase of $50 or More: Version 2
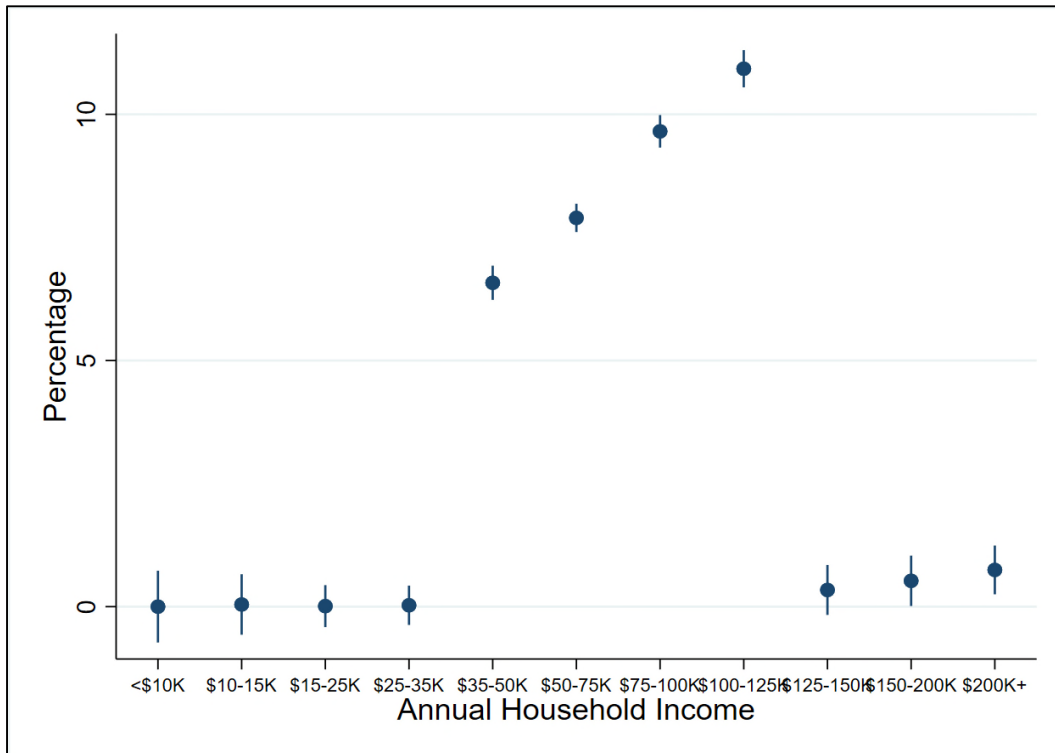


95 percent confidence intervals graphed.

**Appendix**

*1.    Measuring the Welfare Change*

The VMT tax shift policy changes the price of driving per mile $(p_M)$ and the price of fuel $(p_F)$. The

change in welfare (as measured by equivalent variation) for this policy is

$$\Delta W \equiv EV = e(p_M^0, p_F^0, u^1) - e(p_M^1, p_F^1, u^1)$$

where $e(\cdot)$ is the expenditure function at given prices and utility and the superscript 0 indicates pre-

policy prices and superscript 1 indicates post-policy prices and utility. Ignoring non-driving-related

spending, the expenditure function is

$$e(p_M, p_F, u) = p_M M(p_M, u) + p_E E(p_F, u)$$

where $M$ and $E$ are compensated demands and $p_E$ is the price of fuel intensity (the reciprocal of the

price of fuel economy). Since $p_M = p_F E + t_M$, and $F = E \cdot M$,

$$e(p_M, p_F, u) = p_F F(p_M, u) + t_M M(p_M, u) + p_E E(p_F, u).$$

Rewrite this expression as

$$\Delta W = e(p_M^0, p_F^0, u^1) - e(p_M^1, p_F^0, u^1) + e(p_M^1, p_F^0, u^1) - e(p_M^1, p_F^1, u^1).$$

By the Envelope theorem,

$$\frac{\partial e(p_M, p_F, u)}{\partial t_M} = M(p_M, u)$$

and

$$\frac{\partial e(p_M, p_F, u)}{\partial p_F} = F(p_F, t_M, u).$$

Therefore

$$\Delta W = \int_{t_M^1}^{t_M^0} M^c(p_M, p_F^0, u^1) dp_M + \int_{p_F^1}^{p_F^0} F^c(t_M^1, p_F, u^1) dp_F.$$

We can approximate the areas under these compensated demand curves with areas under the

Marshallian demands. Again, this approximation should be reasonable so long as income effects are not

too large (Willig, 1976).

$$\Delta W \cong \int_{t_M^1}^{t_M^0} M(p_M, p_F^0, Y)dp_M + \int_{p_F^1}^{p_F^0} F(t_M^1, p_F, Y)dp_F.$$

Taking a linear approximation to this yields the further approximation

$$\Delta W_i = -\left(\frac{M_{0i} + M_{1i}}{2}\right)dt_M - \left(\frac{F_{0i} + F_{1i}}{2}\right)dp_F.$$

Assuming small impacts on driving and fuel consumption[28], this becomes

$$\Delta W_i = -M_i t_M - F_i dp_F.$$

*2.       Estimates of Demand Changes for VMT and Fuel Efficiency from Tax Swap*

The change in demand for VMT is equal to

$$dM_i = \frac{\partial M_i}{\partial p_M}dp_M = \frac{\partial M_i}{\partial p_M}\{E_i dp_F + dt_M\}$$

and the change in demand for fuel efficiency equals

$$dE_i = \frac{\partial E_i}{\partial p_F}dp_F.$$

Using elasticities from Small and van Dender (2007), we can calculate the change in short or long-run

demand for VMT and fuel intensity:

$$dlnM_i = \varepsilon_{M,p_M}dlnp_M = \varepsilon_{M,p_M}\left(\frac{E_i dp_F + dt_M}{E_{0i}p_{0F}}\right)$$

and

$$dlnE_i = \varepsilon_{E,p_F}dlnp_F.$$

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[28] The median percentage price change in the dataset for a 10 cent drop in the fuel excise tax rate is 4%. Given a long run price elasticity demand for fuel efficiency of .20, E falls by less than 1 percent. Similarly, the median percentage price change per mile is -.04. Given a long run price elasticity demand for VMT of -.22, miles driven rises by less than 1 percent and fuel consumption is essentially unchanged. See Appendix 2 for details.

Table A1 presents elasticity estimates from Small and Van Dender (2007).

| Table A1. Vehicle Price Elasticities | | |
|---|---|---|
| | Short Run | Long Run |
| $\varepsilon_{M,p_M}$ | -0.0452 | -.2221 |
| $\varepsilon_{E,p_F}$ | -0.0440 | -0.2047 |
| Source: Small and Van Dender (2007), Table 5 | | |

From a static (no behavioral change) model, the VMT tax rate that offsets a 10 cent per gallon decrease in the motor fuel excise tax is 0.486 cents per mile. Assuming average fuel intensity in the 2017 NHTS data set along with the average price of gasoline, the long run changes in fuel intensity and VMT is less than one percent.

*3.      Reduced Form Income Elasticity of Demand for VMT*

Small and Van Dender (2007) estimate a three equation system of VMT, vehicle ownership, and fuel efficiency (inverse). They find a SR income elasticity of VMT ($\eta_M$) of 0.11 and a LR estimate of 0.53. This is conditional on efficiency and number of vehicles owned. Following their rebound approach, I can combine the M and V equations to get a reduced form VMT equation that incorporates the number of vehicles chosen. The reduced form SR income elasticity is

$$\eta_{\widehat{M}} = \frac{\varepsilon_{M,V}\eta_V + \eta_M}{1 - \varepsilon_{M,V}\varepsilon_{V,M}} = 0.1125.$$

To get the LR elasticity, I need to divide each elasticity by one minus the lagged dependent variable coefficient for the relevant regression. The LR elasticity estimate is 0.5849.

*4.      Rebound*

For the simulation where we assume a major increase in fuel economy, it is likely that the lower price of driving per mile (due to higher fuel efficiency) will lead to more driving. This is the rebound effect. I incorporate this rebound effect by increasing vehicle miles traveled for all cars. I assume a 10 percent rebound effect based on a recent review of the literature by Gillingham (2018).

Let $\phi$ represent the percentage increase in fuel economy. Let 0 indicate the period before an increase in fuel economy and 1 the period after the increase. Absent a rebound effect, gasoline consumption ($F$) after the increase in fuel economy would be

$$\hat{F}_1 = \frac{M_0}{\psi_1} = \frac{M_0}{\psi_0(1+\phi)} = \frac{F_0}{1+\phi},$$

where the hat indicates the counterfactual fuel consumption without rebound, $M$ is vehicle miles traveled, and $\psi$ is fuel economy (miles per gallon). The projected fuel saving (absent rebound) is

$$F_0 - \hat{F}_1 = F_0\left(1 - \frac{1}{1+\phi}\right) = F_0\left(\frac{\phi}{1+\phi}\right).$$

With a rebound effect of $\rho$, the actual fuel savings will be

$$F_0 - F_1 = (1-\rho)(F_0 - \hat{F}_1) = (1-\rho)F_0\left(\frac{\phi}{1+\phi}\right),$$

and actual fuel consumption is

$$F_1 = F_0\left(1 - (1-\rho)\left(\frac{\phi}{1+\phi}\right)\right).$$

Actual driving is

$$M_1 = \psi_1 F_1 = \psi_1 F_0\left(1 - (1-\rho)\left(\frac{\phi}{1+\phi}\right)\right) = (1+\phi)\psi_0 F_0\left(1 - (1-\rho)\left(\frac{\phi}{1+\phi}\right)\right)$$

$$= M_0(1 + \phi - (1-\rho)\phi) = M_0(1 + \rho\phi).$$

Assuming a rebound factor of 10 percent and a 40 percent increase in fuel economy, driving would increase by 4 percent.

*5.    NHTS Data Details*

The National Household Travel Survey (NHTS) is a comprehensive data set of information about travel behavior for US residents in the entire country. Conducted by the Federal Highway Administration, the

survey has been conducted 8 times with the most recent survey year being 2017. I use the 2017 data for this study. I discuss the construction of key variables here.

*Vehicle Miles Traveled*: An estimate of annual miles traveled by each vehicle in the data set is constructed through a multi-step process. It starts with the odometer readings but makes adjustments for missed readings, purchase of vehicle mid-year, and other tests for bad readings. For most vehicles, the unadjusted odometer reading is the source of miles traveled for the vehicle.

*Fuel Economy Ratings and Fuel Intensity:* Following a methodology from the Energy Information Administration (EIA), the 2017 NHTS adjusts the EPA fuel economy ratings used for the Corporate Average Fuel Economy (CAFE) standards by accounting for actual driving conditions as opposed to test lab conditions. EIA adjusts the EPA measures down by roughly 15 percent to account for differences between actual driving and testing lab performance. They then make a further adjustment to account for vehicle driving patterns (e.g. short trips use more fuel) and seasonal weather conditions by location.[29] I construct a fuel intensity measure as gallons per 1000 miles driven where the miles per gallon measure is the NHTS reported fuel economy rating. For EVs, the NHTS sets the fuel economy rating to the miles per gallon equivalent, the amount of electricity equivalent to a gallon of gasoline. Given my focus on a VMT-gas tax swap, I set the fuel intensity measure for EV's equal to zero. For plug-in hybrids, two fuel economy measures are reported. One measure is the miles per gallon when operating only on gasoline. The other is a miles per gallon equivalent as with EVs. Since I don't know what proportion of driving is done on battery as opposed to gasoline, I carried out the analysis assuming either 0 or 100 percent battery use to bracket results. In the paper, I provide results assuming 100 percent battery use (hence, zero gallons per 1000 miles traveled). Results are not appreciably changed by assuming 0 percent battery use.

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[29] The methodology is described in greater detail in the 2009 NHTS documentation: https://nhts.ornl.gov/2009/pub/DerivedAddedVariables2009.pdf.

*Fuel Consumption:* The NHTS does not measure actual fuel consumption.  Rather it estimates fuel

consumption for each vehicle as annual miles driven divided by the fuel economy rating.  I compute fuel

consumption as annual miles traveled times my fuel intensity variable described above.  Thus, while the

NHTS reports positive gasoline consumption for EVs, I set their consumption to zero (as well as

consumption for PHEVs in one scenario as discussed above).

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