Gasoline Taxes and Consumer Behavior

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March 2011

Abstract

Reducing gasoline consumption could significantly impact energy security, climate change, and local air pollution. We study how consumer vehicle purchases and usage respond to gasoline price changes. In contrast to the previous literature, we separately identify the effects of (permanent) changes in gasoline taxes from those of (potentially transitory) changes in input prices. We find that rising gasoline taxes are associated with larger shifts towards high fuel economy vehicles and greater reductions in gasoline consumption than comparable increases in the tax-exclusive retail price. Interestingly, we do not find a similar pattern for vehicle miles traveled, suggesting that the pattern for gasoline demand decrease comes through shifting mileage from low- to high-fuel economy vehicles and through changes in driving behavior (such as lower driving speeds). Finally, we discuss the implications of our findings for the estimation of implicit discount rates, demand elasticities and the fiscal benefits of higher gasoline prices.

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1 Introduction

Gasoline consumption has important impacts on energy security, climate change, and local air pollution. The U.S. imports about 60% of its petroleum products. Mobile sources account for about 20% of the total annual emissions of carbon dioxide and 60 to 70% of total urban air emissions.

Current U.S. policy uses the Corporate Average Fuel Economy (CAFE) standards to reduce gasoline consumption. CAFE penalizes an automaker if the fleets of passenger cars and light trucks sold do not meet a fleet-wide fuel economy standard for each class of vehicles. A long literature examines the incentives created by CAFE and estimates the cost of the program.[1] In contrast to the U.S., many other industrialized nations use fuel taxes to encourage consumers to reduce fuel use. The average gasoline tax (federal and state) in the U.S. was about 46 cents per gallon in 2009, while it was about $3.40 per gallon in the U.K. and $4.20 in Germany (including VAT). Unlike the CAFE standards, fuel taxes in principle affect both the extensive margin (when a consumer is deciding what vehicle to purchase) and the intensive margin (how much to drive the vehicle).

There are two reasons why policy makers in the U.S. prefer fuel economy standards to gasoline prices. First, the costs of CAFE are less apparent to consumers, unlike the cost of gasoline taxes that consumers bear each time they fill up. The political cost of high fuel taxes may preclude their use. It may be more politically feasible for policymakers to set a stringent fuel economy standard than to raise gasoline taxes an equivalent amount. Second, the recent economics literature finds that consumers respond little to rising gasoline prices. For example, according to some recent estimates, achieving just a 1% reduction in gas consumption would require a gasoline price increase of 10%.[2] Consequently, a very high tax would be required to significantly reduce fuel consumption. Thus, policy makers argue that fuel economy standards provide a much more effective way of reducing gasoline consumption.

In this paper, we examine the second motivation for fuel economy standards. The recent literature identifies the consumer response to gasoline prices using recent variation in gasoline prices driven primarily by fluctuations in oil prices between 2003 and 2008. There are several reasons to expect that a gasoline tax could elicit a greater consumer response. The effect of a change in fuel prices depends on consumer expectations of future fuel costs. Due to the durable good nature of automobiles, consumers may respond to changes in gasoline taxes differently

[1] See, for example, Goldberg (1998), Jacobsen (2010) and Anderson and Sallee (forthcoming).

[2] Small and Van Dender (2007); Hughes, Knittel and Sperling (2008)

from changes they perceive to be less permanent (e.g., due to short-term supply interruptions or changes in the price of crude oil).[3] Similarly, a change in gasoline taxes may encourage consumers to change vehicle miles traveled and gasoline consumption in a way that a change in the tax-exclusive price of gasoline would not. For example, consumers may choose to start car-pooling, using public transportation, or reducing commuting (e.g., working from home or moving closer to work) in response to a price change they perceive as more permanent.

If consumers believe that oil price increases are less likely to persist than gasoline tax increases, consumer behavior may respond more to a tax increase than a commensurate increase in the tax-exclusive price. Moreover, if consumers respond more strongly to gasoline taxes than other price variations, policy analysis that does not take this into account may provide misleading results by under-estimating the effect of higher gasoline taxes.

In this paper, we test whether consumers respond more to gasoline tax changes than to commensurate changes in the tax-exclusive gasoline price. Specifically, we examine three different margins on which consumer behavior adapts: consumption of gasoline, vehicle miles traveled, and vehicle purchase decisions. We examine two separate datasets: (1) aggregate state-level data that allow us to better examine all the margins on which behavior may respond, and (2) household-level data that allow us to better control for other factors that may be correlated with both taxes and decisions. We find that rising gasoline taxes are associated with larger shifts towards high fuel economy vehicles and greater reductions in gasoline consumption than comparable increases in the tax-exclusive retail price. We do not find a similar differential response for vehicle miles traveled.

Our paper informs a number of current tax policy debates. Several recent proposals have called for higher gasoline taxes for either fiscal motives (see e.g., the proposal of the Deficit Reduction Committee), to maintain the solvency of the Highway Trust Fund, or to internalize greenhouse gas emissions. By focusing on the effects of gas taxes, our paper speaks directly to the effectiveness of these proposals.

In addition, our paper addresses a fundamental identification problem in environmental economics. Beginning with Hausman (1979) and Dubin and McFadden (1984), a long literature estimates the implicit discount rate consumers place on future energy costs. The empirical approaches in these papers exploit either cross-sectional or time-series variation in consumers' relative weights of the upfront purchase cost and expected future energy costs of a durable good. The identification problem arises because the econometrician does not observe a consumer's ex-

[3] It is important to note that a number of studies are unable to reject the hypothesis that gasoline prices follow a random walk. [Point about consumer behavior]

pectation of future energy costs. Consequently, it is impossible to estimate implicit discount rates without making assumptions of the consumer's expectation of future energy costs. In some cases, assumptions of future expectations are innocuous - for example, regulated retail electricity prices are unlikely to change unexpectedly. Much of the recent literature estimates implicit discounts for future vehicle fuel costs and exploits large increases in gasoline prices between 2000 and 2001 and between 2003 and 2008. (See e.g., Busse, Knittel and Zettlelmeyer (2009), Allcott and Wozny (2010), Gallagher and Muehlegger (2011)). In these cases, assuming consumer expectations of future gasoline prices seem less reasonable. Our approach addresses this identification problem by decomposing gasoline price changes into a tax component and a tax-exclusive component. Since state and federal tax changes are likely to be perceived as permanent by consumers, we can use variation in the tax component as the source of identification for estimating implicit discount rates.

Finally, our work informs the work of Hughes, Knittel and Sperling (2008) that documents a shift in the short-run elasticity of gasoline over the last three decades. After controlling for the fraction of price increases attributable to tax changes, we find that the demand elasticity of gasoline has not fallen by the same degree. Rather, a greater proportion of recent price changes have been driven by oil price fluctuations than gasoline tax increases. Consequently, in the aggregate, demand elasticity appears to have fallen over time.

The paper proceeds as follows. In section 2, we present some background on U.S. gasoline prices and taxes. We present our analysis of the aggregate state-level data in section 3 and present our analysis of the consumer data in section 4. In section 5, we discuss the implications of our results for the estimation of implicit discount rates and estimates of the elasticity of demand for gasoline. Section 6 concludes.

2 Background on U.S. Gasoline Prices and Taxes

Taxes make up a substantial portion of U.S. retail gasoline prices. As an illustration, we decompose gasoline prices into oil prices and excise taxes. We regress the tax-inclusive price on crude oil prices, state/federal excise tax rates, state fixed effects and state-specific linear time trends:

$$RetailPrice_{it} = \alpha_i + \beta OilPrice_t + \gamma\tau_{it} + \delta_i * t + \epsilon_{it} \tag{1}$$

The state fixed-effects capture time-invariant differences in gasoline prices that arise from differences in transportation costs. The linear time trends allow the retail prices in each location to adjust at a different linear rate over time. Figure 1 decomposes the average US retail gasoline price (dashed line) into an oil component, a tax component and the state fixed effects and time trends. Although much of the intertemporal variation in national gasoline prices is correlated with changes in oil prices, taxes comprise a significant portion of the tax-inclusive gasoline prices for much of the period. [4] Table 1 reports the average nominal gasoline price, state gasoline tax, federal gasoline tax in cents per gallon for five-year intervals beginning in 1966 and ending in 2008. In addition, the table reports the fraction of gasoline price changes over the period correlated with changes in gasoline taxes. The fraction changes substantially over time, rising with changes in state gasoline taxes, increases in the federal gasoline tax (from 4 to 9 cpg in 1983, from 9 to 14.1 cpg in 1991, and from 14.1 to 18.4 cpg in 1994) and falling during periods of time with volatile oil prices.

National averages obscure substantial cross-state variation in excise tax rates. Figure 2 displays snapshots of state gasoline tax rates in 1966, 1976, 1986, 1996 and 2006. Figure 3 presents the mean, max and min state taxes rates as well as the federal tax rate over the period. Although the mean state tax rate rises slowly over time, state tax rates more quickly in some locations than others. In 1966, the difference between the state with the highest and lowest tax rates was 2.5 cpg. In 2008, the difference was 30 cpg - Georgia's excise tax is 7.5 cpg while Washington's excise tax is 37.5 cpg. Moreover, states vary substantially in the frequency with which they increase gasoline excise taxes. From 1966 to 2008, annual state tax rates changed in approximately 26 percent of the state-years.[5] Tax rates rose in 488 state-years and fell in 44 state-years, out of 2064 total observations. Nebraska, North Carolina and Wisconsin change taxes most often, in 29, 24 and 24 years respectively.[6] Georgia only changed the gasoline excise tax twice.

Figures 4 graphs the proportion of the tax-inclusive retail price made up by excise taxes. At the median, taxes make up approximately 26 percent of the after-tax price. This varies substantially over time and across states - the proportion is greatest during the late 1960's and late 1990's when oil prices were relatively low and taxes were relatively high. The proportion is lowest during the early 1980's and after 2005 when oil prices rose substantially. At the peak in

[4] The coefficient on taxes is 1.03 and is statistically indistinguishable from 1, suggesting that gasoline taxes are heavily borne by consumers. This is consistent with the result in Marion and Muehlegger (2011) that finds, under typical supply and demand conditions, state and federal gasoline taxes are fully passed onto consumers and are incorporated fully into the tax-inclusive price in the month of the tax change.

[5] In the annual data, we only count years in which the average annual rate rose or fell relative to the previous year. We do not count multiple changes over the course of a year as part of the total.

[6] In fact, Nebraska changes its gasoline tax even more often than the annual figures suggest. From 1983 to 2008, for which we have monthly data, Nebraska changed its gasoline tax 56 times.

1999, the proportion varies from a low of 25 to 30 percent (at the 5th percentile) to a high of over 40 percent (at the 95th percentile).

Despite gasoline taxes constituting a large proportion of after-tax fuel prices (even in the U.S. where fuel taxes are low), relatively little work examines political and economic factors that influence state and country fuel taxes. Goel and Nelson (1999) find that gasoline taxes are negatively correlated with the tax-exclusive gasoline prices. Since tax increases are more likely than decreases, they interpret this as evidence that states are less reluctant to increase taxes when prices are low. In addition, they find evidence that gasoline taxes were negatively correlated with road toll revenue between 1960 and 1981 and were positively correlated with non-compliance with environmental regulation. Decker and Wohar (2007) examine diesel taxes and find that state taxes are positively correlated with non-compliance with environmental regulation. The paper also finds that diesel taxes are negatively correlated with the trucking industry employment. Internationally, Hammar et al. (2004) find that governmental debt as a percent of GDP is positively correlated with gasoline tax. This is less likely to be relevant in the U.S. where states typically set gasoline taxes aside for infrastructure investment rather than to bridge fiscal gaps. Finally, a few papers examine relatively rare gasoline tax moratoria, granted in response to high after-tax gasoline prices. As an example, Doyle and Samphantharak (2008) examine moratoria in Illinois and Indiana in 2000 and estimate the incidence of gasoline taxes near and far from the state border.

3 Aggregate Data Analysis

In this paper, we examine two distinct data sources: (1) aggregate gasoline consumption, vehicle-miles-traveled at the state-level and new vehicle purchase decisions at the MSA-level, and (2) data on individual household vehicle ownership and driving decisions. Each dataset has a separate set of advantages (and disadvantages). The state-level data allows us to examine the full state-wide response of consumer behavior to gasoline tax and price changes. The MSA-level data on new vehicle sales allow us to examine how new vehicle purchases respond to gasoline price and tax changes. In contrast, the household data are purely cross-sectional and cover a shorter time period than the aggregate data. Although we observe households in different states and times, the survey does not track individual households. Despite this, the household data has two advantages. First, the household data provide a much cleaner measure of VMT than the aggregate data. In the micro data, VMT is measured by two odometer readings several months apart. The household data track each vehicle owned by the household separately. Second, the household data include household-level characteristics, potentially allowing for better control of unobservables correlated with both a state's tax rate and our variables of interest. We therefore use the household data to complement the state- and MSA-level data.

In this section, we present our empirical strategy, data and results using the aggregate. Subsequently, we turn our attention to the household data and perform a complementary set of analyses.

3.1 Empirical Methodology

To estimate the relative impact of tax and non-tax price changes on aggregate gasoline consumption and vehicle miles traveled, we employ a similar empirical approach to Marion and Muehlegger (2008) and a related paper, Davis and Kilian (forthcoming). We consider a regression in which we decompose the tax-inclusive retail price into a tax-exclusive component and the tax rate. For gasoline consumption and VMT, we estimate the following linear equation:

$$ln(q_{sy}) = \alpha ln(p_{sy}) + \beta ln\left(1 + \frac{\tau_{sy}}{p_{sy}}\right) + \delta_s + \phi_y + \epsilon_{sy} \quad (2)$$

where q_{sy} is the dependent variable, either VMT per adult or gasoline consumption per adult, by state and year; p_{sy} is the tax-exclusive gas price; τ_{sy} is the total state and federal tax on gasoline; and δ_s and ϕ_y are state and year fixed effects. We identify the correlation between our dependent variables, tax-exclusive gasoline prices and tax ratios off of within-state deviations from the national trend in gasoline consumption or VMT.

This approach provides a very direct test of whether taxes are more strongly correlated with behavior than tax-exclusive gasoline price changes. If consumers respond equally to taxes and tax-exclusive price changes, α is equal to β and equation 2 reduces to a regression of quantity on the tax-inclusive gasoline price. If, on the other hand, consumers respond more to a change in taxes than to a change in the tax-exclusive price, $\beta > \alpha$. Due to the durable good nature of automobiles, consumers likely respond to permanent changes (e.g., variations in gasoline taxes) differently from transitory changes (e.g., due to short-term supply interruptions).

For vehicle purchases, we estimate a slightly different regression equation than that for gasoline consumption and VMT:

$$log(q_{jm}) = \alpha_0 PP_{tm} + \alpha_1 \frac{PP_{tm}}{mpg_j} + \beta_0 \tau_{tm} + \beta_1 \frac{\tau_{tm}}{mpg_j} + \delta_j + \Theta X_{jmt} + \epsilon_{jmt}, \quad (3)$$

where j is the index for a model (e.g., a 1999 Toyota Camry) and m is the index for an MSA.

q_{jm} is the number of vehicles of model j sold in MSA m. PP is the tax-exclusive gasoline price and τ is the federal and state gasoline tax. $\frac{PP_{tm}}{mpg_j}$ is tax-exclusive dollars per mile and $\frac{\tau_{tm}}{mpg_j}$ is tax dollars per mile. The first two terms capture the effect of tax-exclusive gasoline prices on vehicle demand while the next two terms capture the effect of gasoline taxes. The vector of model fixed effects control for unobservable, time-invariant model characteristics. The regression also controls for MSA fixed effects for different types of vehicles (cars, vans, SUVs, and pickups) as well as MSA-specific time trends for different types of vehicles. The approach provide a parsimonious way to test whether the fuel economy of new vehicles responds more strongly to tax changes than to tax-exclusive price changes. α_0 and α_1 capture the effect of gasoline tax changes on vehicle sales while β_0 and β_1 capture the effect of tax-exclusive price changes. Variations in gasoline prices and taxes across MSAs and, more importantly, variations in fuel cost across vehicle models (even in the same MSA) identify these parameters.

Figure 5 plots annual gasoline prices in Atlanta, Hartford, and San Francisco as well as the average gasoline prices across the 22 MSAs from 1999 to 2006. Similar to the variation across states, taxes and tax-exclusive prices vary cross-sectionally. Figure 6 plots gasoline taxes in the three MSAs as well as the averages across the 22 MSAs. In addition, we find some intertemporal variation in gasoline taxes, although the variation is limited somewhat by the shorter time frame of our sample of vehicle sales. However, as we discussed above, variations in fuel cost across vehicles provide important additional sources for identification.

3.2 Sources

We construct a panel of annual data on gasoline consumption, VMT and vehicle purchase decisions. For gasoline consumption and VMT, we collect data at the state-level from 1966-2008. Vehicle-miles-traveled, gasoline consumption, state and Federal gas taxes are taken from annual issues of Highway Statistics Annual published by the Federal Highway Administration. Tax-inclusive retail gasoline prices are from the EIA State Energy Price Reports. We also collect demographic variables, including population and average family size from CPS, BEA and Census; and per capita income, gross state product, and fraction of the population living in metro areas from BEA. The fraction of the population located in metro areas with rail transit is calculated from the Statistical Abstract of the United States. There are several additional vehicle-related variables that also come from the Highway Statistics reports: number of licensed drivers, the number of registered cars and trucks, and miles of public roads. Except for the federal gas tax, all variables vary by state and year.

To examine aggregate vehicle purchase decisions, we examine annual vehicle sales by model in 22 U.S. MSAs from 1999 to 2006. Accounting for about 15.3% of total U.S. vehicles sales, these MSAs are chosen from all nine census divisions and have large variations in terms of size and average household demographics. The vehicle sales data were purchased from R.L. Polk Company, and contain total annual sales of each of the 1,619 models in all 22 MSAs with the exception of Albuquerque, New Mexico, and Little Rock, Arkansas, where we have sales data only from 2001 to 2006. In total, we have 34,860 observations of sales data for the 22MSAs. These MSAs are representative of the national data in terms of average household demographics and vehicle fleet characteristics. The correlation coefficient between model sales in the 22 MSAs and the national total is 0.94 (see Li, Timmins and von Haefen (2009) for more information on the MSA data). For each vehicle model-year, we observe the EPA combined fuel economy rating, MSRP, and other vehicle characteristics. The MSA gasoline prices are collected from the Cost of Living Index data base by American Chamber of Commerce Research Associates. We use gasoline taxes in the corresponding states as MSA-level gasoline taxes.

3.3 Results

Table 2 presents the main coefficient estimates from equation 2. The top panel shows regression results using VMT as the dependent variable and the bottom panel shows gasoline consumption. Each column reports a different specification.

As a baseline, we begin by regressing gasoline consumption and VMT on the tax-inclusive retail gasoline price, rather than separating the total price into the tax-exclusive price and tax rate. Column 1 reports these coefficients for comparison with column 2, which separates the gas price into the tax exclusive gas price and the tax, as in equation 2. Observations are weighted by the state's population so the coefficients can be interpreted as the population-weighted effect of the gas price and gas tax (column 3 shows un-weighted results for completeness).

Columns 4 and 5 address the fact that there is evidence that the dependent variables, gas price, and gas tax follow a random walk. Because the variables appear to be stationary after first-differencing, column 4 reports a specification in which all variables are first-differenced. Column 5 reports a Prais-Winsten regression, which allows for first order correlation and for heteroskedasticity across states. Columns 6 and 7 report specifications that include additional control variables. Column 6 uses the control variables from Small and van Dender, and column 7 adds quadratic state time trends.

We do not find that vehicle miles traveled are more strongly correlated with gasoline taxes than the tax-exclusive gasoline price. In contrast, gasoline consumption is more negatively correlated with the tax ratio than with the tax-exclusive gasoline price in four of the six specifications.

From the point estimates in Table 2, we calculate the implied tax and price elasticities of demand.[7]Note that the average tax in the sample is \$0.25/gallon and the average tax-exclusive price in the sample is \$0.85. Thus, a one percent tax increase corresponds to a much smaller monetary change than a one percent tax-exclusive price increase. If taxes and tax-exclusive prices have similar effects on consumption or VMT, the point estimate for the tax-exclusive price elasticity would be much larger (0.85 / 0.25) than the point estimate for the tax elasticity.[8] Despite the difference in scale of average taxes and average tax-exclusive prices, in most specifications, the point estimate for the tax elasticity of demand is greater than or at least as big as the point estimate on the tax-exclusive price elasticity of demand. In column (5), where we account for autocorrelation and allow for heteroskedasticity across states, we estimate a tax elasticity of demand for gasoline of -0.076 and a tax-exclusive price elasticity of demand for gasoline of -0.043.

Table 4 examines the relationship between new vehicle sales, tax-exclusive gasoline prices and gasoline taxes. Column (1) presents estimation results where we include the tax-inclusive gasoline price rather than separately estimate coefficient for the tax-exclusive price and gasoline taxes. The first two parameters capture the effect of gasoline prices on vehicle demand.The first coefficient is positive while the second one is negative, implying that higher gasoline prices decrease the sales of low-mpg vehicles and increase those of high-mpg vehicles. The results from this specification suggest the elasticity of average mpg with respect to gasoline prices to be 4.28%, implying that a one-dollar increase in gasoline prices would increase the average mpg of new vehicles sold by 5.37% (about 1.20 mpg). The estimate of fuel economy elasticity of new vehicles to gasoline prices often varies significantly depending on model assumptions and data used. Our elasticity estimate is close to those in several recent studies: Austin and Dinan (2005) estimate a long run elasticity of 0.22; Gillingham (2010) finds a medium-run (2-year) fuel economy elasticity of 0.09; Klier and Linn (2010) estimate an elasticity of about 0.12 using monthly data.

Columns (2) to (5) in Table 4 show results for specifications where we separate tax-exclusive gasoline prices from gasoline taxes. The first two coefficients across all four specifications suggest

[7]See Appendix 1 for the derivations of the tax and price elasticities of demand. We also present the full table of elasticity estimates as Table 3.

[8]Similarly, if the tax-exclusive price and tax have similar effects on gasoline consumption or VMT, we would expect the coefficient on the tax-exclusive price elasticity to be smaller (0.85 / 1.10) than the tax-inclusive price elasticity.

that higher tax-exclusive gasoline prices reduce the sales of low-mpg vehicles and increase those of high-mpg vehicles. The third and fourth parameter estimates imply that the same result holds for gasoline taxes. However, tax-exclusive gasoline prices have much smaller effects than gasoline taxes on vehicle demand. The coefficient estimates from column (2) suggest the elasticity of fuel economy to tax-exclusive gasoline price changes to be 0.057 and that to gasoline tax changes to be 0.198. Because tax-exclusive gasoline prices are much larger than gasoline taxes from 1999 to 2006, it is useful to compare the two effects based on semi-elasticities. A one-dollar increase in tax-exclusive gasoline prices would increase the average mpg of new vehicles sold by only 3.6%, the same increase in gasoline taxes would increase the average mpg of new vehicles by 47.7%.This finding is robust across different specifications of fixed effects. In the three other specifications, we find that sales of high fuel economy vehicles rise more with a tax increase than with a tax-exclusive price increase of comparable magnitude.

We should take the effect from a one-dollar increase in gasoline tax with caution: the average gasoline tax is only about 42 cents so the prediction is far out of sample. Nevertheless, the difference between the fuel economy response to tax-exclusive price changes and that to gasoline tax changes is striking. The effect from the gasoline tax changes is far larger than any estimates that we are aware of on fuel economy response of new vehicles to gasoline prices. This suggests that previous analysis could underestimate by a wide margin the relative strength of gasoline tax changes, for example, to CAFE standards.

Gasoline taxes have a much larger effect than tax-exclusive prices on new vehicle purchases. In contrast, the previous section did not show as large a difference between the effect of taxes and tax-exclusive prices on gasoline consumption . This is perhaps not surprising for two reasons. First, price changes affect gasoline consumption mainly through effects on vehicle fuel economy of all vehicles and on driving intensity. Our previous analysis did not find that VMT responds more to tax-exclusive price changes than to gasoline tax changes in the short run. Second, given that automobiles are durable goods and the significant costs involved in vehicle transactions, we would expect gasoline price changes to affect the market share of new vehicles more strongly than used vehicles. Supporting this hypothesis, Busse, Knittel, and Zettelmeyer (2009) find that the adjustment in new vehicle market to gasoline price changes is primarily in market shares, while it is primarily in vehicle prices in the used vehicle market. Taken together, we believe that the differential effect of tax-exclusive price changes and gasoline tax changes on gasoline consumption is primarily driven by the differential effect on the fuel economy of new vehicles.

3.4 Identification and Interpretation

We perform several additional analyses to help rule out the possibility that omitted variables, correlated with both state tax rates and our variables of interest, are driving the difference between the tax rate and tax-exclusive gasoline prices. Of particular concern are unobserved trending variables - omitted demographic trends affecting vehicle ownership or driving intensity that are correlated with a state raising the gasoline tax.

First, we look for evidence of trends in gasoline consumption occuring prior to changes in the gasoline tax. Figure 3 demonstrates the strong persistence in federal and state gasoline taxes over time. Putting aside the presence of the time dummies in equation 2, which control for aggregate shocks, regressing VMT or gas consumption on the gas tax amounts to comparing average VMT or gas consumption before and after a change in the tax. The estimates in table 2 could therefore be biased by pre-existing trends. We address this possibility by replacing the tax variable in equation 2 with two dummy variables that are equal to one if the state gas tax increases or decreases that year. We also include leads and lags of the increase and decrease variables, and plot the coefficients and 95% confidence intervals in figure 7. Note that it is 10 times more likely for a state to increase its gas tax than to decrease it, and on average each state decreases its gas tax once. These patterns imply that the tax elasticity is estimated primarily from tax increases, and we focus on those results in the figure. The tax change takes place during year 1, and the figure shows no evidence of that pre-existing trends create bias. Because of the small number of instances in which a state decreases its tax, the estimates for the tax decrease variables are highly sensitive to dropping the states that decrease their taxes most often.

Next, we examine a shorter state-level panel of monthly gasoline taxes, prices, and consumption from 1983 to 2008. We regress consumption on the pre-tax price and tax rate, in both levels and after first-differencing.[9] In order for an omitted variable to bias the FD specifications, the omitted variable must change contemporaneously with state changes in excise tax rates. We present the results in table 5. In both cases, we find a significant difference between the coefficients on pre-tax price and the tax rate. While omitted trending variables may bias the levels regressions, omitted variables would have to change contemporaneously with the state gasoline taxes to bias the coefficients of the first-differenced regression.

[9] When regressing in levels, we include state fixed-effects and year fixed-effects. In the FD specification, we only include year fixed-effects.

4 Household Data Analysis

4.1 Empirical Methodology

This section conducts analysis based on household level data, with a focus on the effect of gasoline price changes on vehicle travel. In the aggregate data, state-level VMT is based on annual data imputed by each state transportation commission and reported to the Federal Highway Administration. Unfortunately, each state uses its own methodology to compute annual VMT. Thus, the aggregate VMT measures may not be perfectly comparable (Small and van Dender 2005). In constrast, VMT in the household data is based on consecutive odometer readings, taken several months apart, for each of a household's vehicles - this provides a very accurate measure of household level driving behavior. In addition, the analysis based on aggregate data may suffer from aggregation bias when underlying individual VMT are affected nonlinearly by gasoline prices. .

An additional advantage of household level analysis is that the household data provide detailed demographic characteristics about each household. Each household is categorized into one of eighteen income bins, eight education bins and provides detailed data on the number and age of adults, workers and drivers in the household. In addition, the data provide detailed information about neighborhood (census tract) demographics such as rural and urban indicators, population, working population, and housing density, and availability of rail. Consequently, the household data provide a more detailed set of controls for characteristics that may vary with both a state's tax rate and consumer driving or purchase decisions.

A shortcoming of the household data is that the data period spans only four years (1995, 1996, 2000 and 2001) so variations in gasoline taxes are very limited within a state. In addition, it is important to note that unlike the aggregate data, where we observe both cross-sectional and time series variation, we do not observe a given household over multiple survey waves.

We employ a similar empirical strategy to the one we use to examine the aggregate data in the previous section, but exploit the richer set of demographics and geographic characteristics present in the household data. We estimate the following equation:

$$ln(VMT_i) = \alpha ln(p_i) + \beta ln\left(1 + \frac{\tau_i}{p_i}\right) + \Theta X_i + \epsilon_i \qquad (4)$$

where i denotes a household. The dependent variable is average daily VMT per vehicle across all vehicles in the household .The key explanatory variables include the tax-exclusive gasoline price and the tax ratio in a household's state. We include household demographics, including a quadratic function of household size, the age of the primary driver, the number of adults, the number of workers and the number of drivers in each household.. In addition, we include a large set of fixed effects - we include fixed effects for each income bin, education bin, month of survey, year of survey, census division, and population / housing / worked density bin.

4.2 Sources

The primary sources for the household data are the 1995 and 2001 installments of the National Highway Transportation Survey (NHTS). The NHTS, conducted by agencies of the Department of Transportation through random sampling, provides detailed household level data on vehicle stocks, travel behavior and household demographics at the time of survey. The 1995 survey was conducted from May 1995 to July 1996 on 42,033 households and 75,217 vehicles owned by these households. The 2001 survey was conducted from March 2001 through May 2002. There are 69,817 households and 139,382 vehicles in the data.

To examine vehicle miles traveled, we exploit a subset of the NHTS data. During the 1995 and 2001 installments, participants received an initial survey followed by a second survey several months later. In both, participants were asked to report the odometer readings of all vehicles owned by the household. We calculate daily VMT per vehicle across vehicles owned by a household by comparing the two odometer readings for each vehicle. We also construct the average gasoline price during the odometer reading period based on the date of odometer reading and weekly state gasoline prices. Unfortunately, not all survey participants report the second odometer reading and there are many missing values for the first odometer reading. We drop approximately two-thirds of the households in the 1995 and 2001 survey waves with missing data for either of the two odometer readings or reading dates for any of the vehicles owned by the household. The average daily VMT per vehicle across the 34,234 households in the estimation sample is 50.89 with a standard error of 34.25. Figure 8 plots the distribution of the average daily VMT per vehicle.

Because the observations used for our analysis only constitute about one-third of the full sample, it is important to know how representative the sample of analysis of is. Appendix 3 compares the characteristics of the subsample of participants who report two odometer readings with the characteristics of the full 1995 and 2001 samples. We find that the mean tax-exclusive price and gasoline taxes for the VMT subsample and full sample compare quite closely. Households in the estimation sample are slightly older (mean age 50.66 v. 49.59) and less likely to live in an MSA with a subway system (14% v. 16%). Overall, however, the mean, 10th, and

90th percentiles of the distributions of the variables are quite similar for the full sample and the estimation sample. The appendix figures show the distributions of the categorical variables for both samples. Similarly to the other variables, the distributions for these variables are very similar for the full NHTS and the estimation samples. These comparisons suggest that the estimation sample may be representative of the full NHTS sample, but we treat the estimation results with caution.

4.3 Results

Table 6 presents key parameter estimates as well as the VMT elasticities. Columns (1) to (3) are from specifications that have total gasoline prices in the regression while columns (4) to (6) reports results for specifications that separate tax-exclusive prices from gasoline taxes. All six regressions include a large set of control variables beyond those shown in the table as discussed above. The first and fourth specifications do not include geographic dummy variables while the second and fifth specifications include census region dummies. The third and the sixth specifications include state dummies.

The VMT elasticity with respect to gasoline prices in the third specification is -0.34 with a standard error of 0.15. This is close to the estimate of -0.24 from the analysis using state-level data, bearing in mind that the data period and average gasoline prices are different in the two samples. The average gasoline price in the household data is $1.30 while that in the state data is $1.10. Columns (4) to (6) separate gasoline tax from gasoline prices. When we include census region and especially state dummies in the regression, it is difficult to identify the effect of gasoline taxes. This is likely due to the limited variations in gasoline taxes during the sample period. None of the VMT tax elasticities is significant, whereas the VMT tax-exclusive elasticities are all significant and consistent with the corresponding elasticities in columns (1) to (3). Nevertheless, in all three cases, we cannot reject that the VMT elasticity to tax-exclusive prices is the same with that to gasoline taxes. This finding is also consistent with the results from the state data.

5 Implications

Our results inform several other research questions related to vehicle choice and gasoline consumption. In particular, our work has important implications for estimating consumer valuation of fuel economy, variation in the tax-inclusive demand elasticity of gasoline and the fiscal-motivation for gasoline taxes.

5.1 Estimation of implicit discount rates

First, our paper addresses a fundamental identification problem in estimating consumer discount rates for fuel economy. For illustrative purposes, assume that vehicles only vary in their fuel economies and sticker prices.[10] Faced with an array vehicle choices (indexed by i) with upfront costs p_i and expected fuel costs of $E[c_i t|c_0]$, a rational consumer with discount rate δ focusing entirely cost will choose the vehicle that minimizes total expected costs

$$E[totalcosts] = p_i + \sum_{t=1}^{\infty} \delta_t E[c_i t|c_0].$$

Estimation follows from cross-sectional or time series variation in current fuel costs, c_0. The identification problem arises because the econometrician typically does not observe a consumer's implicit discount rate, nor their expectation of future gasoline prices conditional on c_0. Consequently, it is not possible to estimate implicit discount rates independently from assumptions of consumers' expectation of future gasoline costs.

Our approach overcomes this identification problem by decomposing gasoline price changes into a tax component and a tax-exclusive price. If state and federal tax changes are (more likely) to be perceived as permanent by consumers, estimates of the implicit discount rate based on consumer response to changes in state taxes may provide an unbiased (less biased) estimate of implicit discount rates. Moreover, estimates based on cross-sectional or time series variation in *tax-inclusive* prices may lead to substantial overstatement.

5.2 Intertemporal variation in gasoline demand elasticity

Hughes et al. (2008) report a strong decline in the own-price elasticity of gasoline demand between the 1970s and the early 2000s. Given the long time horizon of our state-level data set, we can similarly test whether the tax or the tax-exclusive elasticity has changed over time. In contrast to their results, we do not find evidence of a similar shift in the tax-exclusive price elasticity or the tax elasticity over time.

If consumers respond differently to state tax changes than to changes in the tax-exclusive price, observed variation in the tax-inclusive price elasticity may be partially attributable to the composition of tax changes.

[10] A second identification challenge arises when vehicle attributes vary with sticker price p_i. We do not address this identification challenge in this note.

5.3 Tax elasticity of tax revenues

Finally, our approach has implications for fiscal policy related to gasoline taxes. Our empirical estimates suggest that a naive estimate of the effect of a one-cent increase gasoline taxes, based on the tax-inclusive price elasticity, would substantially understand true consumer response. Consequently, a fiscally-motivated gasoline tax may appear more attractive than reality.

As an illustration, we calculate the change in tax revenues associated with a five cent-per-gallon increase in federal gasoline taxes using our naive estimate (regressing log of gasoline consumption on the tax-inclusive gasoline price) and the corresponding estimates from column 1 of Table 2. The naive estimate (based on a tax-inclusive price elasticity of -0.192, an average tax-inclusive gasoline price of $1.10 and average state taxes of $0.25), would imply that a five cent-per-gallon increase in state gasoline prices would increase tax revenues approximately 19% over the sample. Using the separately-estimated tax and price coefficients from column 2 in Table 2, we find higher gasoline taxes appear a less attractive (although still a revenue-increasing) fiscal option. A five cent-per-gallon increase in gasoline taxes implies a 15.5% increase in tax revenues.

6 Conclusion

In this paper, we examine three margins along which consumer respond to gasoline prices: (1) consumption of gasoline, (2) vehicle miles traveled, and (3) choice of vehicle. In contrast to the previous literature, we separately estimate consumer response to gasoline taxes and changes in the tax-exclusive gasoline price. We find evidence that gasoline tax changes are associated with larger changes in gasoline consumption and vehicle choices than commensurate changes in the tax-exclusive gasoline price.

Our work has important implications for fuel economy policy. First and foremost, our work suggests that fuel taxes may be a more effective measure of reducing gasoline consumption or inducing consumers to adopt more fuel efficient vehicles than previously thought. Second, our work suggests that previous estimates of the implicit discount rate for fuel economy based on changes in tax-inclusive prices may substantially overstate true implicit discount rates. Finally, our work suggests that traditional estimates may underestimate consumer response to a fiscal benefits of a gasoline tax

In addition, our work has broader implications for the estimation of demand elasticities. For goods or activity where consumers incur fixed costs to change behavior, our work suggests that it is important to consider the source of price variation. If consumers believe tax changes are likely to be more persistent than changes in the tax-exclusive price, the price elasticity of demand will depend on the mix of tax and tax-exclusive excise tax changes.

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Appendix

A1: Estimating the Price and Tax Elasticity of Demand

Following the decomposition in Marion and Muehlegger (2008), we can derive the price and tax elasticities of demand from the coefficients in equation 2. Marion and Muehlegger (2011) find strong evidence that state taxes are fully (and rapidly) passed onto consumers. Under the assumption that consumer bear the entire tax, the tax-exclusive price is not affected by a change in the tax rate, dp/dt = 0. Under this assumption, we take the derivative of equation 2 with respect to price and tax and rearrange terms:

$$\epsilon_p = \alpha - \beta \frac{\tau}{p+\tau}; \qquad \epsilon_\tau = \beta \frac{\tau}{p+\tau}. \tag{5}$$

Similarly, we can derive the quantity change associated with a unit increase in either the tax-exclusive price or gasoline tax.

$$\frac{\partial log(q)}{\partial p} = \frac{1}{p}\left(\alpha - \beta \frac{\tau}{p+\tau}\right); \qquad \frac{\partial log(q)}{\partial \tau} = \beta \frac{1}{p+\tau}. \tag{6}$$

Transforming the point estimates and standard errors from Table 2, we have the following estimated elasticity as well as the quantity change in response to a unit change in the tax exclusive price.

A2: Correlation between gas prices, taxes and other explanatory variables

Our empirical strategy uses both cross-state and time-series variation in the tax-exclusive gasoline price and gasoline tax. The primary empirical concern is that even after including census division and year dummy variables, the tax-exclusive gasoline prices, gasoline taxes and the behavior we wish to study may all be correlated with omitted variables. Hence, the coefficients we estimate on gas taxes and tax-exclusive prices may subsume the effect of the omitted variables.

In principle, we could use several strategies to address the omitted variables. In this appendix, we examine whether gas tax and price are correlated with our other independent variables. To preview our results, we find little evidence that suggests that gasoline prices and taxes are strongly correlated with the other independent variables.

We first calculate the average tax-exclusive gas price and gas tax by Census division and year. We then define two subsamples of the estimation sample, based on whether the household's gas price or gas tax is above or below the corresponding Census division-year mean. For example, the "high tax-exclusive price" sample includes all households with a tax-exclusive price above the mean tax-exclusive price. The other samples are defined analogously. Note that a given household could be in the high tax-exclusive price sample, but in the low tax sample, or vice versa. This happens about half the time, and is consistent with the fact that the tax-exclusive gas price and tax rate are weakly correlated with one another. Also, note that it is also possible that a household in the low tax-exclusive price sample has a higher tax-exclusive price than a household in another Census division that is in the high tax-exclusive sample; this would occur if the first household is located in a Census division in which the average tax-exclusive price is higher than the average price in the Census division of the second household.

Table 7 reports the means of the variables with standard deviations in parentheses. Panel A compares the high (price or tax > mean) and low (price or tax < mean) samples, and Panel B compares the 10th and 90th percentile subsamples. The table also reports the difference in the means across the subsamples. In many cases, the difference is statistically significant (not reported in the table), but is pretty small in magnitude.

A3: Comparison of the NHTS sample and estimate sample

The full NHTS sample includes household-level observations from the 1995, 2001 and 2009 surveys, but participants were only surveyed twice in the 1995 and 2001 surveys. Consequently, we are unable to measure household level VMT in the 2009 survey data. Moreover, approximates two-thirds of the participants in the 1995 and 2001 surveyed did not submit two separate odometer readings. Consequently, we want to know whether the estimation sample "looks similar" to the full sample, which will have implications for our interpretation of the estimation results.

Table 8 and Figures 9 and 10 compare the 1995 / 2001 NHTS and estimation samples. The variables include demographic and other information collected in the survey, as well as other information that was merged by DOT after the survey data were collected. The demographic variables collected in the survey that we use are: household size, number of drivers, number of adults, number of workers, age of respondent, household income (a categorical variable), and education of respondent. Variables merged in by DOT are: housing units per square mile, workers per square mile, population per square mile, urban/rural indicator, and whether the MSA has a subway. The value labels for the categorical variables can be found at the end of this note. For example, for the worker density variable, a value of 1 means <25 workers per square mile, a value of 2 means >25 and <75 per square mile, etc.

From the survey data we have constructed variables measuring household gasoline consumption, VMT, and average mpg of vehicles owned (un-weighted average mpg and VMT-weighted average weighted mpg). These variables are constructed for households with two non-missing odometer readings for all of their vehicles. We have merged the tax-exclusive gasoline price and the total (state plus federal) gasoline tax for these households.

The combined sample, referred to as the full NHTS sample, contains 111,850 households. The estimation sample does not include observations with missing values for any of the independent or dependent variables, and contains 34,234 observations. Note that the estimation sample is actually the estimation sample for the gasoline consumption regressions; the estimation sample differs for other dependent variables. The primary reason why the estimation sample is so much smaller is that there are many households with missing values for at least one odometer reading.

Table 8 compares the full NHTS sample with the estimation sample. Panel A reports un-weighted summary statistics, and Panel B weights observations by the sample weights. The table includes the non-categorical variables, as well as the 0/1 subway variable. The table shows the number of observations with non-missing values for each sample, as well as the mean, 10th and 90th percentiles.

Figures 9 and 10 shows the distributions of the categorical variables for the full sample and the estimation sample. The bars in the figures indicate the share of observations that have the indicated value of the variable, with separate charts for un-weighted and weighted results.

Figure 1: Gasoline Price Decomposition

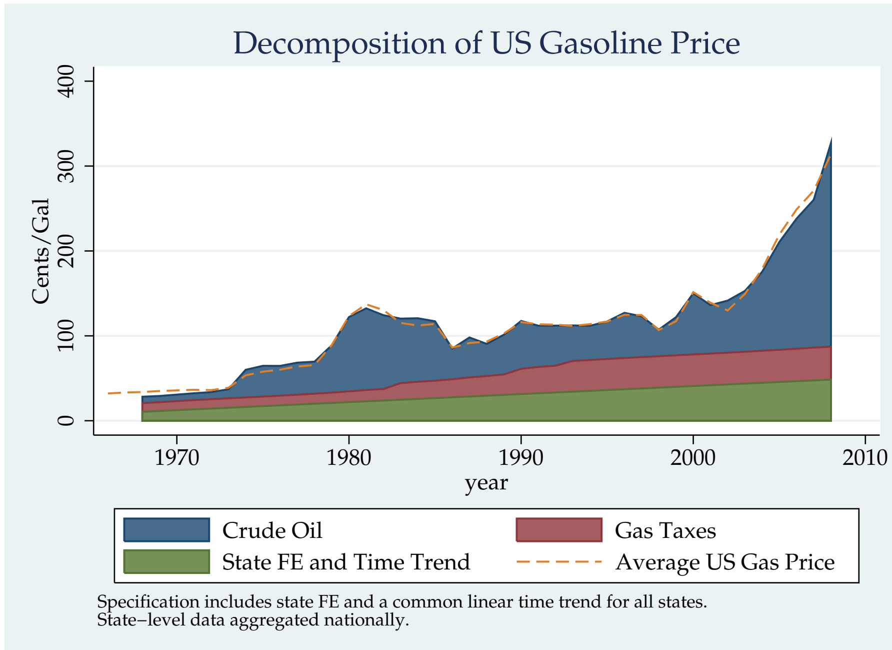


Table 1: Nominal Prices and Taxes (cpg), over time

Years	Average Tax-Inclusive Retail Price	Average State Tax	Average Federal Tax	Percent of Retail Gas Variation Explained by Tax Changes
1968 - 1970	34.0	6.7	4.0	48.3%
1971 - 1975	44.6	7.6	4.0	2.3%
1976 - 1980	80.4	8.4	4.0	2.1%
1981 - 1985	121.8	11.2	7.0	19.3%
1986 - 1990	98.0	15.1	10.1	11.4%
1991 - 1995	113.9	19.1	16.7	25.5%
1996 - 2000	125.0	20.3	18.4	2.2%
2001 - 2005	163.3	20.8	18.4	2.0%
2006 - 2008	278.0	21.8	18.4	0.6%

Figure 2: State Gasoline Tax Rates

Figure 3: Distribution of Gasoline Taxes, by year

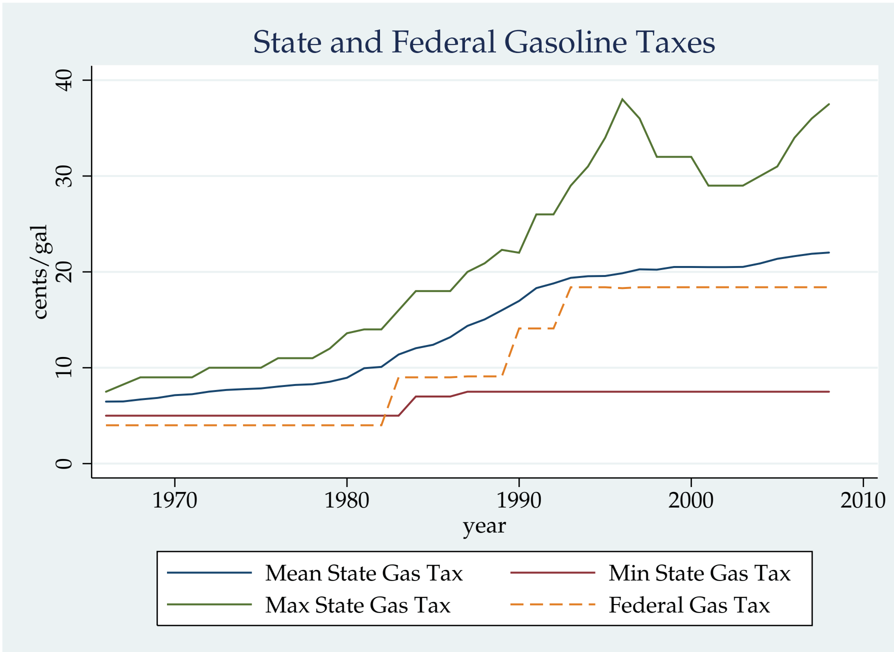


Figure 4: Tax Fraction of Retail Price, by year

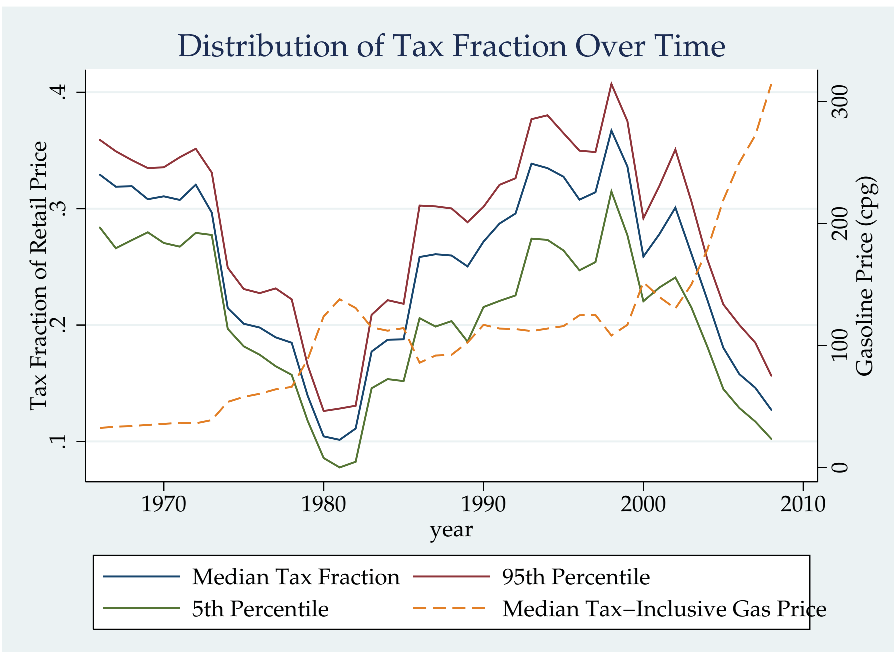


Figure 5: Tax-Inclusive Gasoline Prices, selected MSAs

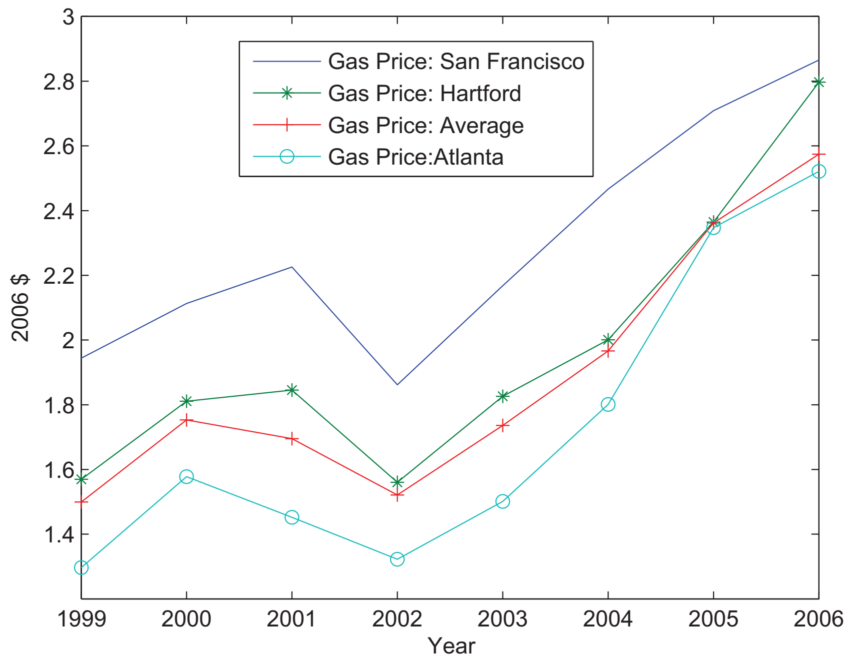


Figure 6: Gasoline Taxes, selected MSAs

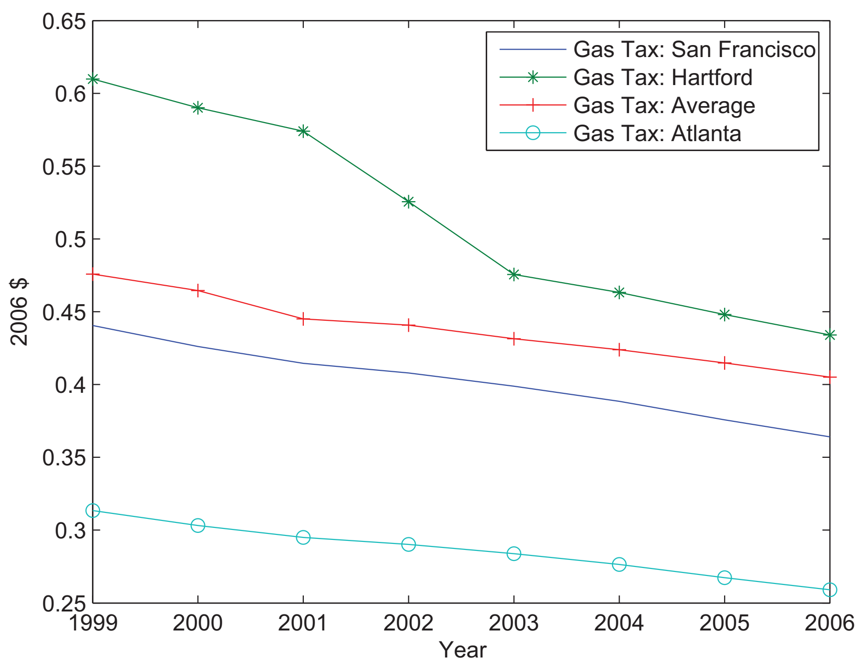


Figure 7: Change in VMT and Gas Consumption, pre- and post-tax change

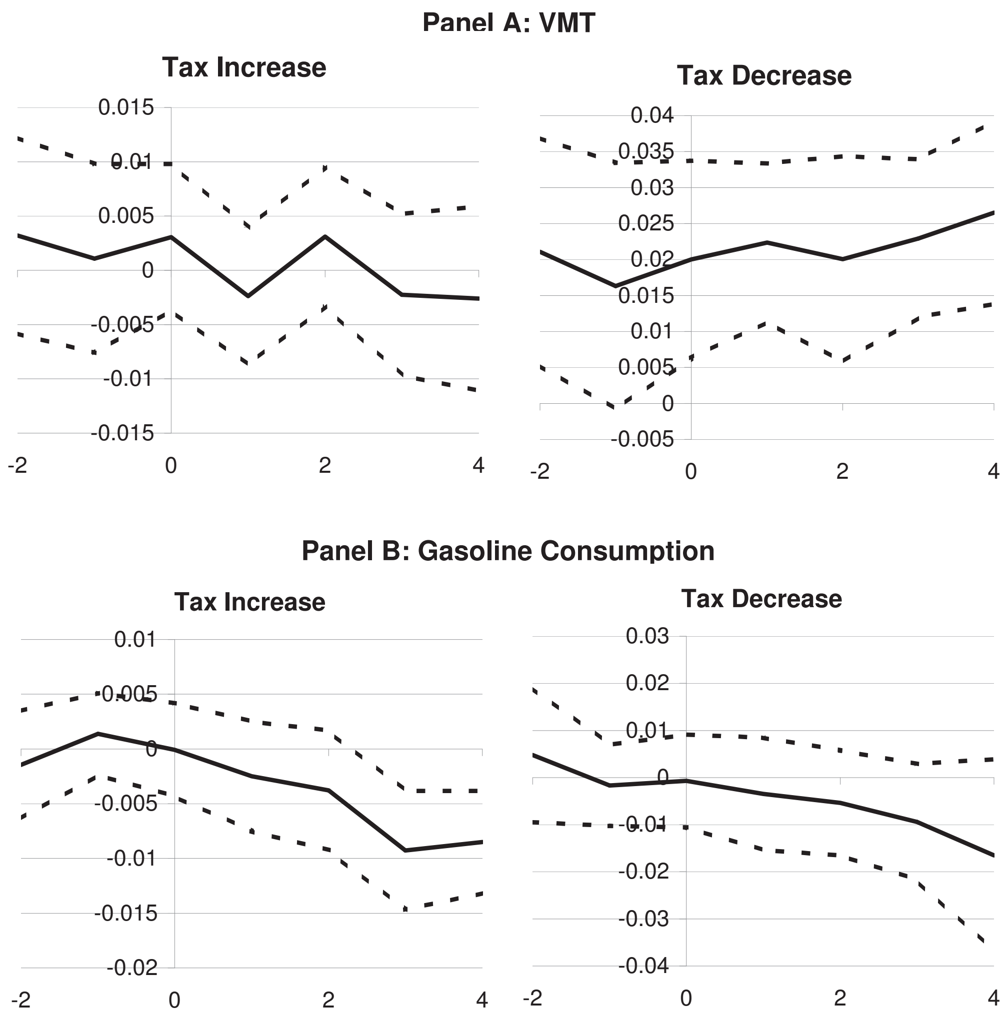


Figure 8: VMT Kernel Density Estimate

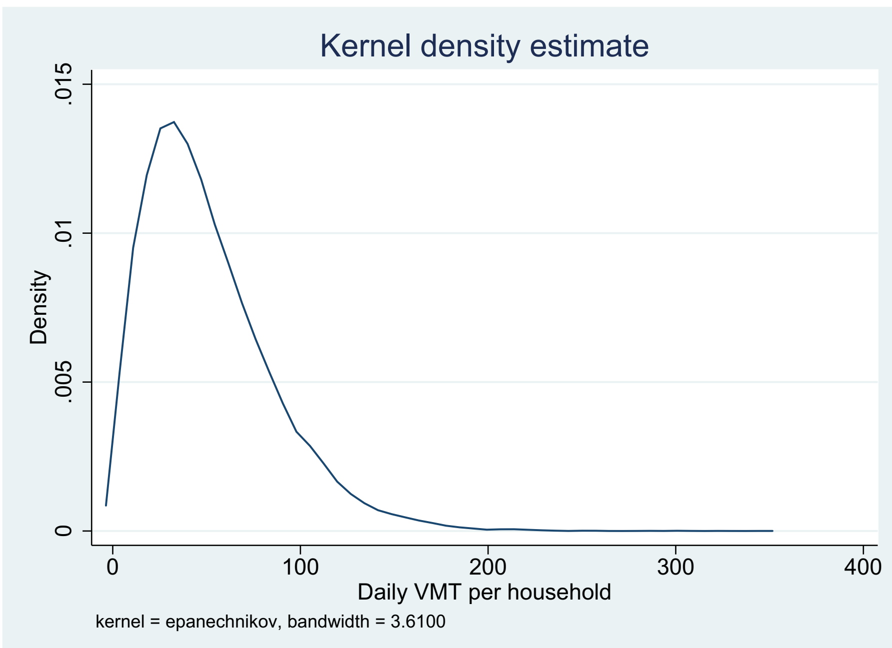
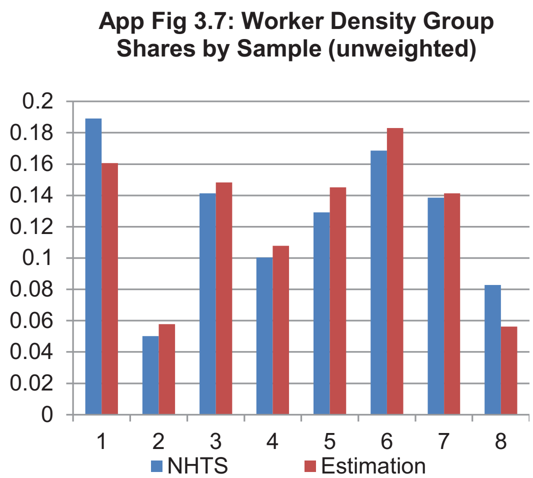
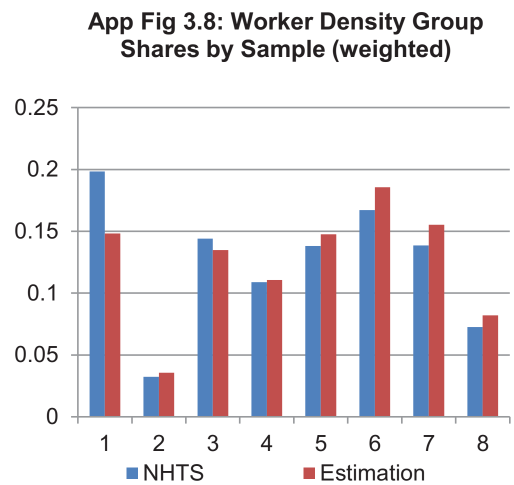
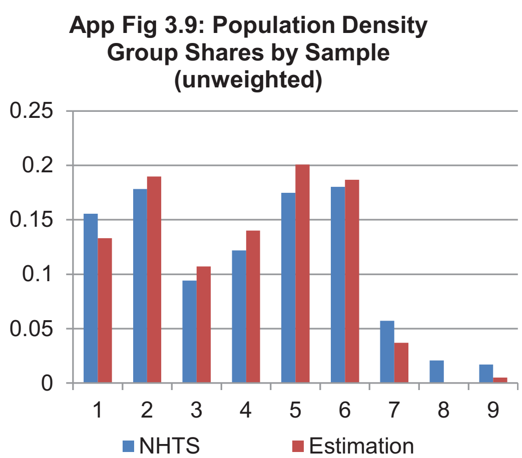


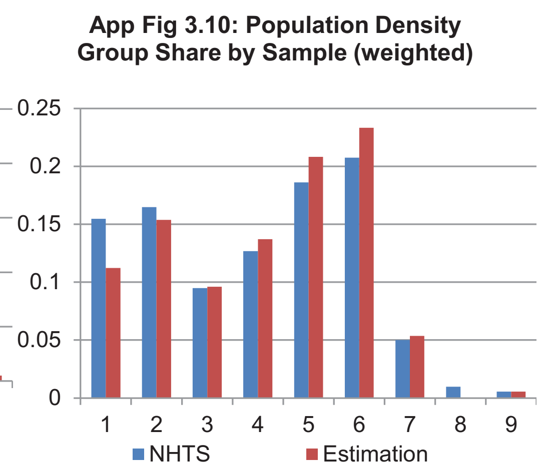
Figure 9: Appendix Tables 3.1-3.6

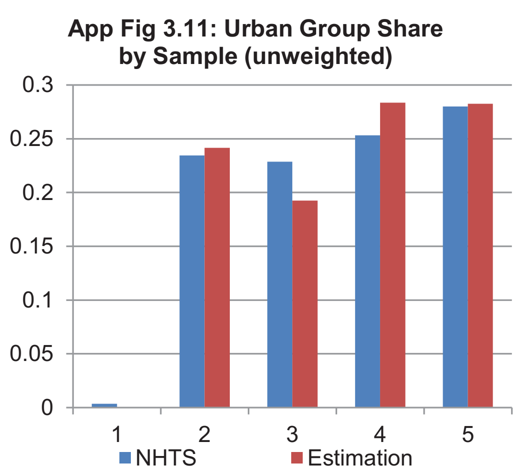
Figure 10: Appendix Tables 3.7 - 3.12











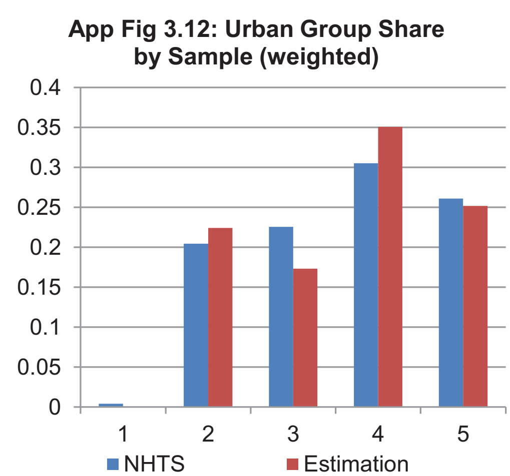


Table 2: Coefficient Estimates for VMT and Gasoline Demand Regressions

Panel A: Dependent Variable: Log VMT per Adult

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log Gas Price	-0.238						
	(0.109)						
Log Tax-Excl Gas Price		-0.245	-0.175	-0.013	-0.031	-0.202	-0.110
		(0.107)	(0.088)	(0.037)	(0.032)	(0.092)	(0.079)
Log (1 + Tax Ratio)		0.043	-0.319	-0.034	-0.070	0.038	0.025
		(0.260)	(0.267)	(0.065)	(0.071)	(0.278)	(0.212)
N	2,064	2,064	2,064	2,016	2,064	2,064	2,064
R2	0.95	0.95	0.93	0.40	1.00	0.96	0.98

Panel B: Dependent Variable: Log Gasoline Consumption per Adult

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log Gas Price	-0.235						
	(0.061)						
Log Tax-Excl Gas Price		-0.227	-0.207	-0.032	-0.119	-0.187	-0.114
		(0.053)	(0.061)	(0.022)	(0.029)	(0.039)	(0.030)
Log (1 + Tax Ratio)		-0.574	-0.765	-0.041	-0.316	-0.490	-0.180
		(0.173)	(0.176)	(0.084)	(0.071)	(0.094)	(0.079)
N	2,064	2,064	2,064	2,016	2,064	2,064	2,064
R2	0.95	0.95	0.90	0.57	0.99	0.97	0.98
Specification	Tax-inclusive gas price	Separate tax from tax-exclusive price	Un-weighted	First differenced	Prais-Winsten regression	Add controls to (2)	Add quadratic state trends to (6)

Notes: The dependent variable in the first panel is the log of vehicle miles traveled per adult and the dependent variable in the second panel is the log gallons of gasoline consumed per adult, by state and year. The bottom of the table shows the specification used in each column. All regressions are estimated by Ordinary Least Squares except for column 5, which reports a Prais-Winsten regression that allows for first order autocorrelation of the error term, heteroskedasticity, and correlation across states. Standard errors are clustered by state except in column 5. Columns 1, 2, and 4-7 report weighted regressions, using the state's share in national population for the corresponding year as the weight. Column 3 is unweighted. Columns 1-3 and 5-7 include state and year dummies, and column 4 includes year dummies. All variables are first differenced in column 4. Column 6 adds to column 2 the family size, log road miles per adult, log gross state product per capita, log number of registered cars and log number of registered trucks, log number of licensed drivers, log real income per capita, fraction of the population living in metro areas, and fraction of population living in metro areas with rail transport. Column 7 adds to column 6 the interactions of a set of state dummies with linear and quadratic time trends.

Table 3: Elasticity of VMT and Gasoline Demand

Panel A: Dependent Variable: Log VMT per Adult

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Price Elasticity	-0.238 (0.109)						
Tax-Exclusive Price Elasticity		-0.255 (0.090)	-0.096 (0.077)	-0.005 (0.026)	-0.014 (0.023)	-0.211 (0.078)	-0.116 (0.040)
Tax Elasticity		0.010 (0.062)	-0.079 (0.066)	-0.008 (0.016)	-0.017 (0.017)	0.009 (0.067)	0.006 (0.051)

Panel B: Dependent Variable: Log Gasoline Consumption per Adult

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Price Elasticity	-0.235 (0.061)						
Tax-Exclusive Price Elasticity		-0.089 (0.044)	-0.018 (0.051)	-0.022 (0.013)	-0.043 (0.021)	-0.070 (0.032)	-0.071 (0.024)
Tax Elasticity		-0.138 (0.041)	-0.189 (0.043)	-0.010 (0.020)	-0.076 (0.017)	-0.118 (0.023)	-0.043 (0.019)
Specification	Tax-inclusive gas price	Separate tax from tax-exclusive price	Un-weighted	First differenced	Prais-Winsten regression	Add controls to (2)	Add quadratic state trends to (6)

Notes: Table reports estimated elasticities with standard errors in parentheses. Each cell uses coefficient estimates from corresponding specification in Table 1. To calculate elasticities, columns 2 and 4-7 use the weighted average of the ratio of the gas tax to tax-exclusive gas price, weighting by adult population. Column 3 uses the simple average of the ratio.

Table 4: Gasoline Taxes, Pre-tax Prices and Vehicle Demand

Dependent Variable: Model-level market share

Variable	(1)	(2)	(3)	(4)	(5)
Gas price	1.1228				
	(0.132)				
dollars per mile (gas price/mpg)	-22.4299				
	(2.4775)				
Pre-tax gasoline price		0.7568	0.1043	0.6688	2.5386
		(0.1322)	(0.1284)	(0.1273)	(0.1598)
Pre-tax dollars per mile		-14.0798	-0.0079	-12.9595	-17.4372
		(2.4706)	(2.3716)	(2.4508)	(3.3004)
Gasoline Tax		8.3211	7.6569	8.3982	0.0936
		(0.4514)	(0.4501)	(0.3569)	(0.4178)
Tax dollars per mile		-187.9146	-173.4143	-183.3634	-147.4233
		(6.5605)	(6.5513)	(6.4841)	(8.7434)
log(MSA median household income)	-3.8307	-3.8132		-3.2027	-2.1324
	(0.2631)	(0.2612)		(0.2392)	(0.3142)
log(vehicle price)/log(income)	-18.7574	-18.8389		-18.2128	-15.3581
	(0.9924)	(0.982)		(0.9778)	(1.4838)
Vehicle model fixed effects	Yes	Yes	Yes	Yes	No
MSA dummies	Yes	Yes	Yes	Yes	No
MSA dummies * van dummy	Yes	Yes	Yes	Yes	No
MSA dummies * SUV dummy	Yes	Yes	Yes	Yes	No
MSA dummies * pickup dummy	Yes	Yes	Yes	Yes	No
MSA dummies * time trend	Yes	Yes	Yes	No	No
MSA dummies * van dummy * time trend	Yes	Yes	Yes	No	No
MSA dummies * SUV dummy * time trend	Yes	Yes	Yes	No	No
MSA dummies * pickup dummy * time trend	Yes	Yes	Yes	No	No
Number of observations	34860	34860	34860	34860	34860
R-squared	0.7343	0.7399	0.7371	0.7365	0.2889
Elasticity of mpg w.r.t. gas price	0.0428				
	(0.0126)				
Elasticity of mpg w.r.t. pre-tax price		0.0566	0.0009	0.0519	0.083
		(0.0106)	(0.0104)	(0.0107)	(0.0127)
Elasticity of mpg w.r.t. gas tax		0.1983	0.183	0.1936	0.1538
		(0.0059)	(0.006)	(0.0058)	(0.0072)

Notes: The dependent variable is the market share of a vehicle model in logarithm. The number of observations is 34,860. Standard errors are in parenthesis. Estimations are based on sales of new vehicles in 22 MSAs, which are chosen from all nine census divisions. The correlation coefficient between total sales from these 22 MSAs and national sales at the model level is 0.94.

Table 5: Gasoline Taxes, Pre-tax Prices and Consumption, monthly

Dependent Variable: Log Gasoline Consumption

Variable	Levels (1)	(2)	First-differenced (3)	(4)
Log Gas Price	-0.196***		-0.248***	
	(0.0298)		(0.0296)	
Log(Tax-Exc Gas Price)		-0.217***		-0.365***
		(0.0276)		(0.0469)
Log(1+TaxRate)		-0.414***		-0.769***
		(0.0461)		(0.157)
Observations	14898	14898	14763	14763
R-Squared	0.987	0.987	0.446	0.446

Notes: All specifications include date fixed effects. Levels regressions also include state FE. Robust standard errors clustered by state. *, **, and *** denote significance at the 10%, 5% and 1% levels.

Table 6: Gasoline Taxes, Pre-tax Prices and Household VMT

Dependent Variable: Mean Daily Vehicle Miles Traveled

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Log gas price	-0.425	-0.224	-0.34			
	(0.116)	(0.131)	(0.147)			
Log Tax-exclusive gas price				-0.425	-0.226	-0.133
				(0.113)	(0.129)	(0.264)
Log gas tax				-0.425	-0.173	0.427
				(0.286)	(0.19)	(0.771)
Census division dummies	No	Yes	No	No	Yes	No
State dummies	No	No	Yes	No	No	Yes
R-squared	0.341	0.343	0.345	0.341	0.343	0.345
Elasticity w.r.t. tax-excl gas price				-0.292	-0.172	-0.266
				(0.099)	(0.101)	(0.099)
Elasticity w.r.t. gas tax				-0.133	-0.054	0.133
				(0.089)	(0.059)	(0.24)

Notes: The number of observations is 34,234. Data is from 1995 and 2001 National Household Travel Survey. The dependent variable is the average daily VMT per vehicle across all the vehicles in a household and the unit of analysis is household. VMT is from two odometer readings with the first being recorded at the time of initial survey and the second being recorded several months later. We only keep households for which there is no missing odometer reading for any of the vehicles owned. All the regressions include a large set of control variables including survey year and month dummies, household demographics (household size, household income, number of workers, number of adults, number of drivers, age of the reference person, education), neighborhood charactersitics at census tract level (housing density, worker density, population density, urban/rural category), MSA size, and availability of rail. We use dummy variables for those defined in categories in the data. Sampling weights are used in all regressions. Cluster standard errors (at states) are reported in parenthesis.

Table 7: Summary Statistics for Non-categorical Household Attributes

Panel A: High = Above Price or Tax Mean in Division-Year; Low = Below Mean

Variable	High Pre-tax Price	Low Pre-tax Price	Difference	High Tax	Low Tax	Difference
Pre-tax Price	0.93 (0.13)	0.86 (0.09)	0.07	0.90 (0.11)	0.88 (0.12)	0.02
Tax	0.40 (0.04)	0.40 (0.04)	-0.01	0.42 (0.03)	0.36 (0.04)	0.06
Household Size	2.54 (1.28)	2.59 (1.31)	-0.05	2.57 (1.29)	2.56 (1.30)	0.01
Number of Drivers	1.87 (0.70)	1.89 (0.70)	-0.02	1.89 (0.70)	1.87 (0.69)	0.02
Number of Adults	1.90 (0.65)	1.91 (0.64)	-0.01	1.91 (0.64)	1.90 (0.65)	0.01
Number of Workers	1.32 (0.95)	1.37 (0.93)	-0.05	1.37 (0.95)	1.31 (0.93)	0.06
Age	51.22 (15.73)	50.04 (15.61)	1.18	50.62 (15.64)	50.59 (15.75)	0.03
MSA Has Subway	0.15 (0.36)	0.10 (0.31)	0.05	0.10 (0.29)	0.19 (0.39)	-0.09
N	17,450	18,657		22,892	13,215	

Panel B: 90/10 Percentiles by Division-Year

	90th , Pre-tax Price	10th, Pre-tax Price	Difference	90th, Tax	10th, Tax	Difference
Pre-tax Price	0.97 (0.18)	0.80 (0.08)	0.17	0.89 (0.11)	0.90 (0.13)	0.00
Tax	0.39 (0.04)	0.40 (0.04)	-0.01	0.43 (0.03)	0.34 (0.05)	0.09
Household Size	2.58 (1.30)	2.57 (1.31)	0.01	2.61 (1.34)	2.56 (1.31)	0.06
Number of Drivers	1.89 (0.70)	1.89 (0.69)	0.00	1.89 (0.70)	1.89 (0.70)	0.00
Number of Adults	1.92 (0.65)	1.92 (0.64)	0.00	1.92 (0.66)	1.91 (0.66)	0.01
Number of Workers	1.32 (0.96)	1.28 (0.96)	0.04	1.34 (0.93)	1.30 (0.95)	0.04
Age	51.59 (15.70)	51.96 (15.79)	-0.36	50.14 (15.56)	51.05 (15.69)	-0.90
MSA Has Subway	0.20 (0.40)	0.11 (0.31)	0.09	0.17 (0.37)	0.30 (0.46)	-0.13
N	3,609	3,611		3,591	3,611	

Table 8: Comparison of NHTS and Estimation Subsample

Panel A: Unweighted

		Full NHTS Sample					Estimation Subsample			
	N	Mean	SD	10th	90th	N	Mean	SD	10th	90th
Pre-tax Price	45,459	0.89	0.12	0.75	1.04	34,234	0.89	0.12	0.76	1.05
Tax	41,389	0.40	0.04	0.35	0.45	34,234	0.40	0.04	0.35	0.45
Household Size	106,831	2.60	1.34	1.00	4.00	34,234	2.56	1.29	1.00	4.00
Number of Drivers	106,831	1.85	0.77	1.00	3.00	34,234	1.88	0.70	1.00	3.00
Number of Adults	111,850	1.89	0.82	1.00	3.00	34,234	1.91	0.65	1.00	3.00
Number of Workers	106,831	1.36	0.96	0.00	2.00	34,234	1.35	0.94	0.00	2.00
Age	111,850	49.59	18.79	29.00	74.00	34,234	50.66	15.67	31.00	73.00
MSA Has Subway	111,850	0.16	0.37	0.00	1.00	34,234	0.14	0.34	0.00	1.00

Panel B: Weighted

		Full NHTS Sample					Estimation Subsample			
	N	Mean	SD	10th	90th	N	Mean	SD	10th	90th
Pre-tax Price	45,459	0.87	0.12	0.74	1.04	34,234	0.89	0.12	0.75	1.05
Tax	41,389	0.37	0.04	0.32	0.44	34,234	0.37	0.04	0.32	0.42
Household Size	106,831	2.54	1.34	1.00	4.00	34,234	2.53	1.35	1.00	4.00
Number of Drivers	106,831	1.85	0.73	1.00	3.00	34,234	1.84	0.73	1.00	3.00
Number of Adults	111,850	1.89	0.70	1.00	3.00	34,234	1.88	0.70	1.00	3.00
Number of Workers	106,831	1.30	0.94	0.00	2.00	34,234	1.31	0.93	0.00	2.00
Age	111,850	50.25	16.15	30.00	73.00	34,234	49.76	15.97	30.00	73.00
MSA Has Subway	111,850	0.20	0.40	0.00	1.00	34,234	0.22	0.41	0.00	1.00