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Growing Electric Vehicle Adoption: Implications for Infrastructure Maintenance and the Tax Burden on Families of Different Funding Policies

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Abstract: This paper examines the distribution of the gasoline tax burden in the presence of increased electric vehicle adoption. Automobile manufacturers and even some states have ambitious goals to phase out gas-powered cars. However, in spite of these plans, the primary source of automobile infrastructure funding in the United States continues to be gasoline taxes. Less demand for gasoline threatens this source of revenue for maintaining roads and further shifts the burden of the tax toward consumers who can't afford the still relatively expensive electric vehicles. The analysis here illustrates the fundamental regressivity of the gasoline tax, then simulates the distributional impact of replacing the current gas tax with a lump-sum/income tax with different assessment rules designed to replace revenue generated by the gasoline tax. For example, many states are considering switching from a gas tax to a tax based on miles driven to shore up infrastructure funding. Alternatively, the required revenue could be paid equally across income quartiles or assessed based on income. Not surprisingly, the degree of regressivity of replacing the gasoline tax depends on how the tax is assessed across the income distribution.

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Key words: gas tax, incidence, consumer demand system, income distribution, equity

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I. Introduction

In January 2021, General Motors announced that it plans to completely phase out cars using internal combustion (gasoline) engines (Eisenstein 2021) by 2035, and they aren't alone. Volkswagen, Nissan, Ford, Daimler (Mercedes-Benz), and Honda all have similar goals to be carbon neutral by some self-imposed deadline (Mills 2021). Additionally, California announced in August 2022 that no sale of new gas-powered cars will be allowed after 2035 (Hoeven 2022). Then the state upped the ante by announcing in March 2023 that half of all heavy trucks sold in the state must also be all-electric by 2035 (Davenport 2023). This shift has potential implications for both infrastructure funding (paid for by gasoline taxes) and the distribution of the tax burden, as plug-in electrical vehicles (PEVs) are still unaffordable for many lower-income families.[1] This paper illustrates the magnitude of this potential shifting tax burden and what it would look like under various scenarios of replacing the gasoline tax with an alternative designed to replace a desired amount of revenue for infrastructure maintenance.

In spite of sales of electric vehicles quadrupling since 2011 (see Figure 1), PEVs constituted only 5 percent of cars sold in 2021 (Paoli, Dasgupta, and McBain 2022). The share of sales more than doubled between 2020 and 2021, whereas sales of other non-electric light-duty vehicles grew only three percent (Minos 2022; also see USFacts.org 2020). Additionally, all major car manufacturers plan to offer by the end of 2024 at least one PEV in their fleet (see Bartlett and Preston 2023).

[Figure 1 about here]

[1] We will use the term Plug-in Electric Vehicle (PEV) to encompass all-electricity/Battery Electric Vehicles (BEV), such as Tesla brand cars or the Nissan Leaf, and also Plug-in Hybrid Electric Vehicles (PHEV), such as the Toyota Prius or Chevy Volt.

Assuming each purchase of a PEV displaces a gas-powered vehicle (at least partially), this growth necessarily means less consumption of gasoline, which, of course, is desirable from an environmental perspective, but not nearly enough by some accounts to achieve environmental goals (Bellan 2018). This paper will not delve into the environmental implications of the growth in electrical vehicle adoption, but is concerned with how this changing consumption pattern is expected to impact the distributional burden of the national gasoline tax and how adoption of an alternative infrastructure funding strategy affects consumer surplus across the income distribution.[2]

In January 2023, the national tax for gasoline was 18.4 cents per gallon (American Petroleum Institute 2022) and has remained constant for decades (Shaper 2018). In FY2020, nearly 22 billion dollars was collected in federal highway tax revenue (Federal Highway Administration 2021, Table FE-10). As this tax is a flat percentage, the tax is naturally regressive at face value (i.e., poorer households who spend the same amount of money on gasoline as a richer household pay a larger share of their income in gasoline taxes). Since PEVs are typically purchased by wealthier households, the burden of the gasoline tax will increasingly fall on poorer households as sales of PEVs increase.[3]

This paper estimates a consumer demand system (based on West and Williams 2007) taking into consideration the consumption of gasoline. Using these results, the distributional implications of increases in the gasoline tax can be simulated. The introduction of electric vehicles into the consumer's expenditure set is simulated by assuming an increasing share of families adopting PEVs as income increases. In addition to simply updating the elasticity of

[2] Vega-Perkins, Newell, and Keoleian (2023) investigate the geographic distribution of the energy burden from electric vehicle adoption.
[3] See Chakraborty et al. (2019).

demand for gasoline, this paper makes the following contributions: (1) it assesses how the growth in PEV consumption is expected to impact households' price elasticity of demand for gasoline and the implications for the degree of regressivity of the tax, and (2) it simulates changes in consumer surplus from the replacement of the gasoline tax with different tax structures designed to generate the same (or greater) revenue as the current gasoline tax. How the alternative tax is assessed across the income distribution has implications for its regressivity.

One form of the alternative tax investigated is designed to simulate a proposal being considered by several states to charge drivers based on miles driven rather than on gasoline purchased (see Povich 2022). This shift is designed so that electric vehicle adopters would continue to contribute to the maintenance of roads even though they are no longer consuming gasoline. From installing devices in vehicles to record miles driven to voluntary reporting of miles, states haven't settled on a final form these laws would take. While we are able to only rely on a proxy for miles driven, this is the first paper, as far as we can tell, that investigates the implication of this policy shift, and others, for consumer welfare and for the regressivity of different infrastructure funding strategies.

II. Background

The gasoline tax is a policy instrument that both supports local and national infrastructure as well as internalizes some negative externalities from gasoline consumption. Because taxes change the price of gasoline directly and are, therefore, a market based approach influencing consumers' behavior, taxation is generally preferred on efficiency grounds to other policy instruments such as mandated fuel standards (Davis and Knittel 2019). Also, since gas taxes, or, more generally, taxes on oil, give consumers more flexibility in their choice set and have the potential of affecting consumption decisions beyond merely vehicle use, they are also preferred from a welfare perspective (Anderson et al. 2011).

However, since gasoline taxes are levied as a flat rate percentage based on the purchase, they are considered a regressive tax. In other words, for the same type of car and same miles driven, a poor household would pay more in taxes as a share of their household income than a rich household.[4] Even if the government has no distributional objectives and is concerned solely with efficiency, and wants to raise a certain amount of revenue through taxes, it is well-accepted that individuals will most likely be better off if the revenue is generated through an income tax/lump-sum tax rather than through an excise (commodity/ad valorem/sales) tax, because of the dead-weight loss generated by the excise tax.

This paper is not concerned with the environmental costs or benefits of electric vehicles making up a larger share of miles driven (on that point, see Holland et al. 2016). Nor is this paper concerned with what the optimal level of gasoline tax would be in order to continue funding infrastructure projects in a world using less gasoline (on that point, see Tscharaktschiew 2015). This paper *is* concerned with estimating the incidence of growing regressivity of the gasoline tax in a world where the share of gasoline-powered vehicles is declining and whose ownership is increasingly dominated by lower-income households. Chakraborty et al. (2019) reports that 88% of electric vehicle owners in a California survey had incomes higher than the median for the state. Additionally, Tal and Nicholas (2016) find that Most buyers of electric vehicles in 2014/2015 across multiple states had household incomes of $50,000 or higher (see Figure 2).

[Figure 2 about here]

[4] For example, Bauer, Hsu, and Lutsey (2021) estimate that household with annual income less than $25,000 spend about 10 percent of their income on vehicle fuel, whereas a household with annual income greater than $150,000 spends less than one percent on fuel.

These findings are unsurprising since PEVs are often between 20 and 90 percent more expensive than comparable internal combustive engines (Kelley Blue Book 2022).

As adoption of PEVs becomes more widespread, states will have to adopt funding strategies that don't depend on gasoline purchases. The Congressional Budget office projects that with no change in funding strategy, the federal Highway Trust Fund will face a $140 billion deficit by the year 2031 (Congressional Budget Office 2021). Some alternative strategies being considered by states will be discussed below.

III. Methodology

There are several steps to the analysis in this paper. First is the estimation of a system of household demand equations. Using those estimates, a measure of tax incidence from an increase in the national gas tax can then be obtained. Finally, by simulating the change in incidence as electric vehicle consumption increases (or, rather, consumption of gasoline decreases) we can estimate how the growth in PEV purchases changes the gasoline tax incidence across household incomes levels. The implication of replacing the gasoline tax with an alternative based on equal share contributions, miles driven, or progressive assessment based on household income is then simulated.

A. Demand System

Following West and Williams (2004), we estimate a linear "Almost Ideal Demand System" (AIDS), made popular by Deaton and Muellbauer (1980). The AIDS is a first-order approximation to any demand system and assumes that observed consumption behavior is the result of rational decision making by a representative consumer that allows aggregation across consumers of individual/household decisions. Re-parameterization of the familiar Deaton and

Muellbauer (1980) expenditure share equations leads to the following estimating equations:[5]

$$s_{ih} = \alpha_i + \sum_j \gamma_{ij} \ln(p_j) + \beta_i[\ln(y_h) - \ln a(\boldsymbol{p})] + \lambda_i \left\{\frac{[\ln(y_h) - \ln a(\boldsymbol{p})]^2}{b(\boldsymbol{p})}\right\} + \sum_k \eta_{ik} Z_{hk} + u_{hi}, \quad (1)$$

where s_{ih} is household *h*'s expenditure share on good *i* with prices p, y_h is household real income, and Z_{hk} are taste shifters that reflect heterogeneity across households. The price aggregators $a(\boldsymbol{p})$ and $b(\boldsymbol{p})$ are parameterized as follows:

$$a(\boldsymbol{p}) = \alpha_0 + \sum_j \alpha_{ij} \ln(p_j) + \sum_j \sum_k \eta_{ik} Z_{hk} \ln(p_j) + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln(p_i) \ln(p_j) \quad (2)$$

$$b(\boldsymbol{p}) = \exp \sum_j \beta_{ij} \ln(p_j) \quad (3)$$

Demand equations for three goods are considered: gasoline, leisure, and all other expenditures. Since there is not a separate share equation specified for electricity, simulating households' switch to electric vehicles amounts to letting the value of their expenditure share on gasoline transfer to the "other good," which includes electricity. We take this flexible approach because it is not known what the exact gasoline-to-electricity trade-off is.

Since all expenditure shares must sum to one, the following requirements must be met (and are imposed by the estimation procedure): α_i the expenditure share's intercepts, sum to 1; all γ_{ij} sum to zero; all β_i sum to zero; and $\gamma_{ij} = \gamma_{ji}$ (Slutsky Symmetry). Other controls in the demand system (accounting for family and location heterogeneity) include standard measure of age, race, educational outcomes, number of children, real non-labor income, propensity to consume gasoline (calculated by estimating a choice model of gasoline), and state and year fixed effects.

Individual net wages (i.e., the price of leisure) and a propensity for a household to consume gasoline are not directly available in the CEX. Therefore, before estimating the share

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[5] See Caro et al. (2022) for further details of the parameterization based on Ray (1983) and for details of Stata procedure _quaidsce_ used to estimate the model (also see Poi 2012).

equations, net wages are estimated using a predictive mean matching strategy based on a Heckman selection model and a household's propensity to consume gasoline is estimated using a probit model.[6] These extra preliminary steps allow us to generalize the results to those not in the labor force and to those who aren't observed consuming gasoline.

B. Tax Incidence

We estimate the impact of an increase in the national gas tax on families' consumer surplus as detailed in West and Williams (2004), with slight modifications. By focusing on consumer surplus, we can exploit the heterogeneous demand elasticities estimated from the system of demand equations described above, and takes the following form:

$$\Delta CS_h = \left\{\frac{\bar{x}_h^g \bar{p}_h^g}{\varepsilon_h^g + 1}\left[1 - \left(\frac{p_h^g}{\bar{p}_h^g}\right)^{\varepsilon_h^g + 1}\right]\right\} + T_h \tag{4}$$

where, ΔCS_h is the change in consumer surplus for the representative household in a given income quartile, ε_h^g is the estimated uncompensated own price elasticity of demand for gasoline, $\bar{x}_h^g$ is mean expenditure share of gasoline for household h before the price change, $\bar{p}_h^g$ is the mean price of gasoline before the price change, p_h^g is the mean price of gasoline after the price change. T_h is a lump-sum transfer that can be thought of the PEV tax credit that the U.S. Federal government has offered from time to time over the years (IRS 2022), a rebate to consumers to soften the blow of a gasoline price increase. We will use T_h (as a negative number) as a means to

[6] One might expect net wages and non-labor income to be endogenous since they may depend on hours of work and because the tax rate depends on income. West and Williams (2007) find little difference in their results with and without instrumenting for net wages and non-labor income. Additionally, gas prices may be endogenous to hours of work potentially boosted by an economic boom (which might also boost gas prices). Again, West and Williams (2007) found no appreciable difference in results instrumenting gas prices. Because each choice of instrument has its own set of issues, we present non-instrumented results here.

incorporate the replacement of the gasoline tax with an alternative lump-sum tax in various forms.

Using consumer surplus under the uncompensated demand curve (as our measure of tax incidence) comes with some caveats. A more rigorous consideration would be to calculate the dollar-equivalent impact corresponding to the area under the *compensated* demand curve. This takes into account the income elasticity of demand and cross-price elasticities, but necessitates evaluation of the indirect utility function. Perhaps most importantly for the analysis here, the calculation of consumer surplus in equation (4) assumes a constant elasticity along the demand curve, which is valid for only small changes in price. Considering the same large price increase that we do here, however, West and Williams (2004; 2007) find only a slight difference between their calculation of consumer surplus under the uncompensated demand curve and the dollar-equivalent (compensated demand) impact on utility. This modest difference is consistent with Hausman's (1981) conclusions, also for an example of gasoline consumption, that the uncompensated approximation "is adequate" to measure the compensated consumer surplus.[7] Also note that the price changes considered in the simulations below are the same for all policies compared, mitigating the bias in levels when considering only relative incidence of different policies.

IV. Data

In order to estimate a demand equation system, information on quantities and prices is needed. Household expenditures (quantities) on gasoline and other goods comes from the

[7] Although he also concludes that using the uncompensated approximation is far from accurate for measuring deadweight loss (which is not something we are trying to do here).

Consumer Expenditure Survey (CEX). The CEX is a nationally representative survey that contains detailed questions on household spending habits, income, hours worked, demographic, and geographic information for all individuals in the household. Households are surveyed up to four times. Following (West and Williams 2004; 2007), the sample is restricted to two types of households: households with one or two adults and their dependent children under 18 years old. Households from the 2016 through 2018 quarterly interview files are included. This time period is chosen since the first plug-in hybrid became available in 2010 and the costs of electric battery vehicles only started to significantly decrease in 2013.[8] Additionally, as seen in Figure 1, electric vehicle model options increased significantly between 2010 and 2016. Proprietary data on prices are obtained from the Council for Community and Economic Research Historical Cost of Living Index. This data set contains quarterly price information for the time period of this analysis.

Other data needed for this paper are the quarterly state unemployment rate and information on state gasoline tax rates, which are obtained via the Bureau of Labor Statistics and the Federation of Tax Administrators, respectively.[9] Unemployment data are important in modeling labor supply decisions, and gasoline tax information by each state over time is needed in order to correctly estimate the change in fuel price. However, state taxes do not vary much over 2016-2018, with only 15 states introducing changes to their state tax rate over this period.

Note that information on electric vehicle purchases is not contained in the CEX, nor does the data contain information on what kind of car a person owns. However, given the relatively low incidence of electric vehicle ownership during this period, it's assumed that most households

[8] See U.S. Department of Energy, https://www.energy.gov/timeline/timeline-history-electric-car, for a timeline of the electric car, which details major technological developments, such as development of adequate battery storage of electricity.
[9] Bureau of Labor Statistics (2020) -- https://www.bls.gov/lau/rdscnp16.htm -- and Federation of Tax Administrators (2020) -- https://www.taxadmin.org/current-tax-rates

are consuming gasoline powered cars. Electric vehicle purchasing decisions will be simulated by modifying household purchases of gasoline.

The sample of households is further restricted to include only adults between 18-64; these are the individuals who are most likely to be working and, thus, most likely to regularly make use of automobiles. Table 1 presents the summary characteristics of households. There are 10,692 one-adult household level observations and 14,390 two-adult household observations. Two-adult households are slightly younger, more educated, have higher incomes, have more children, work more hours, and consume more gasoline (but lower as a share of income).

V. Results

A. First Stage - Selection into the Labor Force and Propensity to Purchase Gas

In order for the estimated elasticities from the demand system to be generalizable to the population not observed working and/or not purchasing gasoline, we begin by imputing a wage for non-workers and by estimating the propensity to purchase gasoline to augment the observed purchases of gasoline.

Imputation of wages for nonworkers is done via predictive mean matching (see Little 1988; Morris, White, and Royston 2014). First, a Heckman selection model (Heckman 1979) is estimated to predict selectivity-corrected wages for all observations. Next, these predicted wages are used to randomly assign to each person with a missing wage the observed wage from the worker that is closest based on the Heckman predicted wage.

Tables A1 and A2 in Appendix A contain the selectivity-corrected wage equation parameter estimates for one- and two-adult (respectively) households. The parameter estimates are mostly as expected from the human capital literature.[10] Table A3 contains the parameter estimates for the estimation of the probability to purchase gasoline. These parameters are used to predict the household's propensity to purchase gasoline, which enters as an additional regressor in the consumption share equations to account for the inclusion of only families with positive gasoline consumption. The specification follows that of West and Williams (2004; 2007).[11]

B. Operationalizing PEV Adoption

For the simulations below, we need to impose some structure on what PEV adoption looks like across the income distribution. Based on current adoption patterns in the U.S., we assume that PEV adoption increases in income. It is assumed that 2%, 5%, 10%, and 20% of households in q1, q2, q3, and q4, respectively, replace their gasoline car with a PEV. The households who adopt are drawn randomly from the quartile and the elasticities reflect the average of 25 separate random draws. PEV adoption is modeled as consumption of gasoline within the household declining from its current level by 99 percent, which assumes a bias toward all-electric, vs. PHEV consumption.

C. Demand System Estimates - current gasoline consumption vs. PEV adoption

The expenditure share equation estimates (see equation 1) are found in Appendix Tables A4 (one-adult households) and A5 (two-adult households). Table 2 presents compensated and uncompensated elasticities of demand for gasoline, leisure, and other goods with respect to

[10] The negative selection term and education coefficients in the two-adult household estimates derive from the inclusion of spouse variables in the propensity to work equations.
[11] Estimation probit equation often yields non-intuitive results, such as the negative coefficient on the price of gasoline. However, there is a very strong negative relationship between the probability of consuming gas and gas price when other regressors are excluded.

changes in their own prices.[12] The model is estimated separately by income quartile and family type and the elasticities are evaluated at quartile means.

[Table 2 about here]

Uncompensated demand elasticities for gasoline range from -1.096 in the lowest quartile of income to -0.73 for the highest quartile for one-adult households, and from -0.99 in the lowest quartile to -0.47 highest quartile. West and Williams (2004) report a range of -0.74 to -0.18, averaged across one- and two-adult households. Like West and Williams (2004), there is very little difference between the compensated and uncompensated elasticities. And like West and Williams (2007), demand is more responsive among one-adult households than among two-adult households.

The weighted average uncompensated elasticity across quartiles of -0.72 is higher than has been found in the recent literature, which reports demand elasticities for gasoline at about -0.33 (for example, see Kilian and Zhou 2020; Levin, Lewis, and Wolak 2017; Coglianese et al. 2017). These studies don't report elasticities across the income distribution; the much higher elasticity estimated here for the lowest quartile may result in an over-exaggeration of the regressivity of the gasoline tax, but that exaggeration will be consistent across simulations so should not dramatically affect comparisons of different policy consideration. This pattern of elasticities is in direct contrast to Spiller, Stephens, and Chen (2017), who find higher income households are relatively more price sensitive to changes in gasoline prices. One potential explanation for this difference in results is that Spiller, Stephens, and Chen (2017) allow direct substitution between automobiles of different fuel efficiency, whereas, increased demand for

[12] Cross-price elasticities are not reported here for space consideration, but are available upon request. See Caro et al. (2022) for compensated and uncompensated elasticity formulas.

more fuel efficient (e.g., PEV) automobiles in the model estimated here enters through the "Other Good" demand.

Figure 3 illustrates these uncompensated demand elasticities for gasoline (averaged across one- and two-adult households) along with elasticities estimated under the assumption of PEV adoption of different levels by quartiles. Even though the within quartile elasticities (except for q4) are statistically significantly different from each another with 95 percent confidence there is very small practical difference (for this specific modelling of adoption) between the elasticities with and without PEV adoption.

[Figure 3 about here]

D. Estimating Tax Incidence

West and Williams (2007) estimate that the optimal tax that would account for infrastructure externalities generated by gasoline powered vehicles is $1.39 -- this would be a 600% increase from the current $0.184 tax. Using the estimated uncompensated demand elasticities, we calculate the incidence (change in consumer surplus, ΔCS_h) across the income distribution of an increase in the gasoline tax to $1.39. Table A6 reports the incidence based on elasticities estimated at current gasoline consumption and the incidence based on elasticities estimated under random PEV adoption by household type. Figure 4 illustrates these changes in consumer surplus, averaged across one- and two-adult households, from this price increase under current gasoline consumption and under adoption of PEVs.

[Figure 4 about here]

As has been found elsewhere, the gasoline tax is highly regressive. The loss in consumer surplus (ΔCS_h) from the tax increase as a share of total expenditures/income is much greater at the lower end of the income distribution. And in a world with adoption of electric vehicles, the gasoline tax is even more regressive. This is in large part due to the assumption that PEV adoption increases in income, making the higher gas tax fall that much more heavily on lower-income households.

VI. Replacing the Gasoline Tax with an Alternative

As of October 2022, many states (California and Oregon being among the earliest) have adopted or are considering adopting charging drivers based on miles driven rather than on gasoline purchased (see Povich 2022; Igleheart 2022). Other states charge annual registration fees, increasing in gas mileage or weight or number of miles that a car can run on electricity (Igleheart 2022). The realization among state legislatures is that as more and more people adopt electric vehicles, less and less revenue will be generated through the gasoline tax to fund vehicle infrastructure. However, states are grappling with issues related to individual privacy, environmental concerns about potentially dampening enthusiasm for electric vehicles, and adequate pricing to cover infrastructure maintenance. For example, Oregon is charging electric vehicle car owners 1.8 cents per mile (Igleheart 2022). This would generate approximately only 40 percent of what West and Williams (2007) estimate should be charged to account for infrastructure externalities.[13]

One question not yet addressed in the literature is how such a shift in tax policy would affect consumer surplus and whether such a tax structure is more or less regressive than the current gasoline tax. This section addresses these questions. Based on classic welfare comparison, any shift from a gasoline excise tax to an equal-yield lump-sum/income tax will

[13] A tax of $1.39/gallon would generate $0.046/mile driven in tax revenues (assuming an average of 30 miles per gallon). Oregon's tax of $0.018/mile driven is only 40 percent of that amount (0.018/0.046).

increase consumer welfare. Figure 5 illustrates this comparison of welfare under an excise tax and an income tax (an early articulation of this result can be found in Wald's 1945).

[Figure 5 about here]

In Figure 5, utility maximization point A is obtained with a price of gasoline of *P* and no taxation; the consumer consumes QZ gasoline. If the government imposes an excise tax of *t*, the price of gasoline raises to *P*+*t* and the consumer is only able to obtain the lower utility reflected by point B; the consumer pays XB for gasoline and the government gets KB in revenue from the tax. If the government, instead of imposing an excise tax, imposes an equal-yield (of revenue KB) tax on income (reflected by lower budget constraint YC at the no-tax price of gasoline *P*), consumer utility is higher at point C. What is theoretically clear from this classic illustration is that however the burden of a lump-sum alternative to the gasoline tax is distributed, consumers will be better off than with a gasoline excise tax.[14]

Taking the estimate from West and Williams (2007) of $1.39 as the gasoline tax that would be needed to pay for vehicle infrastructure externalities, we estimate the incidence of replacing the gasoline tax with an alternative designed to generate the same revenue that would be generated with a $1.39 gas tax. We consider three scenarios of spreading the tax bill across income quartiles -- one where the tax bill is spread equally, a second where the tax bill is paid based on miles driven (as many states are considering), and a third where the tax bill is assessed as an increasing function of income. This is where the T_h term in equation (4) comes in; before now, it has been set to zero. The following constraint is imposed on the three policy simulations:

[14] Harberger (1964) points out that lower excess burden from an income/lump-sum tax vs. an excise tax will not always be obvious (also see I. M. D. Little 1951), but that, "by and large the traditional preference [in terms of higher welfare] for direct over indirect taxation is justified" (p. 58).

$$T_h = \frac{\sum_h \bar{q}_h^g * \ \$1.39}{S_h}$$

where $\bar{q}_h^g$ is the mean quantity of gasoline consumed at current prices, and S_h takes one of three forms depending on the policy:

$S_h = H$, meaning that each household pays an equal share of the total revenue;

$S_h = m_h$, which is the share of miles driven by each household, proxied by household share of total gasoline expenditures at the current price ($\bar{q}_h^g \bar{p}_h^g / \sum_h \bar{q}_h^g \bar{p}_h^g$); and

$S_h = y_h / \sum_h y_h$, which is the household share of total income.

The amount of total revenue that would be generated by a $1.39 gasoline tax (at current gasoline consumption) is calculated. Then, the question becomes, how much is each household taxed to generate that level of revenue. The first option depicted above is for each household to contribute an equal share of the revenue. This flat tax structure of taxation will clearly be the most regressive, as the same amount paid by each household will constitute a much greater share of income among families in the lower quartiles.

The second option is to charge households based on miles driven (as is being explored by several state legislatures, see Povich 2022). This might also be thought of as a use tax. We don't know from the consumption data how many miles are driven by each household, so the amount of tax will be based on the share of total gasoline purchased by each household. It's unclear how regressive this option will be. Kneebone and Holmes (2015) find that low-income individuals and minorities have low "job proximity," meaning that they have to travel further to find appropriate jobs, suggesting the use tax would be regressive, hitting harder on the low end of the income distribution. Based on averages by quartile in Table 1, gasoline expenditures increase with income for both one- and two-adult households, meaning that higher income households would be assessed a greater share of the tax. However, as a share of total expenditures, gasoline is an increasing share for one-adult households but much flatter across incomes for two-adult households. This suggests that the degree of regressivity could be greater for one-adult vs. two-adult households.

The third option is expected to be the least regressive. This option assesses the alternative tax based on the share of total expenditures represented by each household. So, as higher-income households represent a greater share of total aggregate expenditures, they will be assessed a higher tax than the lower income households, and, therefore, is a progressive tax.

Figure 6 illustrates the change in consumer surplus by quartile from each of these alternatives to the gasoline tax. These are weighted average incidences across one- and two-adult households. The incidence of the gasoline tax under PEV adoption in Figure 4 is also included on the graph for comparison. All policy options that replace the gasoline tax with a lump-sum tax (raising the same revenue) result in smaller losses in consumer surplus, as was illustrated in Figure 5.

[Figure 6 about here]

As expected, the option that distributes the total tax equally across household is most regressive, with households in all quartiles losing consumer surplus but by decreasing amounts in income. This option, while producing lower losses in consumer surplus than the gasoline tax, is more regressive than the gasoline tax. The tax assessment based on miles driven spreads the tax more evenly across quartiles, with the loss in consumer surplus decreasing at the lower half of the income distribution and increasing in the upper half. This would appear to be the most equitable option, although still regressive. Taxing households based on income makes the gas tax replacement alternative a progressive tax, with the tax burden increasing in income.

The bottom line from these simulations, is that if states decide they need to generate significantly more revenue than they are currently getting from the gasoline tax, doing so with any of the lump-sum alternatives presented here would reduce consumer surplus by less, in all quartiles, than simply raising the gasoline tax. The difference is that raising the gasoline tax changes the price, making the tax less efficient, whereas the alternatives (as simulated here) essentially treat the various options as a lump-sum tax of different values based on the structure. However, even though all quartiles are better off under a lump-sum tax, the distribution of the tax burden can vary considerably.

VI. Conclusion

As more car manufactures switch their production lines from combustion to electric engines, governments need to figure out how to continue funding vehicle transportation infrastructure. One state estimates that at the current rate of PEV adoption, they would need to raise the gasoline tax by 1.7 cents *per year* through 2040 to generate even just the current level of revenue (Povich 2022). States also need to be aware of how the burden of raising the gas tax, or changing the funding model all together, would be distributed across households.

This paper considers the burden of increasing the gasoline tax from $0.184 to $1.39 per gallon of gasoline (one estimate of the optimal gas tax), and finds, like others, that the gasoline tax is very regressive, with lower-income households bearing a greater burden, as a share of their income, than wealthier households. The regressivity of the gasoline tax is shown to be even greater in a world where some families in each quartile adopt a PEV, largely because the share of families owning PEVs is expected to increase in income, so the burden of the higher gasoline tax would still fall heavily on lower-income households.

In order to assess alternatives to the gasoline tax for generating revenue for infrastructure maintenance, which many states have concluded must be done as more and more households start driving electric vehicles, the analysis simulates three options for a gas tax replacement. Among the options considered, the one simulating a tax based on miles driven (a type of "use" tax) appears to the most equitable, however, still slightly regressive. Basing the alternative tax on household income, would be the least regressive option -- actually resulting in an increase in consumer surplus for the lowest quartile of households.

To offset what will inevitably be higher taxes in some form in order to ensure ongoing infrastructure maintenance, the expected burden on lower-income households could be offset by the electric vehicle tax incentives offered by the U.S. Federal government. As pointed out by Osaka (2021), however, even the current/recent tax credits tend to favor the wealthy. Merely converting the tax *credit* to a *refundable credit* would benefit low-income households who may not have a high enough tax liability to take advantage of the credit (see IRS 2022), or basing the credit (inversely) on income level. Some states are trying to offer additional incentives to lower-income families. California's Enhanced Fleet Modernization Program, for example, pays low-income individuals who live in one of the program-targeted air districts to replece their older, higher-polluting car with a cleaner vehicle.[15] Other states have teamed up with local utility providers to provide income-based incentives.[16]

An additional distributional consideration is the locations of PEV charging stations. Whether stand-alone or as a residential or commercial building amenity, charging stations are

[15] https://ww2.arb.ca.gov/our-work/programs/enhanced-fleet-modernization-program
[16] For example, see the state of Vermont's Drive Electric Vermont initiative, https://www.driveelectricvt.com/.

more scarce in rural areas.[17] Since median household incomes are lower in rural areas (Semega and Kollar 2022), the lack of charging stations adds yet another barrier (in addition to price) to owning a PEV for lower income families. As PEV consumption increases, not only will policy makers have to rethink their funding strategies for infrastructure investment, but they will also need to consider who is bearing the burden of those funding plans.

[17] See U.S. Department of Energy, Alternative Fuels Data Center, https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC.

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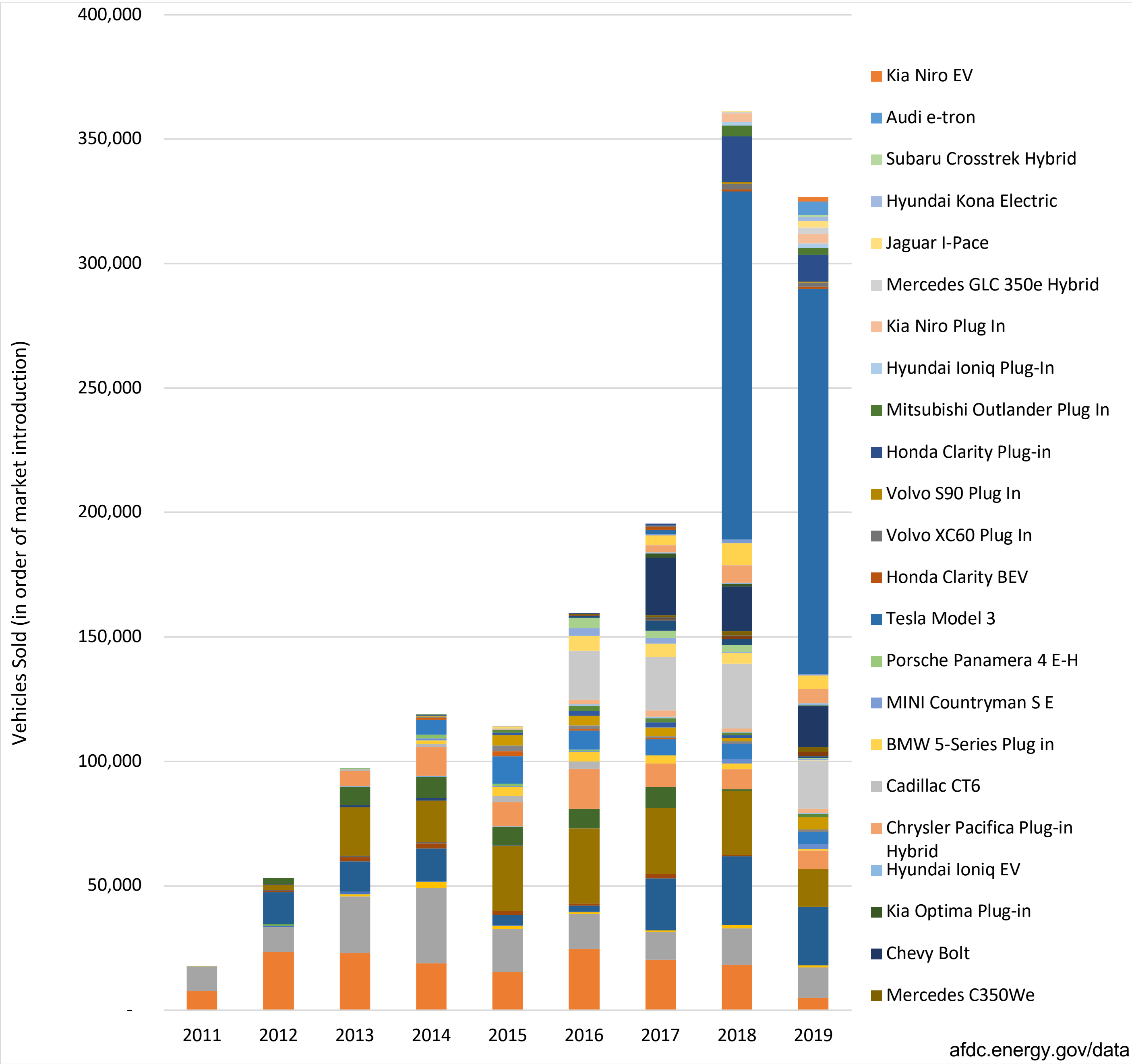
Figure 1 Sales of Plug-In Electric Vehicles

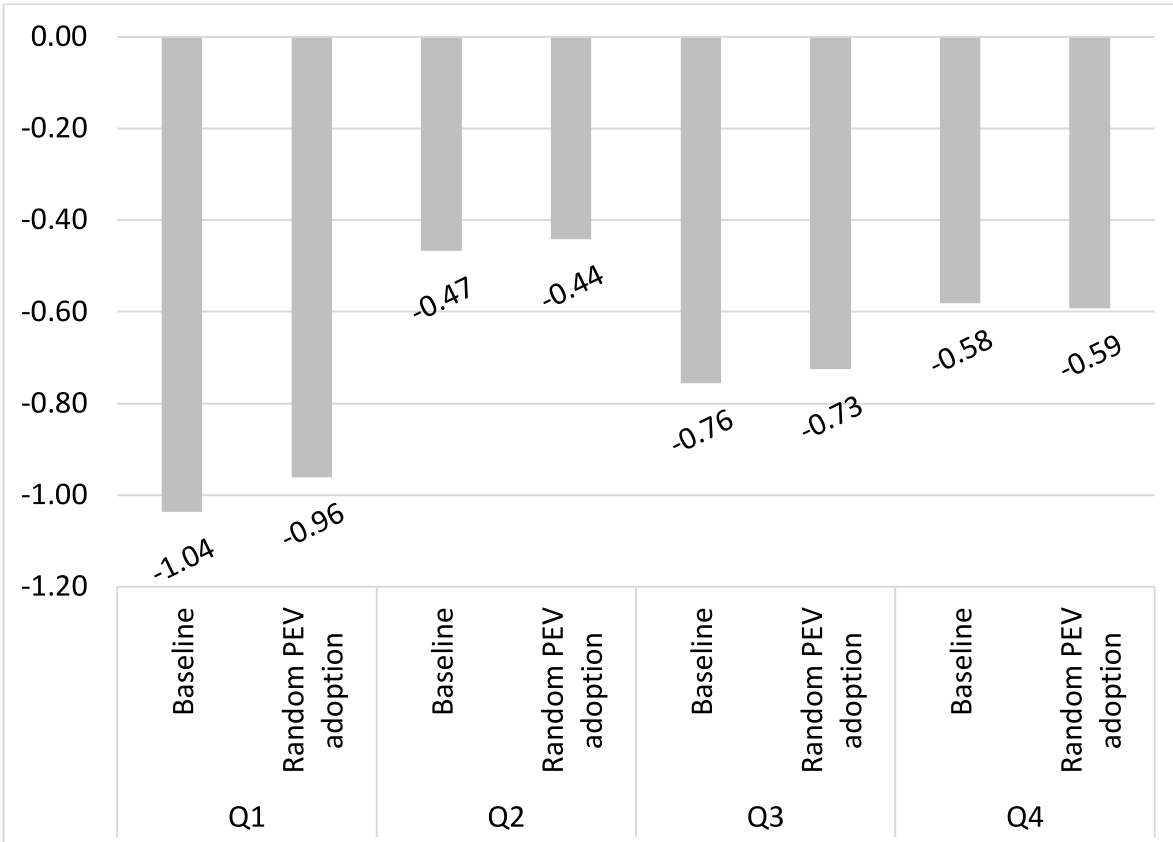


Source: Alternative Fuels Data Center (https://afdc.energy.gov/data/10567).

Figure 2 Income Distribution by PEV Model Purchase

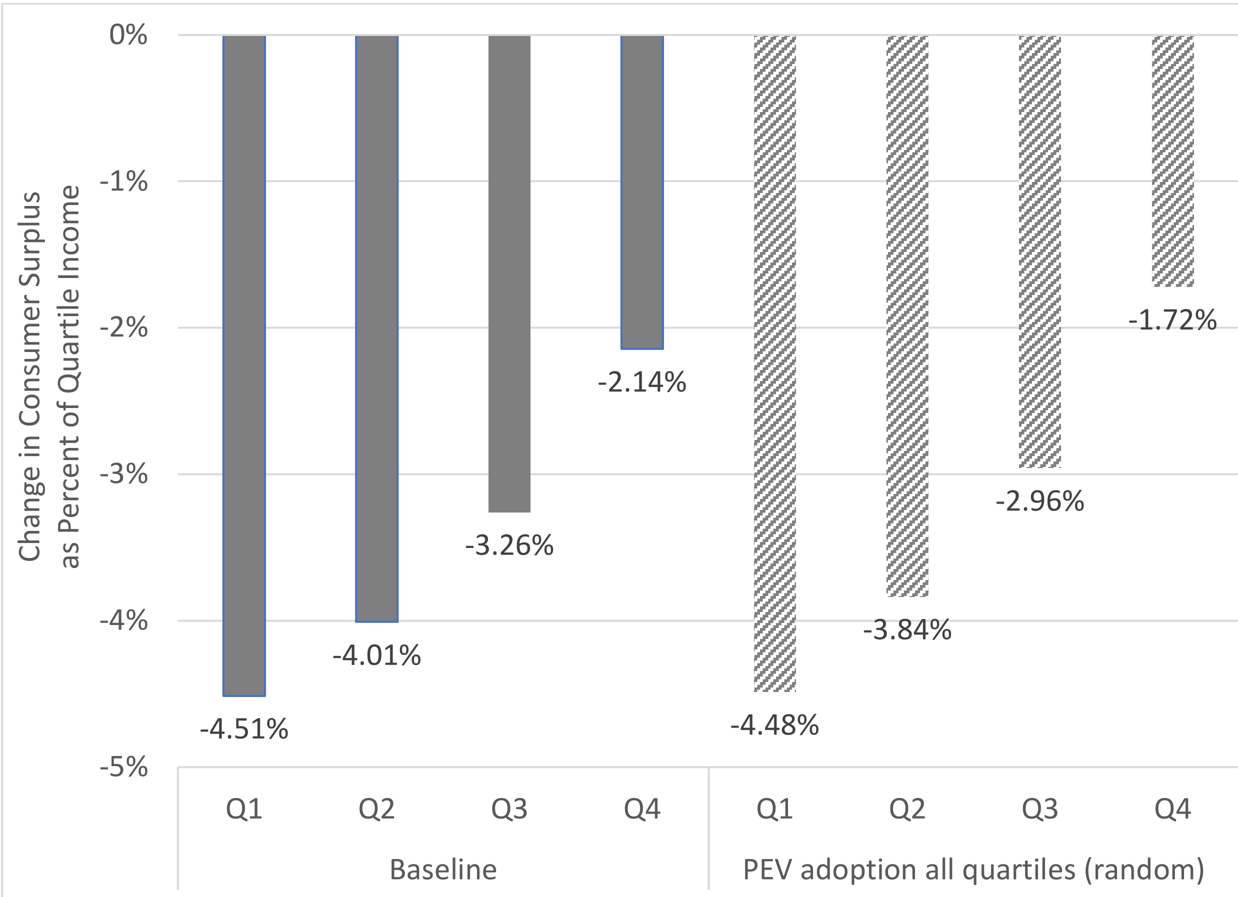
Source: Tal and Nicholas (2016); data reflect survey responses in late 2014 and early 2015.

Figure 3 Estimated own-price uncompensated elasticities using current gasoline consumptions (i.e., Baseline) and then assuming adoption of PEV by increasing shares of households as income increases.



Notes: PEV adoption is simulated by decreasing gasoline consumption by 99% of current consumption for 2%, 5%, 10%, and 20% of households in for q1, q2, q3, and q4, respectively.

Figure 4 Incidence of increasing gasoline tax to $1.39 at current consumption (Baseline) and with random PEV adoption.



Notes: Incidence is weighted average across one- and two-person households. PEV adoption uses elasticities estimated based on simulated PEV adoption (decreasing gasoline consumption to one percent of previous consumption for 2%, 5%, 10%, and 20% for q1, q2, q3, and q4, respectively).

Figure 5 Standard comparison of consumer welfare under excise tax and equal-yield income/lump sum tax.

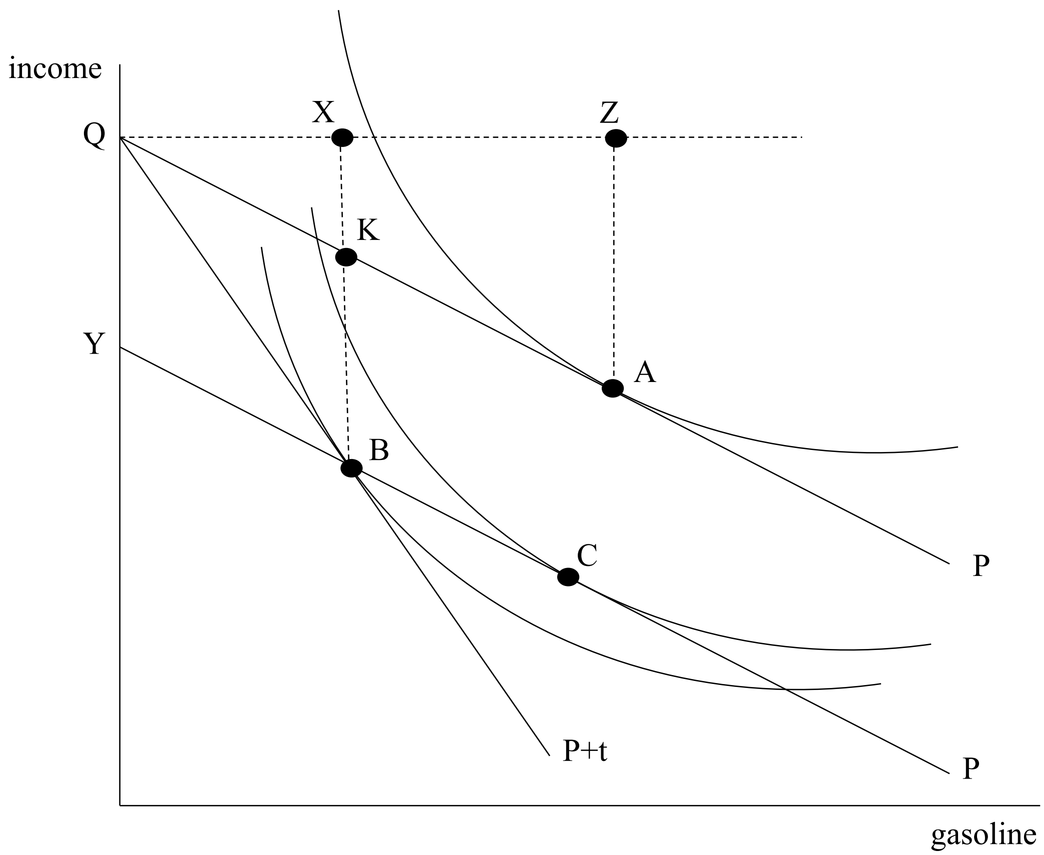
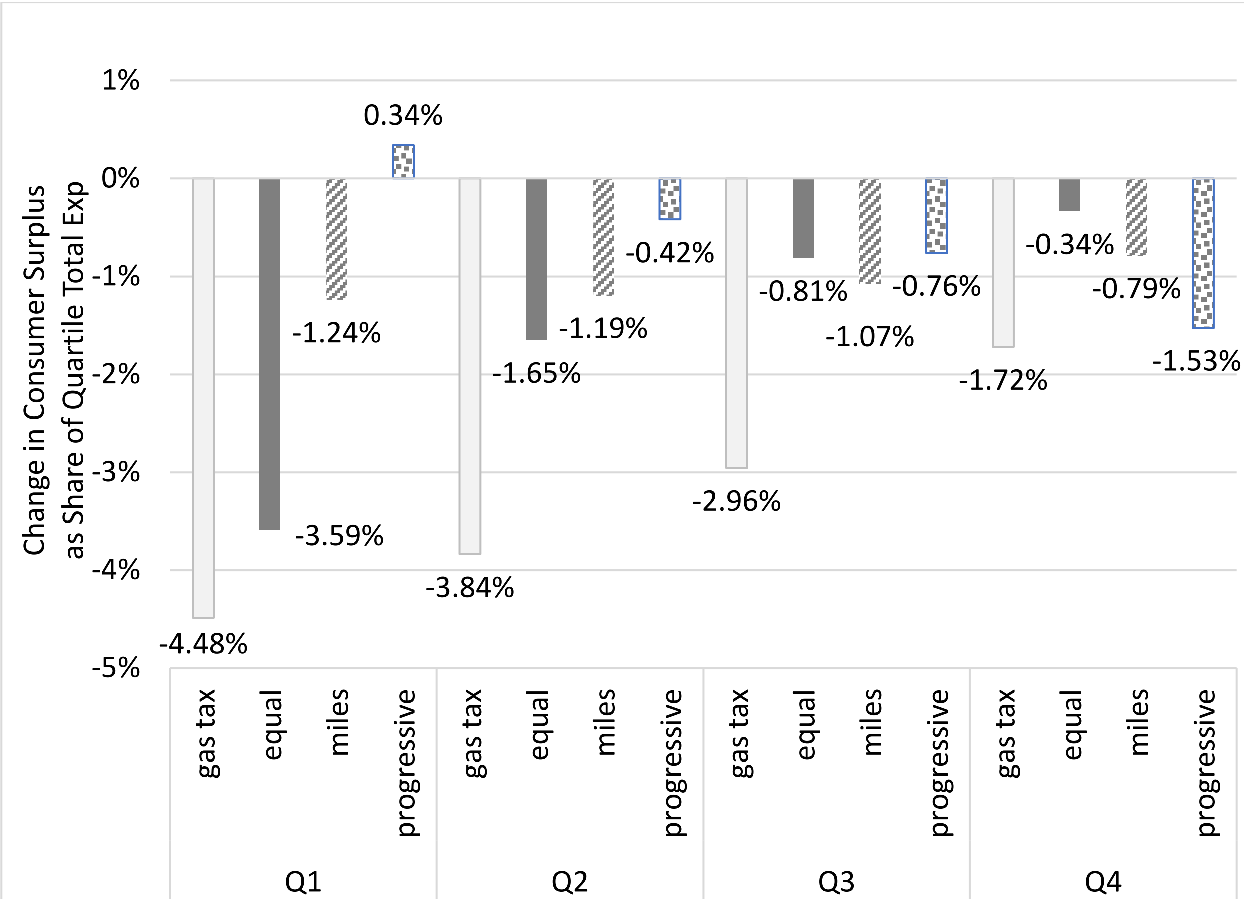


Figure 6 Change in consumer surplus by quartile from differently structured gas tax alternatives designed to replace revenue from a $1.39 gasoline tax, weighted average effects across one- and two-adult households.



Notes: Uncompensated elasticities are used to calculate change in consumer surplus. Each alternative tax is designated to replace revenue that would have been generated from a $1.39 gasoline tax. PEV adoption is operationalized by decreasing gasoline consumption to one percent of previous consumption for 2%, 5%, 10%, and 20% for q1, q2, q3, and q4, respectively. Households adopting PEV is based on random draws within quartile; elasticity estimates and impact results averaged across 25 random draws.

Table 1 Sample Summary Statistics

Variable	One-adult HH	Two-adult HH
age (female)	44.6162	41.802
	[13.7179]	[11.6646]
age male		42.6318
		[12.0463]
White, non-Hispanic (female)	.6616	.6811
	[.4732]	[.4661]
White, non-Hispanic male		.683
		[.4653]
Black, non-Hispanic (female)	.1525	.0759
	[.3595]	[.2648]
Black, non-Hispanic male		.085
		[.2789]
Other, non-Hispanic (female)	.0686	.0878
	[.2529]	[.283]
Other, non-Hispanic male		.0818
		[.2741]
Hispanic (female)	.1173	.1552
	[.3218]	[.3622]
Hispanic male		.1502
		[.3573]
Less than HS (female)	.0732	.0646
	[.2605]	[.2458]
Less than HS male		.0819
		[.2743]
High School (female)	.2178	.188
	[.4128]	[.3908]
High School male		.2224
		[.4159]
Some College (female)	.347	.2955
	[.476]	[.4563]
Some College male		.2812
		[.4496]
College (female)	.362	.4519
	[.4806]	[.4977]
College male		.4145
		[.4926]
Log real income	6.9813	8.3506
	[.9052]	[.4047]
Hrly (imputed) wage (female)	12.1127	14.1449
	[15.522]	[14.0991]
Hrly (imputed) wage male		27.2937
		[24.7619]
Price of gasoline	2.3827	2.3816

Variable	One-adult HH	Two-adult HH
	[.4106]	[.4019]
Composite price of other goods	1.0728	1.0694
	[.2001]	[.1967]
Wkly gas expenditure	15.8364	25.5518
	[15.7906]	[22.4416]
gas expenditure, quartile 1 (% of total exp)	12.26 (1.9%)	14.79 (0.4%)
gas expenditure, quartile 2 (% of total exp)	15.77 (1.5%)	21.27 (0.5%)
gas expenditure, quartile 3 (% of total exp)	16.61 (0.9%)	28.77 (0.6%)
gas expenditure, quartile 4 (% of total exp)	18.51 (0.5%)	37.37 (0.6%)
Wkly hours of work (female)	32.5726	38.176
	[19.2494]	[11.4474]
Wkly hours of work male		39.9418
		[16.5431]
Leisure exp share (female)	.7241	.3099
	[.1875]	[.1354]
Leisure exp share male		.563
		[.1531]
Gas exp share	.0119	.0051
	[.0128]	[.0048]
Other exp share	.264	.1221
	[.1822]	[.0869]
No. children	.3101	1.037
	[.7759]	[1.2284]
Female	.5603	
	[.4964]	
Observations	10692	14390

Notes: Standard errors in brackets. Means include non-missing observations used in estimation of demand system.

Table 2 Baseline Own-price Demand Elasticities (and standard errors) for One- and Two-Adult Households

	Compensated				Uncompensated			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
One-adult Households								
Gasoline	-1.0909	-0.7225	-0.4930	-0.7304	-1.0960	-0.7342	-0.4944	-0.7295
	(0.2628)	(0.3259)	(0.3301)	(0.3263)	(0.2628)	(0.3259)	(0.3301)	(0.3263)
Leisure	-0.0672	-0.1437	-0.0845	-0.0542	-0.8272	-0.7693	-0.7603	-0.7809
	(0.0085)	(0.0070)	(0.0065)	(0.0053)	(0.0085)	(0.0070)	(0.0065)	(0.0053)
Other Good	-0.2259	-0.3142	-0.2837	-0.2789	-0.4608	-0.6769	-0.6064	-0.5531
	(0.0243)	(0.0220)	(0.0240)	(0.0271)	(0.0243)	(0.0220)	(0.0240)	(0.0271)
Two-adult Households								
Gasoline	-0.9900	-0.2660	-0.9473	-0.4693	-0.9932	-0.2683	-0.9499	-0.4717
	(0.2680)	(0.2400)	(0.2552)	(0.2912)	(0.2680)	(0.2400)	(0.2552)	(0.2912)
Male Leisure	-0.0310	-0.0368	-0.0359	-0.0775	-0.6389	-0.6359	-0.6715	-0.5977
	(0.0032)	(0.0043)	(0.0254)	(0.0055)	(0.0032)	(0.0043)	(0.0254)	(0.0055)
Female Leisure	-0.0605	-0.1150	-0.0466	-0.0130	-0.4050	-0.4801	-0.3543	-0.3064
	(0.0083)	(0.0113)	(0.0078)	(0.0087)	(0.0083)	(0.0113)	(0.0078)	(0.0087)
Other Good	-0.0311	0.0172	-0.0093	-0.0107	-0.0755	-0.0163	-0.0635	-0.1947
	(0.0793)	(0.0508)	(0.0643)	(0.0174)	(0.0793)	(0.0508)	(0.0643)	(0.0174)

Note: Elasticities were estimated using *quaidsce* command in Stata 17. Full system coefficients can be found in the appendix and cross-elasticities available upon request.

Appendix A. Parameter Estimates

Table A1 Heckman Selection for Women and Men in One-Adult Households

VARIABLES	Female		Male	
	Wage Equation	Work Equation	Wage Equation	Work Equation
Age	0.0401***	0.0531***	0.0543**	0.0691***
	(0.0127)	(0.00720)	(0.0250)	(0.00802)
Age2	-0.000596***	-0.000834***	-0.000789**	-0.00106***
	(0.000172)	(8.28e-05)	(0.000363)	(9.42e-05)
High School	0.281**	0.445***	0.484***	0.335***
	(0.113)	(0.0516)	(0.143)	(0.0532)
Some College	0.586***	0.646***	0.751***	0.599***
	(0.136)	(0.0491)	(0.213)	(0.0527)
College	0.801***	0.903***	1.231***	0.844***
	(0.167)	(0.0499)	(0.271)	(0.0543)
Black, NH	-0.165***	-0.0407	-0.240***	-0.0636
	(0.0471)	(0.0348)	(0.0617)	(0.0409)
Hispanic	-0.0301	0.0841	-0.409***	-0.307***
	(0.0664)	(0.0534)	(0.113)	(0.0557)
Other, NH	0.0329	0.131***	0.0205	0.198***
	(0.0569)	(0.0420)	(0.0858)	(0.0477)
Married	-0.195***	-0.238***	-0.126	0.0974*
	(0.0652)	(0.0353)	(0.0794)	(0.0513)
Number of Children		-0.115***		0.0553
		(0.0338)		(0.0939)
Ln(total exp)		0.00949***		0.00879**
		(0.00328)		(0.00367)
Quarterly Urate		-0.121***		-0.0513**
		(0.0195)		(0.0209)
Constant	0.249	-0.272	-0.206	-0.747***
	(0.434)	(0.184)	(0.814)	(0.197)
Lambda	0.819***		1.338**	
	(0.292)		(0.571)	
Observations	10.779	10,779	8,639	8,639

Notes: This is estimated to create a demand system comparable to West and Williams (2007). Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. All observations with non-missing values of regressors were included.

Table A2 Heckman Selection for Women and Men in 2-Adult Households

	Female		Male	
VARIABLES	Wage Equation	Work Equation	Wage Equation	Work Equation
Age Female	0.00509	0.0520***		-0.0507***
	(0.00938)	(0.00928)		(0.0103)
Age2 Female	-5.16e-05	-0.00072***		0.000419***
	(0.000112)	(0.000111)		(0.000122)
HS Female	-0.178**	0.198***		-0.0303
	(0.0730)	(0.0496)		(0.0637)
Some College Female	-0.207***	0.426***		0.00838
	(0.0762)	(0.0499)		(0.0631)
College Female	-0.183**	0.711***		-0.0459
	(0.0826)	(0.0513)		(0.0645)
Black, NH Female	-0.137***	-0.0107		-0.194**
	(0.0517)	(0.0805)		(0.0889)
Hispanic Female	0.0223	-0.180***		-0.0160
	(0.0516)	(0.0524)		(0.0683)
Other, NH Female	-0.0123	0.0768*		0.0277
	(0.0407)	(0.0454)		(0.0555)
Married	0.258***	-0.132***	-0.0788	0.221***
	(0.0389)	(0.0320)	(0.106)	(0.0366)
Number Children		-0.291***		-0.0167
		(0.0161)		(0.0244)
Ln(total exp)		0.000455		0.00764**
		(0.00247)		(0.00303)
Quarterly URate		0.00118		-0.0108
		(0.0149)		(0.0184)
Age Male		-0.0392***	-0.113***	0.101***
		(0.00943)	(0.0306)	(0.00928)
Age2 Male		0.000390***	0.00156***	-0.00124***
		(0.000111)	(0.000385)	(0.000110)
HS Male		0.151***	-0.423***	0.203***
		(0.0474)	(0.162)	(0.0539)
Some College Male		0.120**	-0.520***	0.334***
		(0.0483)	(0.173)	(0.0550)
College Male		-0.0141	-0.606***	0.493***
		(0.0494)	(0.187)	(0.0575)
Black, NH Male		0.171**	-0.0845	0.00171
		(0.0767)	(0.126)	(0.0860)
Hispanic Male		-0.134**	-0.0737	-0.102
		(0.0548)	(0.131)	(0.0703)
Other, NH Male		-0.185***	-0.0342	-0.0427
		(0.0454)	(0.105)	(0.0565)
Log (Male Hourly Wage)		0.0152**		

VARIABLES	Female Wage Equation	Female Work Equation	Male Wage Equation	Male Work Equation
		(0.00676)		
Log (Female Hourly Wage)				0.0163*
				(0.00909)
Constant	1.931***	0.442**	5.276***	0.0375
	(0.217)	(0.186)	(0.775)	(0.228)
Lambda	-0.823***		-3.918***	
	(0.129)		(0.590)	
Observations	17,340	17,340	14,768	14,768

Notes: This is estimated to create a demand system comparable to West and Williams (2007). Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. All observations with non-missing values of regressors were included.

Table A3 Gasoline Probit for One-Adult Households and Two-Adult Households

VARIABLES	One-Adult Households Gasoline Probit	Two-Adult Households Gasoline Probit
Ln total expenditures	0.533***	0.568***
	(0.0161)	(0.0107)
Age (or Age Female)	0.00444	0.00334
	(0.0116)	(0.0205)
Age Male		-0.0415**
		(0.0188)
Age2 (or Age2 Female)	-9.21e-05	-4.80e-05
	(0.000138)	(0.000242)
Age2 Male		0.000432*
		(0.000223)
Black, NH (or Black, NH Female)	-0.412***	-0.331**
	(0.0533)	(0.145)
Hispanic (or Hispanic Female)	-0.400***	-0.234*
	(0.0822)	(0.128)
Other, NH (or Other, NH Female)	-0.0821	-0.0194
	(0.0680)	(0.0963)
Black, NH Male		-0.155
		(0.141)
Hispanic Male		0.146
		(0.132)
Other, NH Male		-0.0810
		(0.0962)
High School (or High School Female)	0.176**	0.171*
	(0.0740)	(0.0992)
Some College (or Some College Female)	0.330***	0.454***
	(0.0722)	(0.0997)
College (or College Female)	0.326***	0.155
	(0.0749)	(0.103)
High School Male		0.0409
		(0.0907)
Some College Male		0.251**
		(0.0977)
College Male		-0.0402
		(0.0994)
Married	0.0710	0.253***
	(0.0783)	(0.0667)
Number of Children LT6	0.0362	0.0343
	(0.0570)	(0.0470)
Homeownership	0.679***	0.390***
	(0.0524)	(0.0601)
Log (Price of Gasoline)	1.207***	1.198***
	(0.232)	(0.288)

VARIABLES	One-Adult Households Gasoline Probit	Two-Adult Households Gasoline Probit
Log (Price of Other Good)	-1.778***	-1.709***
	(0.178)	(0.219)
Female	0.00157	
	(0.0448)	
Constant	-4.350***	-3.584***
	(0.287)	(0.451)
Observations	19,418	22,592

Note: This is done because some households may not consume gasoline. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. All observations with non-missing values of regressors were included.

Table A4 Almost Ideal Demand System for One-Adult Households

Variables	Equation	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Age	Gas	5.48e-06	-5.18e-06	-3.34e-06	-3.56e-06
		(2.48e-05)	(3.93e-06)	(3.35e-06)	(3.21e-06)
Age	Leisure	-0.000321***	-2.52e-05*	-2.21e-05	-6.37e-05**
		(8.84e-05)	(1.47e-05)	(1.61e-05)	(3.08e-05)
Age	Other	0.000315***	3.04e-05**	2.54e-05	6.72e-05**
		(8.45e-05)	(1.53e-05)	(1.74e-05)	(3.24e-05)
White, NH	Gas	-0.00328***	-3.35e-05	-8.87e-05	0.000205*
		(0.00108)	(0.000221)	(0.000154)	(0.000121)
White, NH	Leisure	0.0192***	-0.000599	-0.00307***	0.00303**
		(0.00410)	(0.000732)	(0.000833)	(0.00153)
White, NH	Other	-0.0159***	0.000632	0.00316***	-0.00324**
		(0.00397)	(0.000759)	(0.000881)	(0.00162)
Black, NH	Gas	-0.00172*	0.000101	0.000107	0.000187
		(0.000922)	(0.000230)	(0.000170)	(0.000135)
Black, NH	Leisure	0.00829***	0.000839	-0.000741	0.00227
		(0.00315)	(0.000750)	(0.000822)	(0.00173)
Black, NH	Other	-0.00658**	-0.000940	0.000634	-0.00245
		(0.00296)	(0.000771)	(0.000878)	(0.00183)
Hispanic	Gas	-0.00222**	0.000277	0.000128	0.000516***
		(0.00106)	(0.000275)	(0.000179)	(0.000155)
Hispanic	Leisure	0.0148***	-0.00118	-0.00142*	0.00392**
		(0.00384)	(0.000873)	(0.000861)	(0.00179)
Hispanic	Other	-0.0126***	0.000899	0.00129	-0.00444**
		(0.00370)	(0.000905)	(0.000902)	(0.00189)
High School	Gas	-0.00131**	-0.000303	-0.000114	0.000329
		(0.000668)	(0.000417)	(0.000258)	(0.000241)
High School	Leisure	0.0149***	-0.00246**	0.00238	-0.000947
		(0.00243)	(0.000981)	(0.00154)	(0.00298)
High School	Other	-0.0136***	0.00277***	-0.00227	0.000619
		(0.00233)	(0.00104)	(0.00158)	(0.00307)
Some College	Gas	-0.00176**	-0.000493	-0.000103	-1.39e-05
		(0.000850)	(0.000400)	(0.000258)	(0.000196)
Some College	Leisure	0.0198***	3.63e-05	0.00247	-0.00102
		(0.00378)	(0.000906)	(0.00156)	(0.00302)
Some College	Other	-0.0181***	0.000457	-0.00237	0.00104
		(0.00357)	(0.000965)	(0.00160)	(0.00312)
College	Gas	-0.00360***	-0.000787*	-0.000273	-0.000285
		(0.00120)	(0.000408)	(0.000268)	(0.000205)
College	Leisure	0.0270***	0.000518	0.00221	-0.00391
		(0.00502)	(0.000904)	(0.00162)	(0.00299)
College	Other	-0.0234***	0.000269	-0.00193	0.00419
		(0.00485)	(0.000972)	(0.00166)	(0.00310)
Female	Gas	-0.00199***	-0.000241**	-0.000178**	-0.00027***

Variables	Equation	Quartile 1	Quartile 2	Quartile 3	Quartile 4
		(0.000462)	(0.000104)	(7.68e-05)	(7.76e-05)
Female	Leisure	0.0123***	0.00126***	0.000446	-0.00173**
		(0.00192)	(0.000363)	(0.000359)	(0.000874)
Female	Other	-0.0103***	-0.00102***	-0.000269	0.00200**
		(0.00178)	(0.000379)	(0.000380)	(0.000928)
Real Income	Gas	0.00384***	0.000972***	0.00124***	0.000675***
		(0.000609)	(0.000174)	(0.000168)	(0.000114)
Real Income	Leisure	-0.104***	-0.0251***	-0.0195***	-0.0171***
		(0.0110)	(0.000817)	(0.000753)	(0.00138)
Real Income	Other	0.101***	0.0242***	0.0183***	0.0165***
		(0.0107)	(0.000828)	(0.000762)	(0.00140)
# Children	Gas	5.49e-05	-0.000162*	-0.00019***	-3.36e-05
		(0.000249)	(9.02e-05)	(6.84e-05)	(6.24e-05)
# Children	Leisure	0.00515***	-2.44e-05	-0.00151***	-0.00131*
		(0.00119)	(0.000352)	(0.000401)	(0.000776)
# Children	Other	-0.00520***	0.000186	0.00170***	0.00135*
		(0.00114)	(0.000363)	(0.000427)	(0.000814)
Gas Propensity	Gas	-0.00742***	-0.00133***	-0.00148***	-0.00204***
		(0.00198)	(0.000448)	(0.000434)	(0.000582)
Gas Propensity	Leisure	0.0427***	-0.00992***	-0.0100***	-0.0199***
		(0.00785)	(0.00227)	(0.00265)	(0.00679)
Gas Propensity	Other	-0.0353***	0.0113***	0.0115***	0.0219***
		(0.00744)	(0.00235)	(0.00290)	(0.00721)
α	Gas	0.0610***	0.0442***	0.0799***	0.0556***
		(0.00789)	(0.0113)	(0.0105)	(0.00709)
α	Leisure	0.347***	0.754***	0.932***	1.121***
		(0.0236)	(0.0587)	(0.0610)	(0.0665)
α	Other	0.592***	0.201***	-0.0122	-0.176***
		(0.0237)	(0.0605)	(0.0641)	(0.0676)
β	Gas	-0.0303***	-0.00834***	-0.0158***	-0.0107***
		(0.00537)	(0.00237)	(0.00254)	(0.00179)
β	Leisure	0.711***	0.134***	0.0740***	0.0468***
		(0.0748)	(0.0118)	(0.0117)	(0.0142)
β	Other	-0.680***	-0.126***	-0.0581***	-0.0361**
		(0.0731)	(0.0121)	(0.0122)	(0.0147)
γ	Gas, Gas	-0.00260	0.00376	0.00407	0.00103
		(0.00492)	(0.00478)	(0.00306)	(0.00166)
γ	Gas, Leisure	-0.0116***	-0.00782***	-0.0107***	-0.00632***
		(0.00143)	(0.00150)	(0.00137)	(0.000676)
γ	Gas, Other	0.0142***	0.00405	0.00658**	0.00529***
		(0.00499)	(0.00503)	(0.00302)	(0.00176)
γ	Leisure, Leisure	0.148***	0.124***	0.114***	0.0718***
		(0.00537)	(0.00642)	(0.00870)	(0.0105)
γ	Leisure Other	-0.136***	-0.117***	-0.104***	-0.0655***

Variables	Equation	Quartile 1	Quartile 2	Quartile 3	Quartile 4
		(0.00514)	(0.00675)	(0.00924)	(0.0107)
γ	Other, Other	0.122***	0.113***	0.0972***	0.0602***
		(0.00709)	(0.00878)	(0.0102)	(0.0112)
Observations		2,674	2,673	2,673	2,672

Notes: Specification and regressors follow that of West and Williams (2007). Estimations include state and year fixed effects not shown here. Robust standard errors are clustered by households. *** p<0.01, ** p<0.05, * p<0.1

Table A5 Almost Ideal Demand System for 2-Adult Households

Variables	Good	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Age Female	Gas	1.76e-05*	-1.39e-05*	-4.09e-06	-4.66e-05*
		(8.97e-06)	(8.28e-06)	(8.65e-06)	(2.49e-05)
Age Female	Leisure-Male	0.000101	0.00013***	-8.58e-05**	0.000217*
		(0.000146)	(4.99e-05)	(3.93e-05)	(0.000123)
Age Female	Leisure-Female	-0.00045***	0.000123*	4.86e-05	0.00034***
		(0.000113)	(6.85e-05)	(3.97e-05)	(0.000110)
Age Female	Other	0.00036***	-0.00024***	4.13e-05	-0.00051***
		(8.93e-05)	(8.62e-05)	(3.79e-05)	(0.000168)
Age Male	Gas	-9.58e-06*	-5.50e-06	1.54e-07	2.85e-05
		(4.98e-06)	(7.52e-06)	(8.46e-06)	(2.21e-05)
Age Male	Leisure-Male	0.00018***	5.92e-05	6.05e-05	-0.00031***
		(6.04e-05)	(5.54e-05)	(4.26e-05)	(0.000112)
Age Male	Leisure-Female	-4.75e-05	-6.01e-05	-5.22e-05	-0.000151
		(5.06e-05)	(6.59e-05)	(4.09e-05)	(0.000103)
Age Male	Other	-0.000124**	6.40e-06	-8.52e-06	0.00043***
		(4.87e-05)	(8.14e-05)	(3.79e-05)	(0.000163)
Age2 Female	Gas	-2.31e-07**	2.18e-07**	3.59e-08	5.23e-07*
		(1.07e-07)	(1.01e-07)	(1.00e-07)	(2.83e-07)
Age2 Female	Leisure-Male	-1.03e-06	-1.9e-06***	9.26e-07*	-2.17e-06
		(1.80e-06)	(6.22e-07)	(4.73e-07)	(1.44e-06)
Age2 Female	Leisure-Female	5.56e-06***	-2.7e-06***	-4.05e-07	-3.9e-06***
		(1.38e-06)	(8.21e-07)	(4.62e-07)	(1.27e-06)
Age2 Female	Other	-4.3e-06***	4.33e-06***	-5.57e-07	5.54e-06***
		(1.08e-06)	(1.01e-06)	(4.54e-07)	(1.95e-06)
Age2 Male	Gas	1.39e-07**	7.97e-08	-6.66e-09	-2.84e-07
		(5.99e-08)	(8.91e-08)	(9.84e-08)	(2.59e-07)
Age2 Male	Leisure-Male	-2.8e-06***	-8.38e-07	-7.10e-07	3.76e-06***
		(7.26e-07)	(6.63e-07)	(5.11e-07)	(1.33e-06)
Age2 Male	Leisure-Female	1.02e-06	8.38e-07	4.36e-07	1.46e-06
		(6.24e-07)	(7.78e-07)	(4.77e-07)	(1.20e-06)
Age2 Male	Other	1.65e-06***	-7.97e-08	2.81e-07	-4.9e-06***
		(6.06e-07)	(9.79e-07)	(4.52e-07)	(1.90e-06)
White, NH Female	Gas	3.30e-05	8.91e-05	-2.62e-05	-9.72e-05
		(3.61e-05)	(5.83e-05)	(6.04e-05)	(0.000265)
White, NH Female	Leisure-Male	-0.000223	-0.00092***	-0.000190	9.33e-05
		(0.000189)	(0.000287)	(0.000249)	(0.000692)
White, NH Female	Leisure-Female	-4.54e-05	-0.000742*	0.000499**	0.000759
		(0.000227)	(0.000393)	(0.000197)	(0.000742)
White, NH Female	Other	0.000235	0.00157***	-0.000283	-0.000755
		(0.000187)	(0.000492)	(0.000264)	(0.00111)
White, NH Male	Gas	-6.74e-06	-0.00013***	-1.17e-05	0.000296**
		(2.69e-05)	(4.80e-05)	(4.84e-05)	(0.000139)
White, NH Male	Leisure-Male	0.00062***	0.00091***	0.000310	-0.000655

Variables	Good	Quartile 1	Quartile 2	Quartile 3	Quartile 4
		(0.000173)	(0.000258)	(0.000227)	(0.000613)
White, NH Male	Leisure-Female	-0.000286	0.000529	-0.000118	0.000327
		(0.000234)	(0.000352)	(0.000208)	(0.000615)
White, NH Male	Other	-0.000325*	-0.00130***	-0.000180	3.29e-05
		(0.000198)	(0.000388)	(0.000234)	(0.000938)
Black, NH Female	Gas	-2.63e-05	4.22e-05	-3.53e-05	-4.31e-05
		(3.21e-05)	(6.17e-05)	(6.24e-05)	(0.000245)
Black, NH Female	Leisure-Male	-0.000538**	-0.00106***	-0.000437*	-0.000540
		(0.000270)	(0.000283)	(0.000264)	(0.000621)
Black, NH Female	Leisure-Female	-1.26e-05	-0.000917**	0.00067***	0.000537
		(0.000276)	(0.000402)	(0.000217)	(0.000639)
Black, NH Female	Other	0.00058***	0.00194***	-0.000201	4.61e-05
		(0.000218)	(0.000471)	(0.000271)	(0.000955)
Black, NH Male	Gas	-7.5e-05***	-0.00019***	-4.26e-05	0.000140
		(2.47e-05)	(4.75e-05)	(4.99e-05)	(0.000139)
Black, NH Male	Leisure-Male	0.00065***	0.00107***	0.000225	-0.000184
		(0.000207)	(0.000253)	(0.000238)	(0.000619)
Black, NH Male	Leisure-Female	-0.000101	0.000520	0.000106	0.000464
		(0.000285)	(0.000336)	(0.000217)	(0.000577)
Black, NH Male	Other	-0.000474**	-0.00140***	-0.000288	-0.000419
		(0.000235)	(0.000354)	(0.000244)	(0.000933)
Hispanic Female	Gas	-2.32e-05	3.57e-05	-9.69e-05	-9.63e-05
		(3.22e-05)	(6.03e-05)	(5.96e-05)	(0.000256)
Hispanic Female	Leisure-Male	-0.000591**	-0.00166***	-0.000499*	0.000154
		(0.000283)	(0.000288)	(0.000267)	(0.000593)
Hispanic Female	Leisure-Female	-6.36e-05	-0.000546	0.00077***	0.000866
		(0.000258)	(0.000422)	(0.000223)	(0.000580)
Hispanic Female	Other	0.00068***	0.00217***	-0.000174	-0.000924
		(0.000211)	(0.000480)	(0.000269)	(0.000873)
Hispanic Male	Gas	-7.8e-05***	-0.00020***	-0.00015***	-2.81e-05
		(2.46e-05)	(4.61e-05)	(4.84e-05)	(0.000140)
Hispanic Male	Leisure-Male	0.0008***	0.00116***	-0.000122	-7.52e-05
		(0.000205)	(0.000250)	(0.000241)	(0.000620)
Hispanic Male	Leisure-Female	-0.00070***	0.000348	0.000160	0.000516
		(0.000190)	(0.000359)	(0.000224)	(0.000597)
Hispanic Male	Other	-1.86e-05	-0.00130***	0.000107	-0.000413
		(0.000154)	(0.000380)	(0.000233)	(0.000976)
High School Female	Gas	3.77e-05	-9.02e-05*	-5.25e-05	-4.27e-06
		(4.46e-05)	(5.03e-05)	(5.18e-05)	(0.000122)
High School Female	Leisure-Male	-0.000429	0.000361	0.000207	0.000751
		(0.000301)	(0.000248)	(0.000339)	(0.000619)
High School Female	Leisure-Female	-0.000632**	0.000454*	0.000376	0.000234
		(0.000248)	(0.000270)	(0.000236)	(0.000591)
High School Female	Other	0.00102***	-0.000725*	-0.000530	-0.000980

Variables	Good	Quartile 1	Quartile 2	Quartile 3	Quartile 4
		(0.000251)	(0.000398)	(0.000343)	(0.000950)
High School Male	Gas	4.97e-05	2.39e-05	5.81e-05	0.000166
		(4.22e-05)	(4.95e-05)	(4.57e-05)	(0.000159)
High School Male	Leisure-Male	0.000599*	-0.000178	-0.000206	-0.00162**
		(0.000317)	(0.000274)	(0.000329)	(0.000759)
High School Male	Leisure-Female	-0.000795**	0.000662**	-0.000264	-0.00121
		(0.000368)	(0.000308)	(0.000230)	(0.000750)
High School Male	Other	0.000146	-0.000507	0.000412	0.00266**
		(0.000310)	(0.000399)	(0.000324)	(0.00122)
Some College Female	Gas	-2.48e-05	-0.000122	2.49e-05	-0.000233
		(5.97e-05)	(7.40e-05)	(8.27e-05)	(0.000250)
Some Coll. Female	Leisure-Male	-1.21e-05	0.000878**	0.00123***	0.00352**
		(0.000385)	(0.000398)	(0.000466)	(0.00142)
Some Coll. Female	Leisure-Female	5.04e-05	0.00133***	-0.000571	0.00137
		(0.000437)	(0.000497)	(0.000510)	(0.00132)
Some Coll. Female	Other	-1.35e-05	-0.00208***	-0.000679	-0.00466**
		(0.000404)	(0.000599)	(0.000606)	(0.00234)
Some Coll. Male	Gas	8.27e-05	0.000112	9.35e-05	0.000266
		(6.00e-05)	(7.17e-05)	(7.94e-05)	(0.000206)
Some Coll. Male	Leisure-Male	0.000536	-0.00096***	-0.00116***	-0.00338***
		(0.000412)	(0.000368)	(0.000451)	(0.00113)
Some Coll. Male	Leisure-Female	-0.000825*	-0.000661	0.000650	-0.000430
		(0.000461)	(0.000475)	(0.000509)	(0.00106)
Some Coll. Male	Other	0.000206	0.00151**	0.000420	0.00354**
		(0.000426)	(0.000604)	(0.000614)	(0.00176)
College Female	Gas	3.36e-05	-5.72e-05	-6.36e-05	8.54e-05
		(5.55e-05)	(6.35e-05)	(5.88e-05)	(0.000148)
College Female	Leisure-Male	8.66e-06	0.000488	0.000349	0.000495
		(0.000361)	(0.000334)	(0.000373)	(0.000742)
College Female	Leisure-Female	-0.000904**	-0.000202	0.000237	-0.000422
		(0.000408)	(0.000408)	(0.000279)	(0.000724)
College Female	Other	0.000862**	-0.000228	-0.000522	-0.000158
		(0.000337)	(0.000578)	(0.000389)	(0.00112)
College Male	Gas	8.12e-05	0.00017***	0.00018***	6.66e-05
		(4.94e-05)	(6.31e-05)	(5.80e-05)	(0.000188)
College Male	Leisure-Male	0.000137	-0.000755**	-0.000436	-0.00134
		(0.000354)	(0.000349)	(0.000379)	(0.000933)
College Male	Leisure-Female	-0.000559	0.000196	-9.52e-05	0.000224
		(0.000481)	(0.000427)	(0.000293)	(0.000935)
College Male	Other	0.000341	0.000392	0.000355	0.00105
		(0.000415)	(0.000568)	(0.000372)	(0.00145)
Real Income	Gas	0.00029***	0.00051***	0.00046***	0.000170**
		(3.46e-05)	(6.68e-05)	(6.93e-05)	(8.20e-05)
Real Income	Leisure-Male	-0.00392***	-0.00736***	-0.00932***	-0.0140***

Variables	Good	Quartile 1	Quartile 2	Quartile 3	Quartile 4
		(0.000259)	(0.000471)	(0.000543)	(0.000683)
Real Income	Leisure-Female	-0.00255***	-0.00545***	-0.00356***	-0.00774***
		(0.000242)	(0.000563)	(0.000509)	(0.000497)
Real Income	Other	0.00618***	0.0123***	0.0124***	0.0216***
		(0.000179)	(0.000407)	(0.000776)	(0.000972)
# Children	Gas	1.45e-05**	8.81e-06	3.17e-06	0.00012***
		(6.52e-06)	(1.44e-05)	(1.27e-05)	(3.28e-05)
# Children	Leisure-Male	-3.68e-05	7.80e-05	-0.000197**	-4.96e-05
		(4.89e-05)	(8.89e-05)	(7.95e-05)	(0.000127)
# Children	Leisure-Female	-4.96e-05	0.000288**	-4.17e-05	-0.000311**
		(7.24e-05)	(0.000125)	(8.25e-05)	(0.000149)
# Children	Other	7.19e-05	-0.000375**	0.00024***	0.000244
		(5.41e-05)	(0.000149)	(7.20e-05)	(0.000210)
Gas Propensity	Gas	-0.000113	-0.000383**	-0.000196	0.000142
		(0.000110)	(0.000191)	(0.000235)	(0.00113)
Gas Propensity	Leisure-Male	-0.00211*	0.000238	-0.000878	-0.00107
		(0.00112)	(0.00112)	(0.00144)	(0.00532)
Gas Propensity	Leisure-Female	-0.000939	0.000970	0.00192*	0.00134
		(0.00125)	(0.00139)	(0.00109)	(0.00490)
Gas Propensity	Other	0.00316***	-0.000825	-0.000843	-0.000418
		(0.00110)	(0.00170)	(0.00137)	(0.00815)
α	Gas	0.0188***	0.0343***	0.0445***	0.0426***
		(0.00236)	(0.00506)	(0.00702)	(0.00667)
α	Leisure-Male	0.411***	0.183***	-0.343***	0.0487*
		(0.0382)	(0.0495)	(0.0881)	(0.0270)
α	Leisure-Female	0.256***	0.0308	0.317***	0.0608**
		(0.0299)	(0.0463)	(0.0556)	(0.0278)
α	Other	0.314***	0.752***	0.982***	0.848***
		(0.0268)	(0.0296)	(0.0502)	(0.0376)
β	Gas	-0.00312***	-0.00613***	-0.00731***	-0.00442***
		(0.000549)	(0.00102)	(0.00126)	(0.00116)
β	Leisure-Male	0.0240***	0.0769***	0.171***	0.137***
		(0.00823)	(0.00949)	(0.0118)	(0.00667)
β	Leisure-Female	0.0482***	0.0863***	0.0264**	0.0773***
		(0.00701)	(0.00956)	(0.0118)	(0.00620)
β	Other	-0.0691***	-0.157***	-0.190***	-0.210***
		(0.00546)	(0.00566)	(0.00578)	(0.00853)
γ	Gas, Gas	1.47e-05	0.00346***	0.000148	0.00297*
		(0.000993)	(0.00116)	(0.00151)	(0.00172)
γ	Gas, Leisure-Male	-0.00250***	-0.00248***	-0.000269	-0.00182***
		(0.000178)	(0.000297)	(0.000916)	(0.000224)
γ	Gas, Leisure Female	-0.00132***	-0.00107***	-0.00227***	-0.00142***

Variables	Good	Quartile 1	Quartile 2	Quartile 3	Quartile 4
		(0.000183)	(0.000402)	(0.000298)	(0.000232)
γ	Gas Leisure Other	0.00380***	8.41e-05	0.00239	0.000265
		(0.00106)	(0.00128)	(0.00155)	(0.00181)
γ	Leisure Male, Leisure Male	0.219***	0.215***	0.155***	0.204***
		(0.00195)	(0.00301)	(0.0210)	(0.00277)
γ	Leisure Male, Leisure Female	-0.185***	-0.176***	-0.151***	-0.126***
		(0.00184)	(0.00278)	(0.00730)	(0.00221)
γ	Leisure Male, Other	-0.0323***	-0.0363***	-0.00404	-0.0758***
		(0.00214)	(0.00440)	(0.0149)	(0.00218)
γ	Leisure Female, Leisure Female	0.207***	0.187***	0.199***	0.199***
		(0.00270)	(0.00534)	(0.00250)	(0.00236)
γ	Leisure Female, Other	-0.0207***	-0.0102**	-0.0455***	-0.0713***
		(0.00281)	(0.00461)	(0.00588)	(0.00215)
γ	Other, Other	0.0492***	0.0464***	0.0471***	0.147***
		(0.00454)	(0.00605)	(0.0115)	(0.00365)
Observations		3,597	3,597	3,598	3,597

Notes: See notes to Table A4.

Table A6 Tax incidence (as percent of total expenditures) from gasoline price increase, current gasoline expenditure and PEV adoption.

	One-adult Households				Two-adult Households			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Current gasoline consumption								
Gasoline price elasticities	-1.0960	-0.7342	-0.4944	-0.7295	-0.9932	-0.2683	-0.9499	-0.4717
	(0.2628)	(0.3259)	(0.3301)	(0.3263)	(0.2680)	(0.2400)	(0.2552)	(0.2912)
Consumer Surplus (ΔCS_h)	-4.25	-3.53	-3.07	-2.16	-4.71	-4.36	-3.40	-2.13
PEV adoption								
Gasoline price elasticities	-1.0569	-0.7566	-0.5155	-0.6932	-0.8888	-0.2063	-0.8811	-0.5169
	(0.2707)	(0.3453)	(0.3714)	(0.4121)	(0.2693)	(0.2584)	(0.2852)	(0.3749)
Consumer Surplus (ΔCS_h)	-4.19	-3.35	-2.77	-1.75	-4.70	-4.19	-3.09	-1.70

Note: Uncompensated gasoline price elasticities (and standard errors) calculated at quartile means. Tax Incidence as a percentage of total expenditures.

Table A7 Estimated tax incidence (as percent of total expenditures) from replacing gasoline tax with an alternative tax policy designed to generate revenue that would have been generated by a $1.39 gasoline tax, three options for revenue replacement; random PEV adoption assumed

	One-adult Households				Two-adult Households			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Tax based on equal quartile shares	-1.4005	-0.5397	-0.4698	-0.2908	-5.2192	-2.4681	-1.0684	-0.3686
Tax based on miles driven	-0.5188	-0.5282	-0.5692	-0.5161	-1.7699	-1.6875	-1.4469	-0.9913
Tax based on income share	0.6040	-0.1150	-0.5777	-1.0891	0.1412	-0.6425	-0.8977	-1.8538

Note: Tax Incidence as a percentage of total expenditures. Consumer surplus response calculated using uncompensated elasticities. Alternative tax enters consumer surplus as a negative lump-sum payment in equation (5). Alternative tax amount calculated to replace revenue that would be generated by implementing a $1.39 gasoline tax. Percent of HH in each quartile adopting PEV generated by 25 repeated random draws. Elasticities and incidence for each quartile averaged over the random draws. percent of families in each quartile increases with quartile (gasoline consumption decreases to one percent of previous consumption for 2%, 5%, 10%, and 20% for q1, q2, q3, and q4, respectively). Miles driven proxied by the share of total revenue (under original gasoline tax policy) generated by each quartile.